10-9-79

CHAPTER I: GENERAL PROVISIONS

REGULATION 10: PREAMBLE

Rule 101: Declaration of Policy

WHEREAS, the Legislature of the State of Arizona has found that air pollution exists in the State and in Pima County, and that such air pollution is potentially and in some cases actually dangerous to the health of the citizenry, often causes physical discomfort, injures property and property values, discourages recreational and other uses of the State's resources, and is esthetically unappealing; and

WHEREAS, the State Legislature has adopted and implemented a Statewide program to control present and future sources of air pollution to insure the health, safety, and general welfare of all the citizens of the State, protect property values, and protect plant and animal life; and

WHEREAS, the State Legislature has adopted statutes which grant the counties the right to control the emissions of air contaminants as provided herein; and

WHEREAS, the Board of Supervisors of Pima County, Arizona has determined that air pollution is frequently emitted into the atmosphere from several types of sources in Pima County;

NOW, THEREFORE, in consideration of and for the benefit of the people of the County, it is declared policy that every effort shall be made to identify by source and amount the various types of contaminants in the atmosphere; and

It is further declared policy that all contaminants emitted from each source originating in Pima County shall be prevented or reduced, irrespective of the proportion that each source contributes to the total air pollution; and

That these RULES AND REGULATIONS shall apply to all types of air contaminant emissions in Pima County, subject to the jurisdictional authority regarding types and sizes of emissions sources defined by Arizona Revised Statutes and referenced herein.

10-9-79

Rule 102: Purpose

A. The purpose of these RULES AND REGULATIONS is to prevent and to reduce air pollution originating in Pima County, so as to restore and preserve the quality of the outdoor air in all areas of Pima County to which the general public has access.

B. These RULES AND REGULATIONS are specifically intended to progressively reduce the levels of air pollutants in areas which exceed one or more health-related or welfare-related standard, and to prevent the levels of air pollutants from exceeding analogous standards where the air is already clean. Therefore, the Air Quality Control Officer shall periodically evaluate progress made toward these goals, and he shall within 60 days of such time as information becomes available to him that the air quality in any area of the County which already exceeds a health-related or welfare-related standard is further deteriorating—or within 60 days of learning that any maximum allowable incremental increase in air pollutants set forth herein to preserve the air quality of the County is being exceeded—review the adequacy of these RULES AND REGULATIONS and propose to the Air Quality Advisory Council and Board of Supervisors appropriate revisions or additions to correct any deficiencies. Furthermore, the Control Officer shall prepare and make available to the general public an annual report describing such progress.

10·9·79

Rule 103: Authority

A. These RULES AND REGULATIONS are adopted pursuant to the authority granted by Title 36, Chapter 6, Article 8, Section 36-770, et seq., Arizona Revised Statutes, abbreviated hereinafter as ARS when referring to a specific Statute.

10.9.79

REGULATION 11: JURISDICTION

Rule 111: General Applicability

A. These RULES AND REGULATIONS shall apply to all persons in Pima County, including citizens, residents, transients, and all other persons except where specifically exempted by Arizona Revised Statutes.

109.79

Rule 112: State and/or County

A. These RULES AND REGULATIONS shall apply to all types, kinds, and sizes of air pollutant emission sources in Pima County except those sources under the jurisdiction of the Arizona Department of Health Services.

B. These RULES AND REGULATIONS shall not apply to emission sources under the original jurisdiction of the Arizona Department of Health Services unless regulatory authority has been delegated to Pima County pursuant to ARS 36-1705 or 36-1706.

1. Emission sources under original jurisdiction of the Arizona Department of Health Services, and subject to delegation from time to time, include:
    a. Major sources of air pollution, including any source capable of generating more than 75 tons per day of air contaminants, uncontrolled, and
    b. Air polluting operations and activities of all agencies and departments of the State and its political subdivisions, and
    c. Motor vehicles, and
    d. Air polluting mobile or portable machinery and equipment capable of being operated in more than one county.

10·9·79

Rule 113: Limitations

A. Nothing in these RULES AND REGULATIONS shall be construed so as to:

1. Regulate or control air pollution existing solely within commercial or industrial plants, works, or shops owned by or under the control of the person causing the air pollution, or
2. Prevent normal agricultural soil-cultivation and crop-producing practices which cause dust.

10.9.79

REGULATION 12: ADMINISTRATION

Rule 121: Air Quality Control District

A. The Pima County Air Pollution Control District, having been created by Pima County Ordinance 1966-44, in accordance with ARS 36-773C and 36-775 and consisting of an operating division of the Pima County Health Department, is hereby continued and shall be known as the Pima County Air Quality Control District.

10.9.79

Rule 122: Executive Head

A. The Director of the Pima County Health Department shall be the Air Pollution Control Officer and the executive head of the Pima County Air Quality Control District. He shall perform such duties and exercise such powers as are prescribed by law, and shall be known hereafter as the Air Quality Control Officer.

10.9.79

Rule 123: Governing Body

A. The Pima County Board of Supervisors shall be the governing body of the District, and the Air Quality Control Officer shall administer these RULES AND REGULATIONS.

10.9.79

REGULATION 15: LEGAL SEVERABILITY

Rule 151: Severability Clause

A. Should any regulation, rule, part, subpart, paragraph, item, clause, or phrase of these RULES AND REGULATIONS be declared unconstitutional or invalid for any reason, the remainder of these RULES AND REGULATIONS shall not be affected thereby, with all remaining portions of said RULES AND REGULATIONS continuing in full force.

10.9.79

REGULATION 16: INTERPRETATIONS

Rule 161: Format

A. These RULES AND REGULATIONS are organized in outline format with divisions subdivisions, and numbering and lettering schemes having the meanings indicated below:

Chapter No. (Roman numerals I thru IX, e.g., I).

REGULATION No. (two-digit Arabic numerals with first digit numerically identical to the corresponding chapter number, e.g., 10).

Rule No. (three-digit Arabic numerals further subdividing the regulation numbers, with the first two digits numerically identical to the corresponding regulation number, e.g., 101).

Part Letter (single upper-case letter in alphabetical order, and called part, e.g., A).

Paragraph No. (single-digit Arabic numeral, in numerical order, and called paragraph, e.g., 1).

Item No. (single lower-case letter, in alphabetical order, and called item, e.g., a).

Clauses or phrases (un-numbered, un-lettered).

No two chapters, regulations, or rules have the same number.

B. Tables are numbered corresponding to their counterpart rule, part, or paragraph numbers.

C. Figures are numbered corresponding to their counterpart rule, part, or paragraph numbers.

D. Test methods and equipment specifications are numbered corresponding to their counterpart rule numbers, or as specified within the corresponding rule.

E. Tables and figures are positioned at the end of each chapter in which they are first referenced, respectively, in the order in which they are first referenced.

F. Pages are numbered consecutively throughout each chapter, excluding Tables of Contents, which shall not affect the interpretation of any regulation, rule, or other provision herein.

10.9.79

Rule 162: Headings and Special Type

A. Chapter, regulation, rule, and part headings used in these RULES AND REGULATIONS are inserted for convenience only and shall not affect the interpretation of the respective divisions or subdivisions. However, titlesor numbers of a chapter, regulation, rule, part, paragraph, table, or figure shall be used to identify any additional requirement when referenced herein.

B. When the word CHAPTER, RULE, REGULATION, or other subdivision is presented in upper-case letters within a rule, it refers to the particular chapter, rule, regulation, or other subdivision in which the word appears. If any similar word is not fully capitalized when used in a rule, it is followed by an identifying number or letter, e.g., Chapter III.

C. Braces, i.e., {}, appearing after a heading or definition denote reasonable similarity of the definition or heading with a corresponding definition or acronym used in a requirement or regulation adopted by the U.S. Congress or the U.S. Environmental Protection Agency. The acronym inside the braces is identical to the Federal convention. All such devices are inserted for convenience only and shall not affect the interpretation of any rule in these RULES AND REGULATIONS.

10.9.79

Rule 163: Use of Number and Gender

A. As used in these RULES AND REGULATIONS, words in the singular shall be deemed to import the plural, and words in the masculine gender shall be deemed to import the feminine, and vice versa, as the case may require.

10·9·79

Rule 165: Effective Date

A. These revisions shall become effective immediately upon their adoption, continuing the predecessor Pima County Air Pollution Control District RULES AND REGULATIONS of 1971, as amended, and Pima County Air Pollution Control District Ordinance 1972-38, as amended, in full force and effect without interruption. The foregoing shall be published in a document known as the Pima County Air Quality Control Rules and Regulations, Revised.

CHAPTER I: GENERAL PROVISIONS

10-18-85

REGULATION 16: INTERPRETATIONS

Rule 166: Adoptions by Reference

A. When the Arizona Department of Health Services' (ADHS) Rules and Regulations are adopted by reference herein, the following terms shall have the corresponding meanings as shown below:

Term in ADHS Rules and Regulations	Meaning in these RULES AND REGULATIONS
Director	Control Officer
Bureau of Air Quality Control	Air Quality Control District
Hearing Board	Pima County Air Quality Hearing Board

B. When parts of the U.S. Code of Federal Regulations are adopted by reference herein, the term Administrator in EPA Rules and Regulations shall mean Control Officer in these RULES AND REGULATIONS unless the context of the EPA Regulations indicates otherwise.

C. References to the U.S. Code of Federal Regulations refer sequentially to Title, Code of Federal Regulations, Part, Section and Paragraph; e.g., 40 CFR 52.01(a) means Title 40, Code of Federal Regulations, Part 52, Section .01, Paragraph (a).

D. Any adoptions by reference supercede other portions of these RULES AND REGULATIONS which may conflict with the adoption by reference.

10-9-79

REGULATION 17: DEFINITIONS AND MEANINGS

Rule 171: Words, Phrases, and Terms

Words, phrases, and terms used in these RULES AND REGULATIONS shall have the following meanings except where any narrative portion specifically indicates otherwise. The order of presentation of each such paragraph or term in this RULE is such that once a word, phrase, or item is defined, its meaning shall be used to interpret succeeding definitions.

B. Basic Definitions

1. air contaminant or air pollutant

   Smoke, vapors, charred paper, dust, soot, grime, carbon, fumes, gases, sulfuric acid mist aerosols, aerosol droplets, odors, particulate matter, windborne matter, radioactive materials, or noxious chemicals, or any other material in the outdoor atmosphere other than chemically uncombined nitrogen, oxygen, carbon dioxide, and water.

   a. common air pollutant

      An air pollutant so classified in Chapter VI herein. (Common air pollutants are abundant in most industrial or metropolitan atmospheres. Ambient air quality standards have been set for these pollutants to protect human health and welfare.)

7. emission or emissions

   An effluent containing one or more air contaminants.

   a. dust or dust emissions

      Minute solid particles released or discharged into the atmosphere by natural forces or mechanical processes.

   b. stack emissions

      Emissions which enter the atmosphere by passing through a vent, stack, flue, or other similar containing or restrictive device designed or installed for the principal purpose of discharging the effluent.

   c. fugitive emissions

      Emissions which enter the atmosphere without passing through a vent, stack, flue or other similar containing or restrictive device designed or installed for the principal purpose of discharging the effluent, including fugitive dust as defined below.

   d. fugitive dust

      Dust emissions other than stack emissions.

8. <u>source</u> or <u>emission source</u>

A physical arrangement, equipment, device, facility, structure, activity, fire, or operation which emits, or has the potential for emitting, air contaminants.

a. <u>source operator</u>

An originator, owner, operator, or lessee of an emission source.

C. Classes of Sources

1. <u>Regarding Ages of Sources or Time of Installation</u>

a. <u>existing source</u>

A source in operation at the time of, or the construction or modification of which commenced prior to, or for which the Control Officer granted an Installation Permit prior to, the effective date of adoption of these RULES AND ~~R~~EGULATIONS. The term "commenced" or "commences" used herein mean that a source operator has obtained an Installation Permit and either has:

i. begun or caused to begin a continuous program of physical on-site construction of the source, or

ii. entered into a binding agreement which cannot be cancelled or modified without substantial loss to the source operator regarding the source.

b. <u>new source</u>

A source which commences construction, installation, modification, operation, or for which the Control Officer or Hearing Board grants an Installation Permit, on or after the effective date of adoption of these RULES AND REGULATIONS.

2. <u>Regarding Sizes of Sources</u>

a. <u>major source</u>

One or more sources owned or operated by the same owner, operator, or lessee at a contiguous geographical area which collectively, i.e., with total emissions aggregated, either emits or has the potential for emitting 100 tons per year or more of a single air contaminant. This definition applies individually to specific air contaminants. The word potential means capable of emitting at maximum operating capacity of 8,760 hours per year if the source were constructed and operated without any emissions control devices, processes, or procedures—unless such controls or procedures are vital to the production of the product for which the source was designed or is principally operated, or unless such source is subject to enforceable permit conditions or other limitations herein applicable to hours of operation which reduce its potential emissions.

For purposes of applying this definition, fugitive emissions as well as stack emissions shall be included in calculating or estimating potential emissions. However, emissions from mobile sources as defined below, as well as emissions which result solely from construction and/or any other closely related, temporary emissions operation or activity, shall not be used in calculating or estimating potential emissions.

c. new major source

A major source as defined above for which the Control Officer or Hearing Board grants an Installation Permit, or which commences construction, installation, or operation after the effective date of adoption of these RULES AND REGULATIONS--whichever occurs first in time; or any existing major source which develops a potential for emitting any air contaminant not previously emitted; or any existing major source which increases its potential emission rate; or any existing minor source or new minor source which becomes a major source after the effective date of adoption of these RULES AND REGULATIONS. This definition applies individually only to common air pollutants as defined herein.

In those cases where a source becomes a new major source through expansion or modification, the emissions limitations and work practices specified herein for new major sources shall apply only to those new or modified portions of the source which cause the source to exceed an overall potential emission rate (contained in the definition of major source) of 100 tons per year, insofar as such portions can be reasonably identified and associated with the excess emission rate. Expanding or modifying a source in a piecemeal manner to avoid coverage of any requirement herein for a new major source is prohibited.

d. modification or alteration (of a source)

Any change whatsoever which changes the potential emission rate of a source.

3. Regarding Mobility of Sources

   a. stationary source

   A source constructed, installed, or planned with the intent of leaving the source at its initial location throughout its lifetime, or any source which remains or will remain at the same contiguous geographical area for more than six months, other than a mobile source or portable source as defined below.

E. Process-Associated Terms

1. Regarding Control Technology

   b. lowest achievable emission rate (LAER)

   The lowest emission rate applicable to a designated air pollutant for a class or category of source as determined by the Control Officer. The permit applicant shall submit a proposed emission rate with his application.

   In no event shall the emission rate be less stringent than:

   1. The lowest rate achieved in practice by such class or category of source, unless the permit applicant demonstrates that such rate is not achievable because the technology necessary to achieve the rate is unavailable due to proprietary restrictions, or
   2. The lowest rate contained in any State Implementation Plan for such class or category of source, unless the permit applicant demonstrates that such rate is not achievable, or
   3. The applicable new source performance standard for the class or category of source,

   whichever is most stringent.

   The emission rate established by the Control Officer shall be determined by reference to all guidance documents, regulations, and other information published and made available to the Control Officer by the Administrator of the Environmental Protection Agency, and the emission rate established by the Control Officer shall become a binding condition of the Installation Permit.

   In any case, the information relied upon by the Control Officer shall be made available to the permit applicant upon request.

10·9·79

Rule 172: Meanings of Mathematical Symbols

Mathematical symbols appearing in these RULES AND REGULATIONS shall have the following meanings:

Symbol	Meaning
$<$	less than
$\leq$	less than or equal to
$>$	greater than
$\geq$	greater than or equal to
M	the multiplier one thousand
MM	the multiplier one million
n^3	the number represented by n to the third power

Exponents are shown in large type to avoid confusion with footnote numbering. For example, $\mu g./m.^3$ indicates micrograms per cubic meter, and ug./m.[3] indicates micrograms per meter, reference footnote three.

10-9-79

Rule 173: Chemical Symbols and Abbreviations

Chemical symbols and abbreviations appearing in these RULES AND REGULATIONS shall have the following meanings:

Symbol or Abbreviation	Meaning	Symbol or Abbreviation	Meaning
AB	asbestos	H_2SO_4	sulfuric acid
Al	aluminum	NO_2	nitrogen dioxide
Be	beryllium	NO_x	oxides of nitrogen
CH_2Cl_2	methylene chloride	O_2	oxygen
CH_3CCl_3	methyl chloroform	O_3	ozone
CH_4	methane	Pb	lead
$C_2Cl_3F_3$	trichloro-trifluoroethane	P_2O_5	phosphorous pentoxide
C_2H_6	ethane	S	sulfur
CO	carbon monoxide	SO_2	sulfur dioxide
CO_2	carbon dioxide	SO_3	sulfur trioxide
Cu	copper	SO_x	oxides of sulfur
F	fluorine	TRS	total reduced sulfur
Fe	iron	TSP	total suspended particulate matter
HC	hydrocarbon		
Hg	mercury	VC	vinyl chloride
HNO_3	nitric acid	Zn	zinc
H_2S	hydrogen sulfide	Δp	pressure drop between two points

10-9-79

Rule 174: Scientific Units

Scientific units appearing in these RULES AND REGULATIONS shall have the following meanings:

Unit	Meaning
dscf.	a dry cubic foot of gas at standard conditions of 20°C. (68°F.) and 760 mm. of mercury (29.92 in. of Hg), excluding any water vapor therein
g.	gram; a unit of mass (453.6 g. = one lb.)
gr.	grain; a unit of mass equal to 0.002286 ounce (7000 gr. = one lb.)
ppm.	parts of pollutant per million parts of effluent, by volume (gases only)
µg./m.^{3}	micrograms pollutant per cubic meter of effluent or air
Btu.	British thermal unit (heating value)
Mw-hr.	rating of power generating equipment; mega (million) watts times hours

10-18-85

Rule 175: Acronyms

The following acronyms used herein are those defined by the U.S. Environmental Protection Agency:

Acronym	Meaning
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NSPS	New Source Performance Standards
NAAQS	National Ambient Air Quality Standards

10·9·79

CHAPTER II: PERMITS

REGULATION 20: OPERATIONS AND ACTIVITIES WHICH REQUIRE PERMITS

Rule 201: Statutory Authority

A. Statutory provisions relating to the Control Officer's jurisdiction over permit requirements are contained in the Arizona Revised Statutes, ARS 36-1705, 36-1706, and 36-770, et seq.

B. Equipment Installation Permits and Operating Permits (requiring fees) shall be issued pursuant to ARS 36-779.01.

C. Open Burning Permits (requiring fees) shall be issued pursuant to ARS 36-789.

D. Activity Installation Permits and Operating Permits, including Activity Installation Permits for construction/destruction activities (not requiring fees), shall be issued pursuant to ARS 36-779.

10.9.79

Rule 202: Installation Permits

A. A person who plans to erect, install, or replace an emission source which may cause, emit, contribute to, or control air pollution; or who plans to expand or modify any source in such a manner that the potential or actual emission rate would increase or decrease by virtue of the expansion or modification; or who plans to engage in an activity which may cause or contribute to air pollution—except as specifically exempted herein—shall obtain an Installation Permit from the Control Officer. The permit shall be obtained prior to beginning construction or modification of the source, commencement of the activity, or before entering into a binding agreement related to construction of the planned emission operation or activity which cannot be cancelled or modified without substantial loss to the person, whichever occurs first in time.

   1. An Installation Permit shall remain in effect until an Operating Permit (if applicable) for such emission source is granted, or the Installation Permit is revoked, or the operation or activity covered by the Installation Permit is terminated. However, in no case shall the term of any Installation Permit extend beyond two years from its effective date.

B. The provisions of this RULE shall not apply to motor vehicles, to agricultural equipment used in soil-cultivating or vegetative-crop-producing-and-harvesting operations, to soil-cultivating or vegetative-crop-producing-and-harvesting activities which cause dust, nor to fuel burning equipment which in the aggregate with other such equipment of the applicant at the same contiguous geographical area is rated at less than 500,000 British Thermal Units per hour.

   1. Fuel burning equipment associated with a one- or two-family residence does not require an Installation (or an Operating) Permit.
   2. Small air polluting operations or activities not requiring Installation (or Operating) Permits are exempted according to size, as noted in the fee schedules in this CHAPTER.

C. Emission sources requiring Installation Permits include, but are not limited to, those listed in the fee schedules or tables of permit requirements in the latter part of this CHAPTER.

10-18-85

CHAPTER II: PERMITS AND INSPECTIONS

REGULATION 20: OPERATIONS AND ACTIVITIES WHICH REQUIRE PERMITS

Rule 202: Installation Permits

D. An existing emission source having a current Operating Permit which relocates from one geographical area within Pima County to another shall not require an Installation Permit, providing the following conditions are met:

1. Regulation 38: Nonattainment-Area Standards does not apply, and
2. Regulation 39: Attainment-Area Standards does not apply, and
3. There is no change in the potential emissions from any of the equipment being relocated, and
4. The relocated equipment is not aggregated from more than one location to the new site.

A source which relocates must obtain a new Operating Permit as provided in Rule 203 herein.

10·9·79

Rule 203: Operating Permits

A. Before an emission source may be operated on a continuous or intermittent basis—except as specifically exempted herein—an Operating Permit shall be obtained from the Control Officer.

   1. An Operating Permit shall remain in effect for no longer than one year from its effective date, and continued operation of the source shall require annual renewal of the Operating Permit, subject to compliance with all applicable provisions set forth herein.

B. Emission sources requiring Operating Permits include, but are not limited to those listed in the permit fee schedules or tables of permit requirements in the latter part of this CHAPTER.

   1. Construction/destruction activities require Installation Permits only.

10-9-79

REGULATION 21: PERMITTING PROCEDURES

Rule 211: Permit Applications

A. An application for a permit shall be filed in writing in the manner prescribed by the Control Officer, and shall contain all information necessary to enable the Control Officer to make the determination to grant or deny the permit.

1. The Control Officer may require: descriptions of equipment and method of operating the source; the size, design, and capacity of the source; the planned startup date of the source; and detailed emission estimates. Before acting on an application for a permit, the Control Officer may require additional information, including the dates of planned burnings for Open Burning Permits.
2. Applications for Installation Permits must be submitted by the property or project owner, lessee, or developer; or jointly by the prime contractor and owner, prime contractor and lessee, or prime contractor and developer. The prime contractor's responsibility for fulfilling the conditions of the permit shall terminate after his work has been completed unless he is also the owner, developer, or lessee. When the prime contractor is relieved of responsibilities as described above, the remaining permittee shall assume full responsibility of assuring that all permit conditions are fulfilled.

10·9·79

Rule 212: Sampling, Testing, and Analysis Requirements

A. Prior to issuing an Installation Permit, the Control Officer may require the applicant to test the ambient air or other variables in the vicinity of the source, as detailed in Rule 504 herein.

B. Prior to issuing an Operating Permit, the Control Officer may require the applicant to measure the emissions from the source or the ambient-air quality in the vicinity of the source.

C. The requirements of this RULE shall generally apply only to new major sources.

   1. Sampling and testing requirements and procedures are established in Chapters III, IV, V, and IX herein.

10·9·79

Rule 213: Public Notification/Public Comments

A. If the Control Officer has determined that an application for an Installation Permit represents a new major source, he shall perform the following before granting the permit:

1. Make available for public inspection at AQCD's central office located at 151 West Congress Street, Tucson, Arizona, all non-confidential information submitted by the applicant, comments and conclusions by

the Control Officer regarding the impact of the planned source on the air quality, and the Control Officer's tentative decision to approve or deny the permit,

2. Advertise in a local publication of wide circulation the availability and location of the information described above,
3. Provide a 30-day period for the public to submit written comments on the planned source,
4. Send copies of the public notice, analysis, and tentative decision to: the Regional Administrator, Region IX, Environmental Protection Agency; the Chief of the Arizona State Bureau of Air Quality Control; the head of any county air quality control agency whose jurisdiction could be affected by the emissions from the planned source; the Mayor of the City of Tucson; the Mayor of the City of South Tucson; the Mayor of the Town of Marana; the Mayor of the Town of Oro Valley; the Executive Director of the Pima Association of Governments; and to each Federal Land Manager and head of any Indian Governing Body whose jurisdictions could be affected by the planned source,
5. Provide a forum for a public hearing where interested persons may verbally present their views on the planned source, if objections to the Control Officer's tentative decision to grant the permit are received in writing,
6. Consider all written and verbal comments before making a final decision on granting or denying the permit. The Control Officer shall weigh all public comments, and make the final decision to grant or deny the permit based solely on his conclusion that the planned source either has complied with or will be able to comply with all applicable provisions of these RULES AND REGULATIONS throughout the term of the permit. The Control Officer shall not be influenced by comments not relevant to applicable requirements established herein, and
7. Make available for public inspection in the same location specified

in Paragraph 1 above, a summary of all written and verbal comments, including the Control Officer's final determination.

B. The requirements of this RULE shall not apply to Activity Installation Permits for construction/destruction activities.

C. The Control Officer shall either grant or deny a permit within 30 days from the date of receipt of the complete application.

   1. The Control Officer may deny an application for a permit only for those reasons stated in Regulation 23 of this CHAPTER.

10·9·79

Rule 215: Permit Revocation

(Refer to ARS 36-785F, Authority for the Hearing Board to revoke permits.)

10.9.79

REGULATION 22: CONDITIONS OF THE PERMIT

Rule 221: General Control

A. The Control Officer may specify on each permit conditions which in his judgment are necessary to assure adequate control and monitoring of emissions for the expected lifetime of the source. Adequate control shall mean only those controls (e.g., devices, mechanisms, operation practices, times of operation, monitoring of process variables, or emission rates) which if installed, conducted, or operated properly should allow the source to comply with all applicable control standards.

B. The granting of a permit shall not exempt the permittee from any other applicable provision of these RULES AND REGULATIONS.

10·9·79

Rule 222: Permit Display or Posting

(Refer to ARS 36-779.06.)

: : :

10.9.79

Rule 223: Permit Transferability

(Refer to ARS 36-779.04.)

10.9.79

Rule 224: Fugitive Dust Producing Activities

A. A permittee whose permit specifically allows fugitive dust producing operations or activities is responsible for controlling windblown dust, dust from haul roads, and dust emitted from land clearing, earthmoving, demolition, trenching, blasting, road construction, mining, racing event, and other activities, as applicable.

1. Dust emissions shall be controlled by applying adequate amounts of water, chemical stabilizer, or other effective dust suppressant until the area becomes permanently stabilized by paving, landscaping, or otherwise.
2. The permittee shall not leave land in such a state that fugitive dust emissions (including windblown dust or dust caused by vehicular traffic on the area) would violate these RULES AND REGULATIONS.

10.9.79

Rule 225: Open Burning Permit Conditions

A. A person granted an Open Burning Permit must comply with the following:

1. Permissible burning hours are noon to 4 p.m. unless stated otherwise on the permit,
2. Burning must be at a safe distance from structures,
3. Burning must be constantly attended with reasonable control tools at hand,
4. Burning may not be conducted on public land or on other land not owned or leased by the permittee without written permission from the owner or land manager,
5. Fire must be dead out when left, and
6. The burning of materials other than those specified by the permit is prohibited.

10.9.79

Rule 226: Permits for State-Delegated Emission Sources

A. If the Director of the Arizona Department of Health Services delegates to the Control Officer jurisdiction over an emission source, all requirements and conditions for permits contained herein shall apply to the delegated source.

B. Additional requirements for delegated emission sources shall be as follows:

1. An Equipment Operating Permit may be issued by the Control Officer to operate mobile or portable equipment at more than one location in the County, and
2. Owners or operators holding Equipment Operating Permits for portable equipment shall notify the Control Officer of any change of operating location.

10·9·79

REGULATION 23: DENIALS OF PERMIT APPLICATIONS

Rule 231: Non-Compliance

A. The Control Officer shall deny an application for a permit if the applicant cannot prove to the satisfaction of the Control Officer, on the basis of information presented by the applicant and other available data, that the planned source is designed, controlled, equipped, or capable of being operated or conducted such that compliance with all applicable provisions of these RULES AND REGULATIONS would be possible throughout the term of the permit.

   1. If the Control Officer determines that air polluting equipment, air pollution control equipment, or an activity has not been erected, installed, or commenced in accordance with the requirements herein, he shall deny the Operating Permit until the deficiencies are corrected.

10.9.79

Rule 232: Notification of Denial

A. When the Control Officer denies a permit, he shall notify the applicant in writing of the reason for denial.

   1. This notification shall be served in person or by registered mail, and such service may be proved by the written acknowledgment of the person served, or affidavit of the person making the service.

10.9.79

REGULATION 24: PERMIT FEE SCHEDULES/NON-FEE REQUIREMENTS

Rule 241: General Provisions

A. An applicant for an Equipment Operation or Open Burning Permit approved by the Control Officer shall pay a fee calculated according to the schedules listed at the end of this CHAPTER, the following provisions, and any other provisions established in subsequent RULES.

1. Permit fees shall be applied collectively to all operations conducted at a contiguous geographical area.
2. Small equipment exempted in a table does not require a permit unless the equipment is part of a source at a contiguous geographical area whose aggregated capacity exceeds the exemption.
3. If more than one fee schedule or sub-schedule applies to the same operation or piece of equipment, the schedule yielding the higher fee shall apply. If a composite fee schedule covers multiple equipment at a contiguous geographical area, individual fee schedules for that particular equipment shall not apply.
4. A seasonal, stationary industry listed in Table 244-A which requires an Operating Permit and is shutdown for more than six consecutive months in any annual permit period shall be assessed annual Operating Permit fees equal to one-half of the calculated fee.
5. Each Operating Permit shall be renewed on the anniversary date of the permit, if the source is in compliance with these RULES AND REGULATIONS.
6. Equipment installed for the sole purpose of reducing or eliminating emissions shall not be included in a fee assessed for an Equipment Operating Permit. Air pollution control equipment requires payment of an Installation Permit fee.

B. Emission sources which require Activity Operating Permits are listed in Table 244-C, and no fees shall be assessed for these permits.

10-9-79

Table 242

ACTIVITY INSTALLATION PERMIT REQUIREMENTS FOR CONSTRUCTION/DESTRUCTION ACTIVITIES

S.S.[1]	Permit Activity	Rate Components	Fee	Exemptions
A	Landstripping	—	—	<1 acre
B	Earthmoving	—	—	<1 acre
C	Trenching	—	—	<300 ft.
D	Blasting	—	—	—
E	Road Construction	—	—	< 50 ft.
F	Demolition	—	—	<100 sq. ft.

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[1] Sub-schedule for identification only.

Table 243

OPEN BURNING PERMIT FEE SCHEDULES

S.S.[1]	Permit Activity[2]	Rate Components	Minimum Fee
A	Temporary Open Burning	$7.00 base, plus $1.50 per day of burning	$ 8.50
B	Extended Open Burning	$11.00 base, plus $2.00 per day of burning	$13.00

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[1] Sub-schedule for identification only.

[2] See Table 204 for examples of burning categories.

6-1-81

Rule 242: Installation Permit Fees/Non-Fee Requirements

B. An Installation Permit fee shall be equal to one-fourth of the fee calculated using Tables 244-A or 244-B, or $19.00, whichever is larger.

6-1-81

Table 243

OPEN BURNING PERMIT FEE SCHEDULES

S.S.[1]	Permit Activity[2]	Rate Components	Minimum Fee
A	Temporary Open Burning	$8.00 base, plus $1.75 per day of burning	$ 9.75
B	Extended Open Burning	$13.00 base, plus $2.50 per day of burning	$15.50

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[1] Sub-schedule for identification only.

[2] See Table 204 for examples of burning categories.

10·9·79

Rule 243: Open Burning Permit Fees

(Refer to Table 243, Open Burning Permit Fee Schedules)

10-9-79

Rule 244: Operating Permit Fees

A. Operating Permit fees shall be calculated according to the schedules in Tables 244-A and 244-B.

   1. If a source is a "Permit Operation" under Table 244-A, Table 244-B does not apply, except that:

      a. Fees for storage vessels (containing petroleum liquids or gases) listed in Table 244-B apply in addition to the fees assessed under Table 244-A, and

      b. If the source contains equipment listed in Table 244-B which is not an integral part of the "Permit Operation" under Table 244-A, the fees required in Table 244-B shall also apply.

6-1-81

Table 244-A

EQUIPMENT OPERATING PERMIT FEE SCHEDULES FOR CATEGORICAL SOURCES

(Aggregate megawatt, Btu./hr., hp., gal., and sq. ft., separately)

S.S.[1]	Permit Operation	Rate Components
A	Animal Feed Processing Plant	$381.00 base, plus $2.50 per hp. of equipment
B	Aluminum Sweating Furnace	$571.00 base per sweating furnace, plus $4.65 per sq. ft. of maximum cross-sectional area of primary sweating chamber
C	Hot-Mix Asphalt Plant	$450.00 per plant.
D	Brick and/or Block Mfg. Plant	$190.00 base per plant, plus $2.50 per hp. of equipment
E	Chemical Mfg. Plant (not otherwise covered herein)	$12.00 base, plus $0.33 per 100 gal. of total liquid and gaseous reagent and product storage capacity, plus $0.05 per 1000 Btu./hr. fuel burning equipment, plus $3.37 per hp. of equipment
F	Concrete Batch Plant	FOR PLANTS < 20 hp.: $12.00 base, plus $10.00 per hp. of equipment FOR PLANTS ≥ 20 hp.: $215.00 per plant
G	Cotton Gin	$1075.00 per gin
H	Metallic-Ore Processing Plant (e.g., copper, molybdenum, etc.)	EITHER $381.00 base, plus $0.162 per 1000 Btu./hr. fuel burning equipment, plus $0.075 per hp. of equipment; OR $38.00 base, plus $0.019 per 1000 Btu./hr. fuel burning equipment, plus $2.18 per hp. of equipment; whichever of the above is smaller.
I	Fossil-Fuel Fired Steam Gen. Plant (e.g., oil, gas, or coal burning electric power plant)	$260.00 base, plus $6.15 per megawatt generating capacity
J	Rendering Plant	$381.00 base, plus $2.50 per hp. of equipment, plus $0.044 per 1000 Btu./hr. fuel burning equipment
K	Rock Crushing Plant and/or Sand-and-Gravel Screening Plant	$25.00 base, plus $1.42 per hp. of equipment
L	Fuel Pipeline Transmission Facilities	$125 per compressor plus $0.035 per hp. of equipment

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[1] Sub-schedule for identification only.

6.1.81

Table 244-B

EQUIPMENT OPERATING PERMIT FEE SCHEDULES FOR NON-CATEGORICAL SOURCES

S.S.[1]	Permit Equipment	Rate Components	Exemptions
A	Incinerator	$31.00 base, plus $7.60 per sq. ft. of maximum cross-sectional area of primary combustion chamber	-
B	Petroleum-Liquid Storage Vessel	FOR CAPACITIES ≤ 40,000 GAL. PER VESSEL: $17.00 per vessel, plus $0.60 per 1000 gal.	<250 gal.
		FOR CAPACITIES > 40,000 GAL. PER VESSEL: $95.00 per vessel, plus $0.035 per 1000 gal.	
C	Non-Petroleum Liquid and/or Gaseous Storage Vessel (storage of air polluting liquids or gases only)	$17.00 per vessel, plus $0.60 per 1000 gal.	<250 gal.
D	Natural Gas and/or LPG Fuel Burning Equipment (Aggregated Total Heat Ratings)	FOR HEAT RATINGS <5,000,000 Btu./hr.: $19.00 base, plus $2.00 per 100,000 Btu./hr. in excess of 500,000 Btu./hr.	<500,000 Btu./hr.
		FOR 5,000,000 ≤ Btu./hr. <20,000,000[2]: $110.00 base, plus $1.00 per 100,000 Btu./hr. in excess of 5,000,000 Btu./hr.	
		FOR HEAT RATINGS ≥ 20,000,000 Btu./hr.: $262.00 base, plus $0.11 per 100,000 Btu./hr. in excess of 20,000,000 Btu./hr.	

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[1] Sub-schedule for identification only.

[2] Means HEAT RATINGS ≥ 5,000,000 Btu./hr. but < 20,000,000 Btu./hr.

Table 244-8, Continued

S.S.[1]	Permit Equipment	Rate Components	Exemptions
E	Non-Natural Gas, Non-LPG Fuel Burning Equipment (Aggregated Total Heat Ratings)	FOR HEAT RATINGS <5,000,000 Btu./hr.: $63.00 base, plus $2.28 per 100,000 Btu./hr. in excess of 500,000 Btu./hr.	<500,000 Btu./hr.
		FOR 5,000,000 ≤Btu./hr. <20,000,000[2]: $166.00 base, plus $2.03 per 100,000 Btu./hr. in excess of 5,000,000 Btu./hr.	
		FOR HEAT RATINGS ≥20,000,000 Btu./hr.: $471.00 base, plus $0.30 per 100,000 Btu./hr. in excess of 20,000,000 Btu./hr.	
F	Motors and/or Engines (internal combustion engines or others used to drive air polluting equipment)	FOR POWER RATINGS < 500 hp. PER ENGINE: $12.00 base, plus $0.60 per hp.	-
		FOR POWER RATINGS ≥ 500 hp. PER ENGINE: $317.00	
G	Abrasive Blasting Equipment	$55.00 per unit of equipment	-
H	Surface Coating Operations and/or Paint Spray Booths (for air polluting operations only)	$22.00 per unit of equipment or paint spray booth	-
I	Asphalt Kettles and/or Asphalt Tankers Used in Roofing Operations	$41.00 per kettle or equipment unit	-
J	Dry Cleaning Equipment	$44.00 base, plus $0.125 per pound of rated capacity of machines	-
K	Exhaust Fume Hood	$16.00 per fume hood	Domestic Cooking
L	Solvent Degreasing Unit	$38.00 per solvent degreasing unit	-
M	Miscellaneous Air Polluting Equipment	$35.00 per piece of equipment or operational unit	-

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[1] Sub-schedule for identification only.

[2] Means HEAT RATINGS ≥ 5,000,000 Btu./hr. but < 20,000,000 Btu./hr.

10·9·79

Table 244-C

ACTIVITY OPERATING PERMIT FEE REQUIREMENTS

S.D.[1]	Permit Activity	Rate Components	Exemptions
A	Racing Event Site	—	—
B	Unpaved Parking Lot	—	Space for < 5 cars
C	Mining Activities	—	—
D	Sanitary Landfill	—	—
E	Effluent Water Treatment or Settling Ponds and/or Sewage Sludge Bed (for potentially air polluting fluids only)	—	—
F	Miscellaneous Fugitive Air Polluting Activities	—	—

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[1] Sub-schedule for identification only.

10·9·79

REGULATION 25: PERMIT FEE SCHEDULES ADJUSTMENTS

Rule 251: Permit-Fee Studies Related to Inflation

A. Within 30 days of a decision by the Board of Supervisors to award a Cost-of-Living Allowance (COLA) to a majority of Pima County employees, the Control Officer shall re-evaluate his total permit-related service cost, and send the results of the re-evaluation to the Air Quality Advisory Council.

1. If the results indicate that the total permit-related service cost has increased since the date of adoption of these RULES AND REGULATIONS or subsequent amendments, the Control Officer shall propose to increase all permit fee schedules by the percentage increase in service cost.
2. The first such study shall be in calendar year 1979, provided the Board of Supervisors awards a COLA during that year.
3. The Air Quality Advisory Council shall make appropriate adjustments to any new fee schedules proposed by the Control Officer and forward its recommendations to the Board of Supervisors within 30 days of receipt of the Control Officer's study.
4. The Board of Supervisors shall hold a public hearing on the proposed permit fee increase before taking appropriate action.

10·9·79

Rule 252: Periodic Review of Individual Fee Schedules

A. At least once every five years, the Control Officer shall re-evaluate the service costs associated with individual classes of sources, and propose appropriate adjustments.

   1. Detailed justifications for the fee adjustments shall be made by the Control Officer.

   2. The Control Officer and the Air Quality Advisory Council shall jointly conduct study sessions, and provide opportunities for conferences and public hearings with all affected source operators before recommending to the Board of Supervisors significant adjustments to any individual fee schedule.

6-1-81

REGULATION 26: INSPECTIONS

Rule 261: Compliance Inspections

A. The Control Officer shall make such inspections as are necessary to assure compliance with or enforcement of these RULES AND REGULATIONS, any provision of the Arizona Revised Statutes, Title 36, Chapter 6, Article 8, or the provisions of any permit issued pursuant to these RULES AND REGULATIONS or Statutes.

B. The Control Officer shall make such inspections as are necessary for issuance or reissuance of any Installation, Operating, Activity, Conditional or Open Burning Permit authorized or allowed by these RULES AND REGULATIONS or the Arizona Revised Statutes, Title 36, Chapter 6, Article 8.

C. In addition to the inspections authorized by Parts A and B above, the Control Officer may require semi-annual inspections of the following types of sources:

1. Major sources, as defined in Rule 171 of these RULES AND REGULATIONS,
2. Any source of the type for which emissions standards have been established in Table 442-A of these RULES AND REGULATIONS, and
3. Sources of hazardous air pollutants, as listed in Rule 601 of these RULES AND REGULATIONS.

D. The Control Officer may obtain a special inspection warrant pursuant to the provisions of ARS 36-780.01.

10-9-79

CHAPTER III: UNIVERSAL CONTROL STANDARDS

REGULATION 30: PROHIBITED ACTS

Rule 301: Planning, Constructing, or Operating Without a Permit

A. No person shall construct, install, erect, use, replace, modify, or operate an emission source, or enter into a binding agreement affecting the source which cannot be cancelled or modified without substantial loss to the person, without obtaining a permit, unless the permit has been obtained by a second person according to the applicable permit requirements in these RULES AND REGULATIONS.

10·9-79

Rule 302: Non-Compliance with Applicable Standards

A. No person shall cause or permit the planning, construction, installation, erection, modification, use, or operation of an emission source which will cause or contribute to a violation of a performance standard established in these RULES AND REGULATIONS.

1. The actual emission rates of all identical or reasonably similar emission sources under the control of the same source operator at a contiguous geographical area shall be summed to determine compliance with a mass-emissions discharge standard.
2. A source shall comply with a discharge standard over the full range of the source's operating rates.

10·9·79

REGULATION 31: DESIGN OR WORK-PRACTICE CONTROL STANDARDS

Rule 312: Asphalt Kettles

A. Emissions from the operation of an asphalt kettle must be minimized by the following controls:

1. Maintaining the temperature below the asphalt flash point and below the maximum recommended by the asphalt manufacturer,
2. Operating the kettle with lid closed except when charging,
3. Pumping the asphalt from the kettle or the drawing of asphalt through cocks with no dipping,
4. Maintaining the kettle in clean, properly adjusted, and good operating condition, and
5. Firing the kettle with liquid petroleum gas or other low polluting fuel.

10-9-79

Rule 313: Incinerators

A. An incinerator must be operated only from official sunrise to sunset, except when the following are conditions of the Operating Permit:

1. The incinerator is equipped with a continuous monitoring and recording opacity meter,
2. The incinerator is used solely for the destruction of materials which would cause or contribute to air pollution if disposed of in any other practical manner,
3. The incinerating process cannot be operated efficiently during only daylight hours,
4. The opacity monitoring-and-recording equipment is calibrated and maintained in accordance with the manufacturer's specifications, and
5. The opacity monitoring records are kept for at least two years.

10.9.79

Rule 314: Petroleum Liquids

A. Emissions of hydrocarbons from a stationary tank, reservoir, or other container used for storing petroleum liquids must be minimized by applying and maintaining the following controls:

1. A stationary tank, reservoir, or other container which has a capacity of at least 250 gallons but less than or equal to 40,000 gallons which is used for storing gasoline must be equipped with either
   - a. Submerged fill pipe, or
   - b. Refrigeration-type vapor recovery system or an equivalently effective control system,
2. A stationary tank, reservoir, or other container having capacity greater than 40,000 gallons which is used for storing gasoline or other petroleum liquid must be equipped with
   - a. An adequately maintained floating roof, refrigeration-type vapor

recovery system or equivalently effective control system, if the container is used for storage of a petroleum liquid which has a a vapor pressure of at least 1.5 pounds but less than 11 pounds per square inch absolute under actual storage conditions, or

   b. A refrigeration-type vapor recovery system or equivalent if the container is used for storage of a petroleum liquid which has a vapor pressure of greater than or equal to 11 pounds per square inch absolute under actual storage conditions, and

3. A gasoline loading facility which handles at least 20,000 or more gallons of fuel per day must be equipped with submersible filling arms or other equivalently effective controls.

B. A refrigeration-type vapor recovery system or equivalent must be capable of collecting at least 90 percent of the hydrocarbon vapors by weight which would otherwise be vented to the atmosphere during filling of the tank. The system must also be equipped with either an on-site or remotely located vapor-disposal system which processes the vapors so that their escape to the atmosphere is prevented.

   1. The Control Officer shall determine compliance of a vapor recovery system by evaluating the equipment planned for or used at the source and certifying the equipment as meeting the applicable standard.

C. This RULE shall not apply to:

   1. Pressure vessels which are designed to operate in excess of 15 pounds per square inch gage without emissions to the atmosphere except under emergency conditions,

   2. A tank having a capacity of at least 250 gallons but less than 2,000 gallons which was installed prior to 1969, and

   3. An underground tank installed prior to 1969 which has a capacity less than or equal to 40,000 gallons, if the fill line between the fill connection and the tank is offset.

10.9.79

Rule 315: Roads and Streets

A. Dust emissions from an existing unpaved public road must be minimized with use of an effective dust suppressant, paving, detouring, barring access, limiting vehicular speeds, or other equivalently effective controls applied to the entire width of the road surface available to vehicular traffic.

B. Dust emissions from the construction phase of a new road must be minimized by applying the same measures specified in Part A of this RULE.

C. No new unpaved private driveway shall be constructed unless the road will not be used by more vehicular traffic than that associated with a one- or two-family private residence, and the road will not be adjacent to any recreational, institutional, educational, or retail sales facility.

D. No new unpaved service road or unpaved haul road shall be constructed unless dust will be suppressed after construction by intermittently oiling, watering, limiting access, or applying chemical dust suppressants to the road, in such a way that visible dust emissions caused by vehicular traffic on the road do not diffuse beyond the property line within which the emissions become airborne.

E. No new public road shall be constructed unless the following conditions are met (zoning terms and paving specifications in the following are those defined by or equivalent to those of the Pima County Planning Department and Pima County Highway Department, respectively):

   1. If zoned CR-1 (one full acre or larger) or less dense, at least a 4-inch base coarse and double bituminous surface treatment shall be applied, or

   2. If zoned CR-2 or denser, at least a 4-inch base coarse covered with at least 1.5 inches of asphaltic concrete shall be applied, and

   3. A chemically treated substitute base and appropriate surface treatment may be used if approved by the Pima County Highway Department.

F. The surfacing of roadways with asbestos tailings is prohibited.

10.9.79

Rule 316: Particulate Materials

A. Dust emissions from the processing of material must be minimized by hooding and use of dust collection equipment, water sprays, or use of wet scrubbers, fabric filters (baghouses), electrostatic precipitators, or other equivalently effective controls.

B. Dust emissions from construction activity must be minimized by applying adequate amounts of water or other equivalently effective dust controls.

C. Dust emissions from the transportation of materials must be minimized by covering stock loads in open-bodied trucks, limiting vehicular speeds, or other equivalently effective controls.

D. Dust emissions from the storage of material must be minimized by enclosing the material within structures, planting and maintaining vegetative growth over the material, use of chemical dust suppressants, or other equivalently effective controls.

E. Emissions from a sandblasting or other abrasive blasting operation must be minimized by applying water to suppress visible emissions (wet blasting), enclosing the operation, or use of other equivalently effective controls.

10·9·79

Rule 318: Vacant Lots and Open Spaces

A. Dust emissions from the construction, use, alteration, repair, demolition, clearing, leveling, or excavation of any vacant lot, parking area, housing plot, building site, sales lot, playground, livestock feedlot, or other open area—other than those solely used for soil-cultivation or vegetative-crop-producing-and-harvesting agricultural purposes—must be minimized by intermittently applying water or other effective dust suppressants to the area, paving, detouring, barring access, or other equivalently effective controls.

B. No new vacant lot, housing plot, building site, parking area, sales lot, playground, livestock feedlot, or other open area—other than those used solely for soil-cultivation or vegetative-crop-producing-and-harvesting agricultural purposes—shall be left in such a state after construction, alteration, clearing, leveling, or excavation that naturally induced wind blowing over the area causes visible emissions of airborne dust to diffuse beyond the property lines within which the emissions become airborne.

   1. Dust emissions must be permanently suppressed by landscaping, covering with gravel or vegetation, paving, oiling or applying equivalently effective controls.

C. No vacant lot, parking area, sales lot, or other open urban area shall be used by motor vehicles in such a manner that visible dust emissions induced by vehicular traffic on the area diffuse beyond the property boundary lines within which the emissions become airborne.

D. The exception to visible emissions during periods of high wind speeds as specified in Rule 343-B shall also apply to this RULE.

10·9·79

Table 321

EMISSIONS-DISCHARGE OPACITY LIMITING STANDARDS

Type of Source	Instantaneous Opacity Measurements: Required No. (For a Set)	Instantaneous Opacity Measurements: Excluded No. (Highest Values)	Instantaneous Opacity Measurements: No. to Use For Averaging	Maximum Allowable Average Opacity, %
Asbestos-Containing Operation[1]	25	0	25	0
Cold Diesel Engines[2]	25	0	25	60
Loaded Diesel Engines[3]	26	1	25	60
Incinerators	27	2	25	20
Portland Cement Plants[4]	25	0	25	20
Non-Categorical Sources[5]	25	0	25	40

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[1] An asbestos mill, manufacturing or fabrication operation which uses asbestos as a raw material, or spraying operation which sprays materials containing more than 1% asbestos by weight.

[2] Applicable to the first 10 consecutive minutes after starting up a diesel engine.

[3] Applicable to a diesel engine being accelerated under load.

[4] Applicable to kiln, clinker cooler, and other process equipment.

[5] Any source not otherwise specifically covered within this TABLE.

10·9·79

REGULATION 32: EMISSIONS-DISCHARGE OPACITY LIMITING STANDARDS

Rule 321: Standards and Applicability (Includes NESHAPS)

A. No person shall cause or permit the effluent from a single emission point, multiple emission point, or fugitive emissions source to have an average optical density equal to or greater than the opacity limiting standards specified in Table 321, subject to the following provisions:

1. Opacities (optical densities) of an effluent shall be measured by a certified visible emissions evaluator with his natural eyes, approximately following the procedures which were used during his certification, or by an approved and precisely calibrated in-stack monitoring instrument.
2. A violation of an opacity standard shall be determined by measuring and recording a set of consecutive, instantaneous opacities, and calculating the arithmetic average of the measurements within the set unless otherwise noted herein. The measurements shall be made at approximately fifteen-second intervals for a period of at least six minutes, and the number of required measurements shall be as specified in Table 321. Sets need not be consecutive in time, and in no case shall two sets overlap. If the average opacity of the set of instantaneous measurements exceeds the maximum allowed by any rule, this shall constitute a violation.
3. The use of air or other gaseous diluents solely for the purpose of achieving compliance with an opacity standard is prohibited.

B. When the presence of uncombined water is the only reason for failure of a source to otherwise meet the requirements of this REGULATION, this REGULATION shall not apply.

10-9-79

Table 332

EMISSIONS-DISCHARGE MASS LIMITING STANDARDS

				Emissions Discharge Standards			
Type of Source	Gen. Size Category	Applicable Equipment Size	Other Applicable Conditions	Applicable Air Pollutant	Mass Discharge Rate, lb./hr. (unless otherwise noted)	Mass Concentration gr./dscf. (unless otherwise noted)	Reference Test Method
(a) Incinerators	All	All	—	TSP	—	0.08[2]	1,2,3,4,5
(b) Fuel Burning Equipment[1]	Major	Heat Input $\leq$ 4200 MM Btu./hr.	All Fuels[3]	TSP	$1.02\ Q^{0.769}$ Q = heat input in MM Btu./hr.	0.2	1,2,3,4,5
(c) Fuel Burning Equipment[1]	Major	Heat Input > 4200 MM Btu./hr.	All Fuels[3]	TSP	$17.0\ Q^{0.432}$ Q = same as above	0.2	1,2,3,4,5
(d) Fuel Burning Equipment[1]	Major	All Heat Inputs	Liquid or Solid Fuel[3]	SO_2	1.0 lb./MM Btu.	—	6
(e) Portland Cement Plants	Major	Process Weight $\leq$ 250M lb./hr.	All Equipment	TSP	$17.31\ P^{0.16}$ P = process weight in tons/hr.	0.2	1,2,3,4,5
(f) Portland Cement Plants	Major	Process Weight > 250M lb./hr.	Kiln Discharges Only	TSP	0.30 lb./ton process weight, max. 2-hr. avg.	0.2	1,2,3,4,5
(g) Portland Cement Plants	Major	Process Weight > 250M lb./hr.	Clinker Cooler Discharges Only	TSP	0.10 lb./ton process weight, max. 2-hr. avg.	0.2	1,2,3,4,5
(h) Beryllium Mfg. or Users[5]	All	All	—	Be	10 g./day[4]	—	103,104
(i) Mercury Processing Plants[6]	All	All	—	Hg	2,300 g./day[4]	—	101,102
(j) Sludge Incinerators[7]	All	All	—	Hg	2,300 g./day[4]	—	101,102,105
(k) Ethylene Dichloride Plants	All	All	—	VC	2.0×10^{-4} lb./lb. product[9]	10 ppm[8]	106
(l) Vinyl Chloride Plants	All	All	—	VC	—	10 ppm.[8]	106
(m) Polyvinyl Chloride Plants	All	All	—	VC	2.0×10^{-5} lb./lb. product[9]	10 ppm.[8]	106,107
(n) Non-Categorical Sources[10]	Major	Process Weight $\leq$ 30 ton/hr.	—	TSP	$3.59\ P^{0.62}$ P = process weight in tons/hr.	0.2	1,2,3,4,5
(o) Non-Categorical Sources[10]	Major	Process Weight > 30 ton/hr.	—	TSP	$17.31\ P^{0.16}$ P = same as above	0.2	1,2,3,4,5

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[1] Equipment used primarily for indirect heating in which the material being heated is not normally in contact with the fuel or combustion products.

[2] Adjusted to 12% CO_2.

[3] Heat input testing of fuel by ASTM Method D2015-66, D240-64, or D8126-64.

[4] Maximum 24-hour average.

[5] Includes extraction plants, ceramic plants, foundaries, incinerators, propellant plants, and machine shops which use or process an alloy which contains more than 5% Be by weight.

[6] Includes a stationary source which processes mercury ore to recover mercury, or which uses mercury chlor-alkali cells to produce chlorine gas and alkali metal hydroxide.

[7] An incinerator which is used to incinerate sludge from waste-water treatment plants.

[8] Parts per million, by volume, actual temperature and pressure.

[9] Lb. vinyl chloride/lb. dry-solids polyvinyl chloride product or 100% ethylene dichloride product from reactors only.

[10] Any source not otherwise specifically covered for TSP within these RULES AND REGULATIONS.

10·9·79

REGULATION 33: EMISSIONS-DISCHARGE MASS LIMITING STANDARDS

Rule 331: Applicability

A. This REGULATION shall apply only to emissions which enter the atmosphere by passing through a vent, stack, flue, or other similar containing or restrictive device, or which by reasonable modification of the emissions source the emissions can be directed through such a device for testing purposes.

B. Where the nature of a process, operation, or activity allows more than one interpretation of a requirement in this REGULATION, the more or most restrictive interpretation shall apply.

10·9·79

Rule 332: Compilation of Mass Rates and Concentrations (Includes NESHAPS)

A. The maximum allowable emissions discharge rate (in terms of mass per unit time) and mass concentration (in terms of mass per unit volume of gas) for an air pollutant to which this REGULATION applies shall be those standards established in Table 332.

   1. The use of air or other gaseous diluents solely for the purpose of achieving compliance with a specified mass-concentration standard is prohibited.

B. The following interpretative aids shall apply to the requirements of Table 332:

   1. Entries under the heading Size Category mean the particular standard applies to a major or minor source as noted. "All" means the particular standard applies to major sources and to minor sources,
   2. An entry of "All" under the heading Applicable Equipment Size means the particular standard applies to all sizes of equipment,
   3. An equation containing the symbol Q (heat input) or P (process weight) shall be interpreted as having a multiplier which precedes the symbol and an exponent which follows the symbol, except in the formulas for cotton gins which do not contain exponents following the symbol P,
   4. An entry containing the words process weight, preceded or followed by a quantity and unit, means the standard applies to operations which have a process weight as noted,
   5. A "dash" shown under any heading means there is no special entry applicable to that heading that is also common to all other entries on the same line, and
   6. The numerically identified Test Methods refer to those methods included in Chapter IX.

10·9·79

Table 341

MAXIMUM ALLOWABLE POLLUTANT-CONCENTRATION CEILINGS[1] IN AMBIENT AIR

(Each concentration listed below represents both a *primary* and a *secondary* standard unless otherwise indicated.)

Pollutant	Averaging Time[2]	Allowable Concentration μg./m.^{3}	Reference Test Method
TSP	1 year[3]	75[4]	B
TSP	24 hours	150	B
SO_2	1 year	80	A
SO_2	24 hours	365	A
SO_2	3 hours	1,300	A
HC	3 hours[5]	160	E
O_3	1 hour	235[6]	D
CO	8 hours	10,000	C
CO	1 hour	40,000	C
NO_2	1 year	100	F
Be	30 days	0.01	104
Be	14 days	1.50	103,104
Pb	90 days	1.50	G

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[1] Standards for time periods less than one year may be exceeded only once in any consecutive 12-month period, except for the ozone (O_3) standard.

[2] Arithmetic average unless otherwise noted.

[3] Geometric mean.

[4] The equivalent secondary standard is 60 μg./m.^{3}.

[5] Applicable only during the hours from 6 a.m. to 9 a.m.

[6] Violations are determined according to Method H of Chapter IX herein.

10-9-79

REGULATION 34: AMBIENT-AIR STANDARDS

Rule 341: Applicability

A. This REGULATION applies to all areas, classes, sizes, and ages of sources, including major sources and minor sources, existing as well as new sources, and to fugitive air polluting activities as well as stack emissions.

10.9.79

Rule 342: Mass-Concentration Ceilings

A. The maximum allowable concentrations of air pollutants in the ambient air in all areas of the County shall be those listed in Table 341.

B. Those maximum allowable pollutant concentrations specified in Table 341 for time periods less than one year may, in actual practice be exceeded only once during any consecutive 12-month period, except for the ozone standard.

C. In the case of the ozone standard, the standard is violated when more than one day in any calendar year experiences average hourly concentrations above 235 $\mu g./m.^3$. Violations shall be determined in accordance with procedures (Method H) set forth in Chapter IX herein.

10.9.79

Rule 343: Visibility Limiting Standard

A. No person shall cause or permit the airborne diffusion of visible emissions, including fugitive dust, beyond the property boundary line within which the emissions become airborne.

1. In actual practice, the airborne diffusion of visible emissions across property lines shall be prevented by appropriately controlling the emissions at the point of discharge, or ceasing entirely the activity or operation which is causing or contributing to the emissions.

B. This RULE shall not apply when the naturally induced wind speed exceeds 25 miles per hour as estimated by a certified visible emissions evaluator using the Beaufort Scale of Wind-Speed Equivalents, or as recorded by a U.S. Weather Bureau Station or a U.S. Government military installation.

1. This exception does not apply to the demolition, destruction, transport, or pulverization of structures containing friable asbestos materials, and all dust-producing activities associated with such sources shall be halted when the wind is causing or contributing visible emissions to cross beyond the property lines within which the emissions discharge.

2. Any disregard of, neglect of, or inattention to other controls required herein, during any time when this RULE is in effect, shall automatically waive the exception, and such relaxation of controls shall be a violation.

10·9·79

Rule 344: Odor Limiting Standards

A. No person shall cause or permit emissions from malodorous matter to cross a property line between the source and a residential, recreational, institutional, educational, retail sales, hotel, or business premise without minimizing the emissions by applying good modern practices.

  1. Malodorous matter shall include but not be limited to paints, acids, alkalies, pesticides, fertilizer, and manure.
  2. This RULE shall apply to the processing, storing, use, and transporting of malodorous compounds.
  3. Emissions from live trees, shrubs, plants, flowers, domestic gardening, and residential fireplaces shall not be considered malodorous within the meaning of this RULE.

B. The Control Officer shall not formally prosecute violations of this RULE unless five or more persons register complaints with the Control Officer during a consecutive 12-month period (regarding the same apparent source of odors).

REGULATION 37: NONATTAINMENT/ATTAINMENT AREAS

Rule 371: Tucson Nonattainment Areas

A. An area defined by the following township/range/section coordinates shall be a nonattainment area for TSP:

T13S-R13E sections 5, 8-10, 13-17, 20-28, 33-36,
6 (northeast and southeast quarters only),
7 (northeast and southeast quarters only);
T13S-R14E sections 19-21, 26-35;
T14S-R13E sections 1-3, 10-14, 23-25;
T14S-R14E sections 3-9, 17-19, 30.

Boundaries of the Tucson Area for TSP are shown in Figure 371-A.

B. The Tucson nonattainment area for TSP shall be a Class II attainment area for SO_2, NO_2, and O_3, and those portions not lying within the Tucson nonattainment area for CO herein shall be a Class II attainment area for CO.

C. An area defined by the following township/range/section coordinates shall be a nonattainment area for CO:

T11S-R12E, T11S-R13E, T11S-R14E;
T12S-R12E, T12S-R13E, T12S-R14E;
T13S-R11E, T13S-R12E, T13S-R13E, T13S-R14E, T13S-R15E,
T13S-R16E;
T14S-R11E, T14S-R12E, T14S-R13E, T14S-R14E, T14S-R15E,
T14S-R16E;

T15S-R11E, T15S-R12E, T15S-R13E, T15S-R14E, T15S-R15E, T15S-R16E;

T16S-R12E, T16S-R13E, T16S-R14E, T16S-R15E, T16S-R16E;

Excluding all portions of Coronado National Forest and Saguaro National Monument included in those townships.

Boundaries of the Tucson area for CO are shown in Figure 371-C.

D. The Tucson area for CO shall be a Class II attainment area for SO_2, NO_2, and O_3, and those portions not lying within the Tucson nonattainment area for TSP herein shall be a Class II attainment area for TSP.

Rule 372: Ajo Area

A. An area encompassing Ajo and its immediate surroundings shall be a nonattainment area for SO_2, defined by the following township/range/section coordinates:

T11S-R6W, T11S-R5W;
T12S-R6W, T12S-R5W;
T13S-R6W.

B. An additional area shall be unclassifiable for SO_2, defined by the following coordinates:

T11S-R7W;
T12S-R7W;
T13S-R7W, T13S-R5W.

: : :

C. An area defined by the following coordinates shall be a nonattainment area for TSP:

T12S-R6W.

D. The Ajo area shall be a Class II area for CO, NO_2, and O_3.

E. The approximate boundaries of the areas are shown in Figure 372, and encompass approximately 200 square miles.

Rule 373: General County Areas

A. Portions of the County not otherwise designated as Class I (Attainment), Class III (Attainment), unclassifiable, or Nonattainment areas for specific pollutants shall be Class II (Attainment) areas for TSP, SO_2, CO, O_3, and NO_2.

Figure 371-A

Tucson Nonattainment Area for Total Suspended Particulates

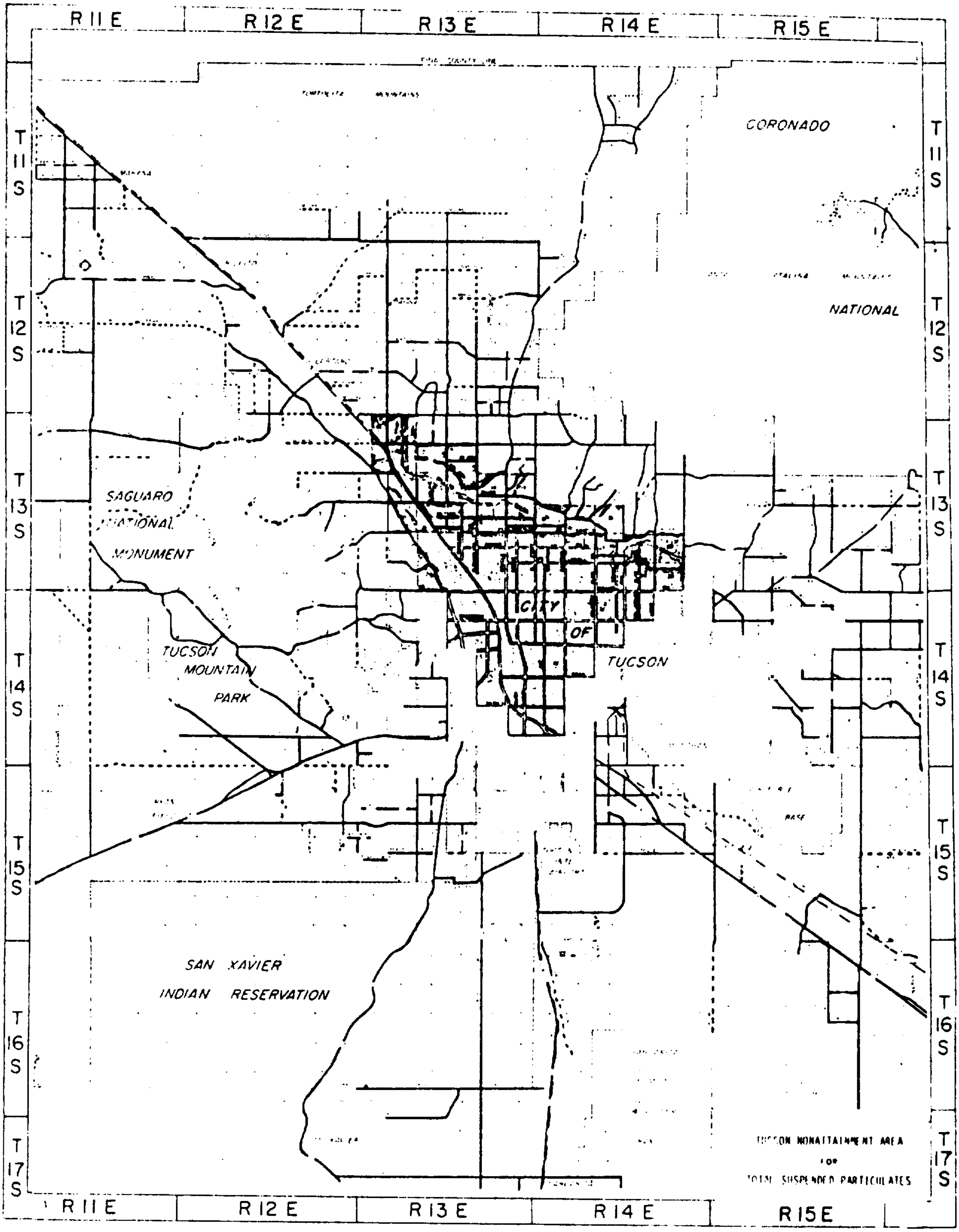


Figure 371-C

Tucson Nonattainment Area for Carbon Monoxide

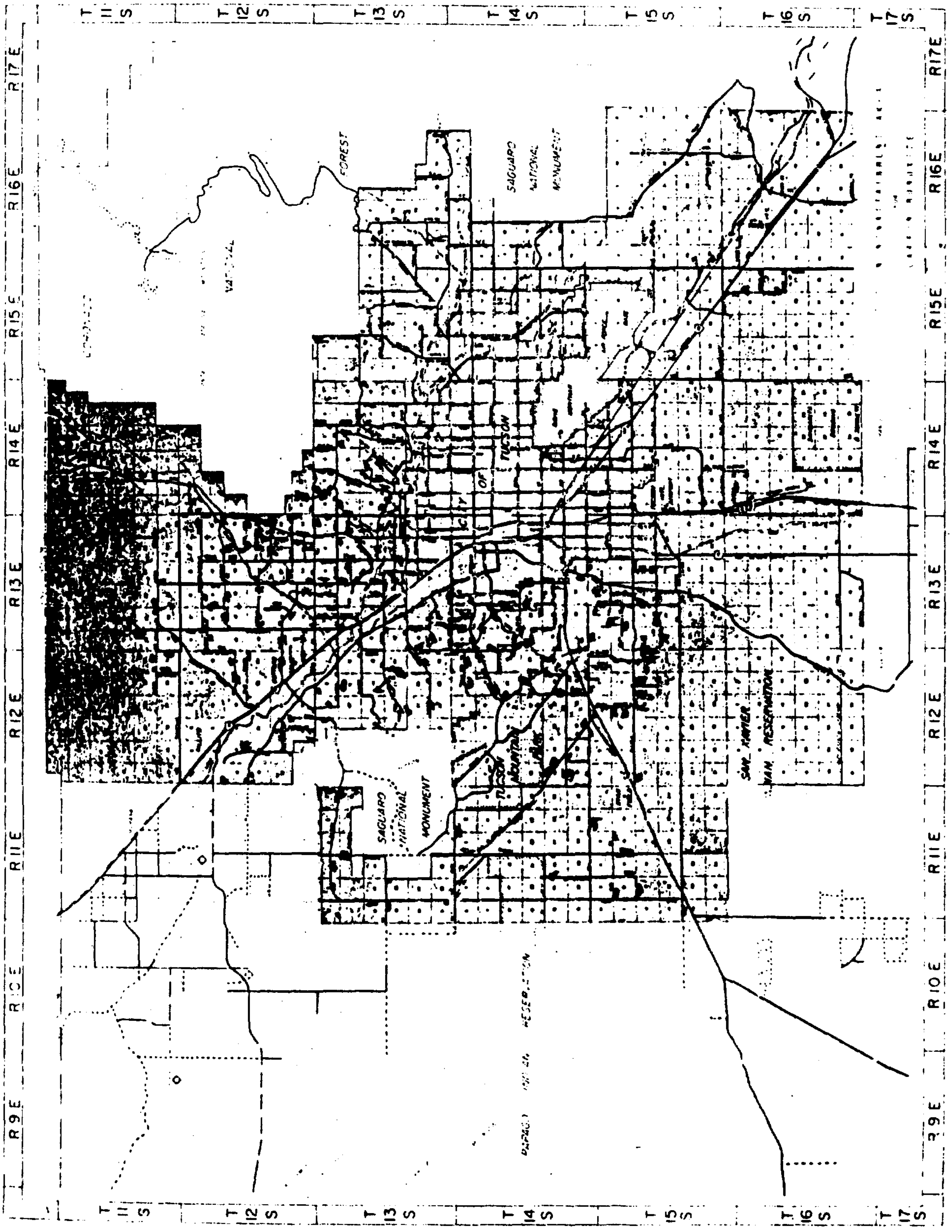
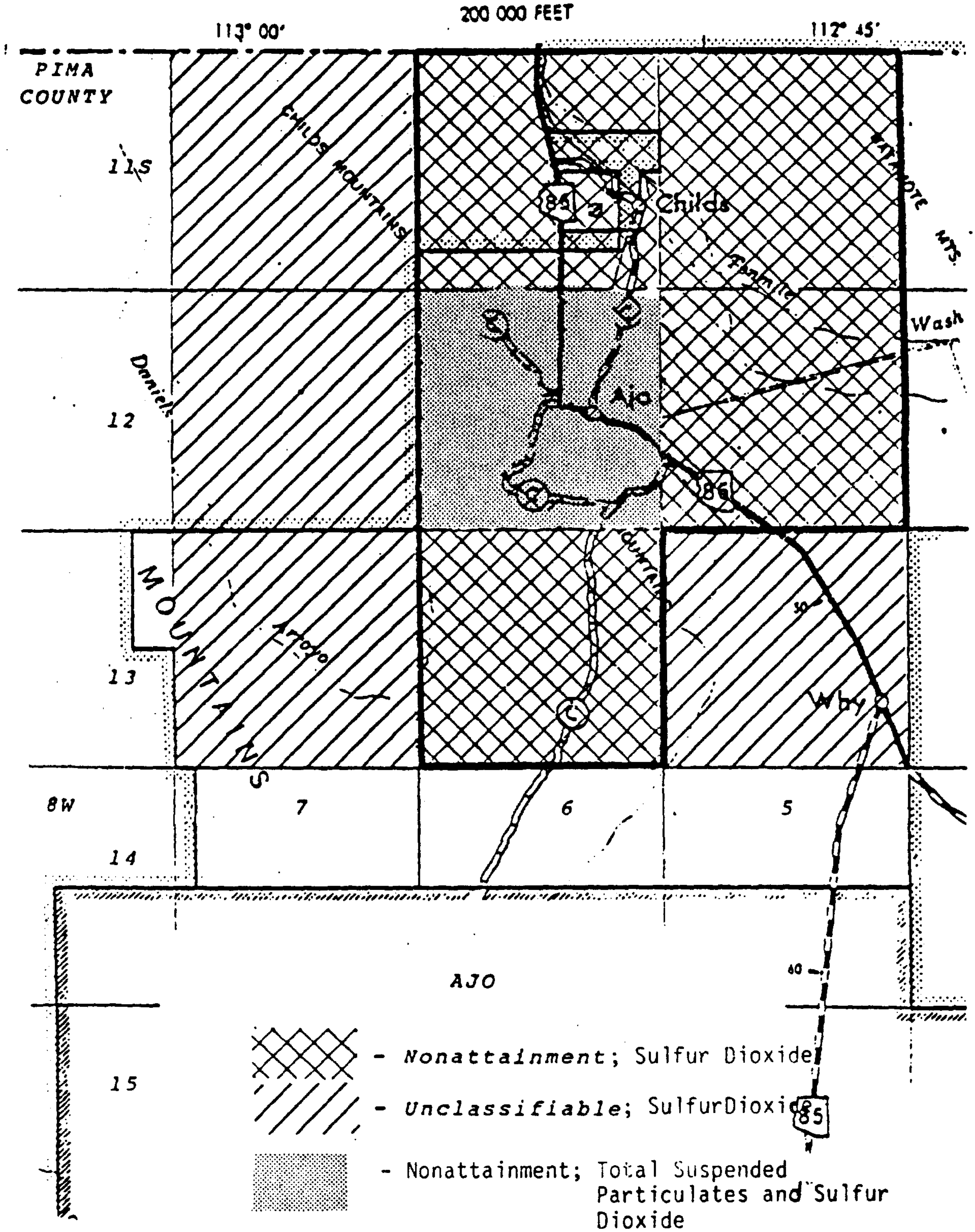


Figure 372

APPROXIMATE BOUNDARIES OF AJO AREA



Rule 373: General County Areas

A. Portions of the County not otherwise designated as Class I (Attainment), Class III (Attainment), unclassifiable, or Nonattainment areas for specific pollutants shall be Class II (Attainment) areas for TSP, SO_2, CO, O_3, and NO_2.

10-18-85

REGULATION 38: NONATTAINMENT-AREA STANDARDS

Rule 381: ADHS Nonattainment-Area Standards

A. The following Articles and Sections contained in Arizona Department of Health Services (ADHS) Rules and Regulations for Air Pollution Control, in effect at the time of this adoption, are hereby adopted by reference and made a part hereof:

1. Article 1. DEFINITIONS,
2. Article 2. AMBIENT AIR QUALITY STANDARDS,
3. Article 3. PERMITS, except for the following:
    a. Testing procedures specified in ADHS Section 9-3-310 shall be replaced with those contained in Regulation 34 or 35 herein;
    b. Permit application forms specified in ADHS Section 9-3-301, E, F, and G shall be replaced with Regulation 21 herein, and
    c. Permit fee provisions and schedules specified in ADHS Section 9-3-319 shall be replaced with Regulation 24 herein.
4. Article 4. EMISSIONS FROM EXISTING AND NEW NON-POINT SOURCES,
5. Article 5. EXISTING STATIONARY POINT SOURCE PERFORMANCE STANDARDS,
6. Article 6. NEW SOURCE PERFORMANCE STANDARDS,
7. Article 9. HAZARDOUS AIR POLLUTANT STANDARDS.

10-18-85

B. The provisions of this REGULATION shall apply only where they are applicable to Class A Installation Permits (as defined in the ADHS regulations) for any new major source or major alteration located in any nonattainment area specified in Regulation 37 herein for the pollutant(s) for which the source is classified as a major source or a major alteration. When the Control Officer issues Operating Permits subsequent to the Class A Installation Permits, the provisions of this RULE shall continue in force.

10·9·79

CHAPTER IV: PERFORMANCE STANDARDS FOR NEW MAJOR SOURCES

REGULATION 40: GENERAL APPLICABILITY

Rule 402: Stack and Shop Emissions

A. The maximum allowable emissions discharge rates and associated maximum allowable mass concentrations of emissions established in this CHAPTER shall apply only to emissions which enter the atmosphere by passing through vents, stacks, flues, or other similar containing or restrictive devices, or which, by reasonable modification of the emission source, can be directed through such devices for testing purposes.

B. The maximum allowable emissions opacities established in this CHAPTER shall apply to any emissions discharge point in an emission source.

10·9·79

Rule 403: Applicability of More Than One Standard

A. A source subject to the provisions of this CHAPTER shall also comply with all applicable provisions of Chapter III.

B. If the nature of an operation or activity allows more than one interpretation of a standard or requirement of this CHAPTER, the more or most restrictive interpretation shall apply.

109.79

REGULATION 41: DESIGNATION OF ATTAINMENT/NON-ATTAINMENT AREAS

Rule 411: Tucson Area

A. A geographical area roughly bounded by the Tortolita and Santa Catalina Mountains on the north, Picacho Peak (Pinal County) and Silverbell Mountains to the northwest, Rincon Mountains to the east, Whetstone Mountains (Cochise County) to the southeast, Santa Rita Mountains (Santa Cruz County) to the south, Sierrita Mountains to the southwest, and Roskruge Mountains to the west shall be known as the Tucson Air Planning Area (TAPA). Geographical coordinates defining the area are:

	Latitude	Longitude
1.	32° 38.5'N	111° 24.0'W
2.	32° 26.5'N	110° 47.5'W
3.	32° 12.5'N	110° 32.5'W
4.	31° 49.5'N	110° 25.5'W
5.	31° 42.0'N	110° 50.5'W
6.	31° 52.5'N	111° 12.5'W
7.	32° 24.0'N	111° 29.0'W

Approximately 85 percent of the Tucson Air Planning Area lies within Pima County. The portion within Pima County encompasses approximately 2,300 square miles, excluding the two Saguaro National Monuments. The approximate boundaries of the Tucson Air Planning Area are shown in Figure 411-A.

B. Except for those portions of Eastern Saguaro National Monument and Western Saguaro National Monument which are wilderness areas, the Tucson Air Planning Area shall be a Class IV (Non-Attainment) area for total suspended particulate matter and carbon monoxide.

C. The Tucson Air Planning Area shall be a Class II (Attainment) area for sulfur dioxide and nitrogen dioxide, and a Class III (Attainment) area for ozone.

D. Two geographical areas represented by the national wilderness portions of Eastern Saguaro National Monument and Western Saguaro National Monument shall be Class I (Attainment) areas for total suspended particulate matter and sulfur dioxide. The approximate boundaries of these areas are shown in Figure 411-A, encompassing approximately 88 square miles.

10-9-79

Figure 411-A

APPROXIMATE BOUNDARIES OF TUCSON AIR PLANNING AREA (TAPA)

CLASS IV (*NON-ATTAINMENT*) GEOGRAPHICAL AREA

LEGEND

■ CLASS I (TSP, CO, O_3, SO_2, NO_2)

▨ CLASS II (TSP, CO, O_3, SO_2, NO_2)

▥ CLASS IV (TSP,CO); CLASS III (O_3); CLASS II (SO_2, NO_2)

10·9·79

Rule 412: Ajo Area

A. An area encompassing Ajo and its immediate surroundings shall be known as the Ajo Air Planning Area (AAPA). Geographical coordinates defining the area are:

	Latitude	Longitude
1.	32° 30.5'N	112° 56.0'W
2.	32° 30.5'N	112° 44.0'W
3.	32° 20.0'N	112° 44.0'W
4.	32° 20.0'N	112° 50.0'W
5.	32° 14.5'N	112° 50.0'W
6.	32° 14.5'N	112° 56.0'W

The approximate boundaries of the Ajo Air Planning Area are shown in Figure 412, and encompass approximately 200 square miles.

B. The Ajo Air Planning Area shall be a Class IV area for total suspended particulate matter and sulfur dioxide.

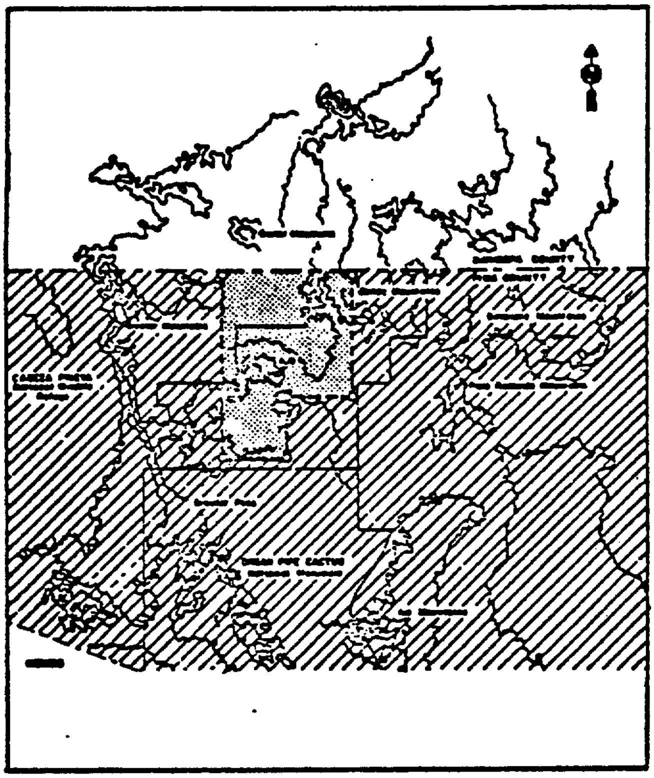
C. The Ajo Air Planning area shall be a Class II area for carbon monoxide, nitrogen dioxide, and ozone.

10·9·79

Figure 412

APPROXIMATE BOUNDARIES OF AJO AIR PLANNING AREA (AAPA)

CLASS IV (*NON-ATTAINMENT*) GEOGRAPHICAL AREA



LEGEND

▨ CLASS II (TSP, CO, O_3, SO_2, NO_2)

░ CLASS IV (TSP, SO_2); CLASS II (CO, O_3, NO_2)

10.9.79

Rule 413: General County Areas

A. Portions of the County not otherwise designated as Class I (Attainment), Class III (Attainment), or Class IV (Non-Attainment) areas for specific pollutants shall be Class II (Attainment) areas for total suspended particulate matter, sulfur dioxide, carbon monoxide, ozone, and nitrogen dioxide.

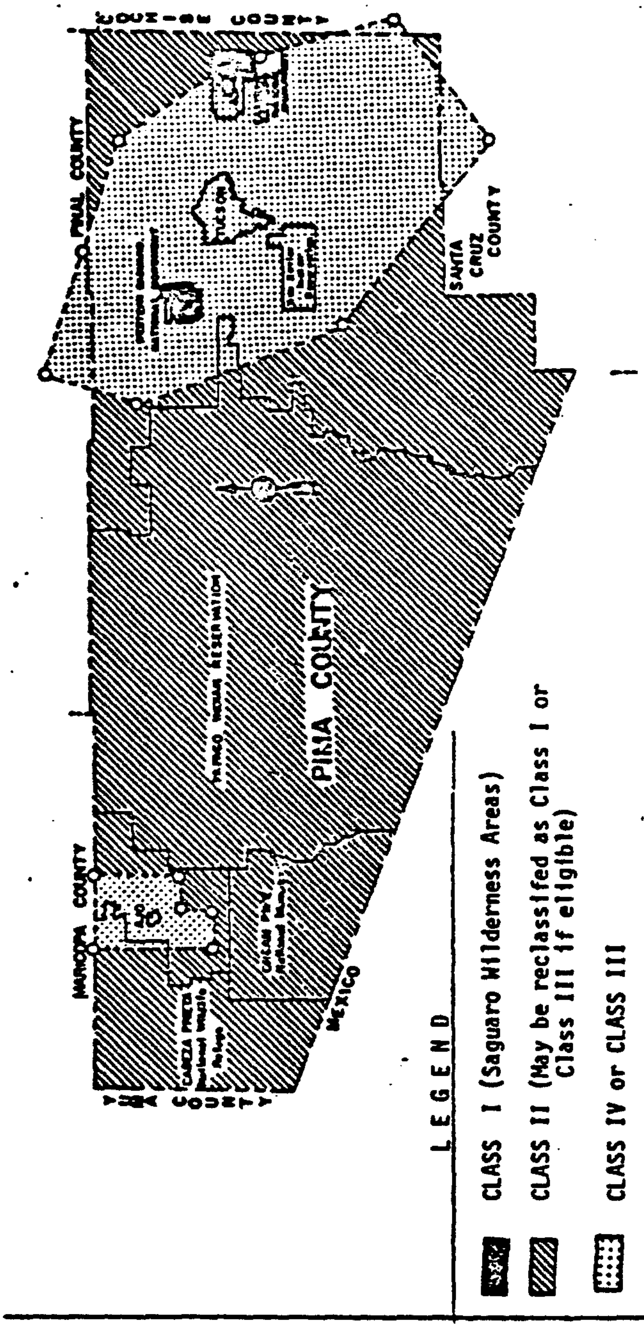
B. The approximate boundaries of the various Attainment/Non-Attainment areas in Pima County are shown in Figure 413.

10.9.79

Figure 413

APPROXIMATE BOUNDARIES OF PIMA COUNTY

ATTAINMENT/NON-ATTAINMENT GEOGRAPHICAL AREAS



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REGULATION 42: STANDARDS FOR NON-ATTAINMENT AREAS

Rule 421: Applicability

A. This REGULATION shall apply to new major sources which are planned to be located in a Class IV (Non-Attainment) area for an individual air pollutant.

B. An existing major source relocated from an Attainment area to a Class IV area, or from one Class IV area to another, shall be considered a new major source.

10·9·79

Rule 422: TSP Clean-Air Plan

A. The intent of this RULE is to reduce the emissions of total suspended particulate matter which affect the Tucson Air Planning Area so that the primary ambient-air standards will be attained throughout the area by December 31, 1982 and the secondary ambient-air standards by December 31, 1990.

1. The planned progress toward achievement of the TSP standards is summarized graphically in Figure 422. A minimum net emission reduction of 8,850 tons of total suspended particulate matter per year from July 1, 1979 through December 31, 1982 is necessary to achieve the primary standards. A minimum net reduction of 3,670 tons of total suspended particulate matter per year from January 1, 1983 through December 31, 1990 is necessary to achieve the secondary standards. These reductions are represented by the slope of the curve labeled Reasonable Further Progress in Figure 422. This RULE shall apply only to the Tucson Air Planning Area.

2. The annual growth rate of actual emissions of total suspended particulate matter from new major sources shall not exceed 85 tons of total suspended particulate matter per year, beginning July 1, 1979, unless Rule 424 (Emission Offset) is applied. The Control Officer shall allocate emission growth rights to applicants for Installation Permits in the order in which the applications are received.

3. The Control Officer shall each year conduct an inventory of actual emissions of total suspended particulate matter in accordance with Rule 423. If an inventory shows that the cumulative emissions of total suspended particulate matter are more than that called for in Figure 422 for the corresponding point in time, the Control Officer shall not grant an Installation Permit to an applicant for a new major source of total suspended particulate matter to be located within the Tucson Air Planning Area until Reasonable Further Progress is achieved for the entire geographical area.

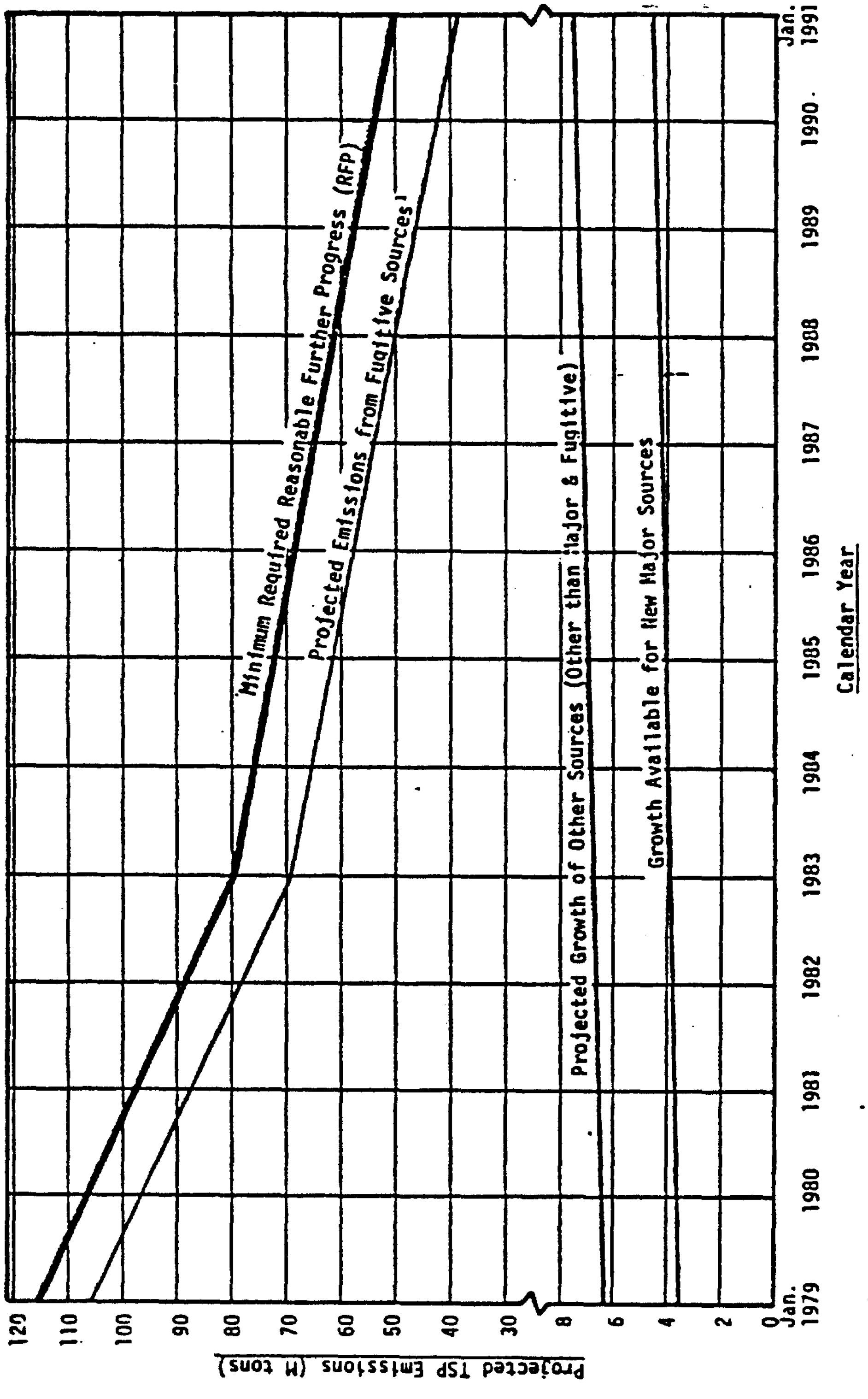
B. At least annually the Control Officer shall review the methodology upon which this RULE is based, as well as the progress toward attainment of the ambient air quality standards. The Control Officer shall appropriately use all available studies provided by local, State, or Federal air quality planning agencies in conducting these reviews. The Control Officer shall propose to the Air Quality Advisory Council and Board of Supervisors modifications to this RULE which may be needed for achieving the goal of this RULE.

1. The Control Officer shall propose changes to make the requirements less restrictive if greater than the planned improvements in air quality are achieved, more restrictive if less than the planned improvements in air quality are achieved, or to make necessary adjustments which result from the availability of improved methods of relating emissions to ambient air quality.

10·9·79

Figure 422

SUMMARY OF TSP CLEAN-AIR PLAN FOR TAPA GEOGRAPHICAL AREA



¹Emissions reflect anticipated reductions through unpaved road paving, paving of road shoulders or curbing, etc.

10·9·79

Table 423

METHODOLOGY FOR RECORDING EMISSIONS IN TSP DATA BANK
(Applicable only within TAPA)

Source Category or Project	Formula for Calculating TSP Emissions, ton/yr.
Paving of Existing Unpaved Road[1]	0.54M(ADT)[2]
Paving and Curbing of Existing Unpaved Road[1]	0.57M(ADT)
Curbing or Paving of Road Shoulders of Existing Paved Road[1]	0.03M(ADT)
Vegetative Stabilization of Dust or Other Permanent Suppression of Dust Associated with Existing Mine Tailings Piles	9.4A[3]
Paving of Existing Unpaved Parking Lot	0.14N(L+W)[4]
Stack Emissions From Industrial Facilities (New or Existing)	(C.O.[5])
Other Fugitive Emissions and Emissions from Mobile Sources	(C.O.[6])

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[1] Either chip seal, concrete, or asphaltic paving, provided road or lot is adequately maintained. Both sides of road are required to be paved and/or curbed, as the particular entry requires.

[2] M = length of road in miles. ADT = Average Daily Traffic, vehicles/day, as specified by the Control Officer on a case-by-case basis, using measured traffic counts if supplied by the source operator. The Control Officer may require the source operator to prove the accuracy of such traffic counts.

[3] A = surface area of pile in acres.

[4] N = average number of vehicles parked per day; L = length of lot in miles; W = width of lot in miles.

[5] Based on mass-emission sampling of the quantities of emissions from each source if test results are available; otherwise based on the Control Officer's estimates of emissions on a case-by-case basis, taking into consideration methodology furnished by the Administrator of the Environmental Protection Agency.

[6] To be specified by the Control Officer on a case-by-case basis, using methods of estimating emissions generally available, taking into consideration methodology furnished by the Administrator of the Environmental Protection Agency.

10.9.79

Rule 423: TSP Emission Data Bank

A. The Control Officer shall establish by July 1, 1979 an emission data bank to track reductions and growth of present and future emissions of total suspended particulate matter in the Tucson Air Planning Area.

1. The bank shall include records of emissions from new sources and reductions in emissions from existing sources which were accomplished after January 1, 1979.
2. Emissions from mobile and stationary sources, stack emissions and fugitive emissions, major- and minor-source emissions, and emissions from stationary sources under jurisdiction of the State Department of Health Services shall be estimated by the Control Officer and the amounts recorded in the emission data bank.
3. The Control Officer shall be guided by the methods presented in Table 423 in estimating emissions of total suspended particulate matter.
4. The Control Officer shall record in the emission data bank, within one month of receipt of the necessary information, a decrease in emissions resulting from completion of a road paving project, road improvement project, or the startup of a new major source. He shall record in the data bank increases or decreases in emissions from other sources at least annually.

B. The Control Officer shall enter and maintain records of emissions of total suspended particulate matter in the emission data bank according to the following conventions:

1. Data shall be recorded in units of tons of emissions per year. An emission reduction shall be a negative entry, representing a deposit (credit). An emission increase shall be a positive entry, representing a withdrawal.
2. A data entry for a new major source owned, operated, or leased by a person other than a governmental entity shall be identified according to the name and mailing address of the source operator, the location of the source, the effective date of the emission change, the date of entry, and the projected increase or decrease in emissions. Such an entry shall be put into a private account and shall be set aside for the exclusive use of the proprietor named at the time of deposit. An emission credit may be transferred from one account to another only upon the request of the proprietor of the account containing the credit. The balance in an account at any time shall be determined by summing the deposits (negative values) and withdrawals (positive values).
3. If a source operator asks the Control Officer to credit the reductions of total suspended particulate matter associated with a temporary shutdown of a major source, then when the source operator re-starts the source, it shall be considered a new major source.
4. A data entry for a source operated by the Federal government, the County, an incorporated city or town, or the State or one of its political subdivisions shall be identified as specified in Paragraph 2. However, unless otherwise requested by the governmental proprietor, all governmental entries shall be consolidated in a public account for the use of the general public as well as the various governmental entities.

B. The Control Officer's estimates of emissions from minor sources, mobile sources, and from existing major sources (both private and public) shall be entered into the public account as the information becomes available.

C. The Control Officer shall make available to an individual proprietor records of his account during normal business hours. The Control Officer shall publish at least annually a summary of the status of the public account.

10.9.79

Rule 424: Emission-Offset Requirements

A. A new major source of total suspended particulate matter which is planned to be located in the Tucson Air Planning Area must comply with at least one of the two succeeding criteria before an Installation Permit is granted:

1. The source's planned actual rate of annual emissions can be accomodated within the growth increments established in Rule 422, or
2. The sum of the following three quantities at the time of permit application is less than the maximum allowable emissions represented by a point on the curve labeled Reasonable Further Progress in Figure 422, approximately corresponding to the time of permit application:
    a. The source's planned actual rate of annual emissions (positive number), plus
    b. The net emission credit (negative number) which the permit applicant has on deposit in the emission data bank described in Rule 423, plus
    c. The net emission credit or debit (negative or positive number) which exists in the public account described in Rule 423.

B. A permit applicant may increase the emission credits in his private account in the data bank by reducing fugitive emissions or emissions from stacks prior to the time of permit application. Similarly, the permit applicant may fully exhaust the emission credits in the public account at the time of permit application. However, in no case shall emission credits in the public account be saved by the Control Officer for a permit applicant if the applicant fails to meet all the requirements for the desired permit at the time of permit application. Consistent with Rule 202 which limits the term of an Installation Permit to two years, an emission credit (from the public account) which has been assigned to a permit applicant shall automatically revert back to the public account if the planned facility is not fully constructed and ready for operation within two years of the date of issuance of the Installation Permit.

10·9·79

Rule 425: Lowest Achievable Emission Rate (LAER)

A. A new major source of total suspended particulate matter or carbon monoxide which is planned to be located in the Tucson Air Planning Area must include provisions for assuring that the source's emissions will represent the lowest achievable emission rate before the Installation Permit is granted.

B. A new major source of total suspended particulate matter or sulfur dioxide which is planned to be located in the Ajo Air Planning Area must include provisions for assuring that the source's emissions will represent the lowest achievable emission rate before the Installation Permit is granted.

10.9.79

Rule 426: Existing Sources in Compliance

A. A permit applicant for a new major source of total suspended particulate matter or carbon monoxide which is planned to be located in the Tucson Air Planning Area must comply with the following requirement for the applicable air pollutant before the Installation Permit is granted:

1. All existing major sources of the applicable air pollutant in the County which are owned, operated or leased by, or under the common control of, the applicant must be either in compliance with all applicable provisions of the RULES AND REGULATIONS or be on approved compliance schedules (Conditional Permits).

B. A permit applicant for a new major source of total suspended particulate matter or sulfur dioxide which is planned to be located in the Ajo Air Planning Area must comply with Paragraph 1 of this RULE before the Installation Permit is granted.

10.9.79

CHAPTER V: TESTING AND MONITORING

REGULATION 50: PERIODIC TESTING

Rule 501: Applicability of Methodology

A. The methods used to measure, test, analyze, and evaluate a quantity or quality associated with a performance standard shall be consistent with, or reasonably equivalent to, the test methods presented in Chapter IX.

1. A deviation from the test methods established herein must be approved by the Control Officer.
2. Whenever a rule in Chapters I through VIII specifies a portion of a test procedure different from a similar procedure contained in Chapter IX, those procedures specified in Chapters I through VIII shall take precedence, and the counterpart procedures in Chapter IX shall be used for all remaining portions of the test.

B. This RULE shall apply to the determination, measurement, and evaluation of ambient air quality, emissions opacities, mass concentrations of emissions, dispersion modeling of air quality, mass-emissions discharge rates, and heat contents of fuels.

C. If measurement of emissions or ambient-air quality is required and an applicable test method is not specified herein, the Control Officer must approve an appropriate method in advance of the test in order for the results of the test to be acceptable.

10.9.79

Rule 502: Testing Frequencies

A. Prior to issuing or renewing an Operating Permit, or when the Control Officer has reasonable cause to believe that a mass limiting emissions-discharge standard or any ambient air standard is being violated, measurement of the quantity of air pollutant being emitted from the source or in the ambient air in the vicinity of the source may be required.

1. The Control Officer may have the necessary tests performed by qualified personnel under his direction, or the source operator may opt (with the approval of the Control Officer) to perform the tests and submit to the Control Officer a report of the tests within 15 days of completion of the time period approved for sampling.

2. The Control Officer shall not require more than one complete series of mass-emissions discharge or ambient-air tests for a particular source in a 12-month period unless the source has been convicted of one or more violations of these RULES AND REGULATIONS in the preceding year, or unless the Control Officer has reasonable cause to believe that these RULES AND REGULATIONS are being violated.

10.9.79

Rule 503: Notification; Fees

A. In any case requiring mass-emissions discharge or ambient-air testing other than opacity measurements, the Control Officer shall give a source operator at least a 30-day written notice of a requirement for a mass-emissions discharge or ambient-air test, other than an opacity test.

B. If the Control Officer himself performs the necessary tests, any expenses he incurs in collecting samples, making the analyses, and preparing the necessary reports shall be charged to the source operator, in addition to permit fees assessed according to these RULES AND REGULATIONS.

   1. The source operator shall pay the testing fee within 30 days of invoicing.

6.1.81

Rule 504: Pre-Installation Testing or Modeling Requirements

A. Prior to issuing an Installation Permit for a new major source, the Control Officer may require the permit applicant to analyze, at his expense, the ambient air, meteorology, terrain, soils and vegetation, and visibility at the site of the proposed source.

1. The effects of emissions from the proposed source on adjacent areas, vegetation, or facilities, and a study of any community growth which may result from the source, may be required.

B. An application for an Installation Permit for a new major source must include an estimate of the effects of the source's planned emissions on the ambient air near the source. The estimate must adequately prove compliance of the source with all applicable ambient air standards by using an assumed stack height which does not exceed a minimally acceptable modeling height, irrespective of other artifically induced

10·9·79

dispersion techniques which the permit applicant might use to minimize the concentrations of air pollutants in the ambient air. For the purposes of this PARAGRAPH, a minimally acceptable modeling height shall mean:

1. A hypothetical stack height of 30 meters for stacks whose effluents would not be influenced by nearby structures or terrain, or
2. The height of the tallest building, process structure, terrain feature, or other non-stack facility either associated with the planned source or which exists at the time of permit application within one-half mile of the planned source,

as the case may require.

C. An estimate of the concentration of a pollutant in the ambient air near a proposed new major source shall be made in accordance with the reference Guideline on Air Quality Models (OAOPS 1.2-080) contained in Chapter IX, provided such document includes a method applicable to the proposed source. If this document does not contain an applicable model, the Control Officer shall refer to Workbook for the Comparison of Air Quality Models contained in Chapter IX herein, and other pertinent guidance furnished to the Control Officer in writing by the Administrator of the Environmental Protection Agency, in specifying to the permit applicant a suitable method for meeting these requirements.

D. In no event shall the Control Officer prohibit the actual construction of a tall stack or restrict the actual height of a stack or other part of the source, provided the permit applicant meets all applicable provisions herein.

E. An ambient-air study covered by this RULE shall be conducted as specified in writing by the Control Officer.

1. The Control Officer shall require only those analyses which are necessary to demonstrate compliance with standards in these RULES AND REGULATIONS if the Control Officer's own data indicate uncertain or marginal compliance of the proposed source with the applicable standard, or if the Control Officer has insufficient data upon which to evaluate the proposed source and he has reasonable cause to believe that construction of the source would cause a violation of a standard. The Control Officer shall provide guidance to a permit applicant who requests help in complying with this RULE.

2. The Control Officer may waive the requirements of Part B of this RULE for a new major source of a pollutant in an area which is nonattainment for that pollutant, if a Nonattainment Area Plan has been approved or conditionally approved by the Administrator of the EPA for that area.

10.9.79

F. If no model in Chapter IX is applicable to the source, and the Control Officer specifies a model inconsistent with additional guidance furnished by the Administrator of the Environmental Protection Agency, Federal Regulations require the permit applicant to obtain written approval from the Administrator for substitution or modification of a model contained herein.

10.9.79

Rule 505: Sampling and Testing Facilities

A. The Control Officer may require the source operator to provide and maintain at his expense sampling and testing facilities. When requested in writing by the Control Officer, a source operator shall provide and maintain performance testing facilities and conditions as follows:

1. Sampling ports adequate for the applicable test method, including (if necessary) extensions of stacks needed for obtaining representative samples,
2. Sampling platforms and access thereto sufficient to assure sampling operator safety and the acquisition of representative samples,
3. Electrical power adequate to perform a test in accordance with the applicable method, and
4. Operation of the source during testing so that representative samples can be obtained.
    a. If source operating conditions must be adjusted during a test, the Control Officer shall notify the source operator in writing at least ten days prior to the test.

10.9.79

Rule 506: Stack Sampling

A. Each mass-emissions discharge test for determining compliance with a standard shall consist of at least three runs using the applicable test method (or reasonable equivalent) in Chapter IX herein.

   1. The arithmetic mean of the results of the three runs shall apply.

   2. If a sample is accidentally lost or if one of the three runs must be discontinued due to forced shutdown, failure of an irreplaceable portion of the sampling train, extreme meteorological conditions, or other circumstances beyond the control of the source cperator, the Control Officer may approve the use of the remaining test runs.

10.9.79

Rule 507: Waiver of Test Requirements

A. If a source operator is required to operate continuous monitoring equipment for one or more air pollutants, periodic testing for the monitored pollutants is not required, provided the source operator operates and maintains the continuous monitoring equipment in conformity with applicable requirements.

REGULATION 51: CONTINUOUS MONITORING

10·9·79

Rule 511: General Requirements

A. A source operator shall procure, install, calibrate, operate, and maintain at his expense equipment necessary for continuously measuring and recording the effluent rate of an air pollutant, an emissions-related process variable, or the concentration of a pollutant in the vicinity of a source when required as a condition of a RULE herein.

B. An operator of an existing source or new major source must equip and maintain a system on each emissions port for continuously measuring and recording the opacity of emissions, if one of the following conditions occurs:

1. If stipulated by the Hearing Board as a requirement of a Conditional Permit (variance), or
2. If the source has been cited and successfully prosecuted for six or more violations of opacity standards which occurred during a consecutive 12-month period and the Control Officer notifies the source operator in writing of the requirement. The Control Officer shall allow the source operator a reasonable amount of time to procure, install, and begin operating the continuous monitoring equipment.

10·9·79

Rule 512: In-Stack Monitoring

A. This RULE applies to existing major sources as well as new major sources.

B. A Fossil Fuel-Fired Steam Generating Plant requires continuous in-stack monitors of the following types:

1. Sulfur dioxide monitor, if the source contains sulfur dioxide pollutant control equipment, plus
2. Nitrogen oxide monitor, if the ambient air standard for nitrogen dioxide is exceeded anywhere in the County as determined by the Control Officer, plus
3. Percent Oxygen or percent carbon dioxide monitor, if either the amount of O_2 or CO_2 is used to convert the output of a sulfur dioxide or nitrogen oxide monitor to emission rate, plus
4. Opacity monitor, unless gaseous fuel is the only fuel burned, or oil or a mixture of gas and oil are the only fuels burned, or unless the source is able to comply with all opacity standards and mass-emissions standards for total suspended particulate matter, and has never been convicted of a violation of an opacity standard or mass-emissions standard for total suspended particulate matter.

C. A Nitric Acid Plant requres a continuous in-stack nitrogen oxide monitor if the ambient air standard for nitrogen dioxide is exceeded anywhere in the County as determined by the Control Officer.

D. A Sulfuric Acid Plant requires a continuous in-stack sulfur dioxide monitor.

E. A Petroleum Refinery requires a continuous in-stack opacity monitor if the source contains a fluid bed catalytic cracking unit.

10·9·79

CHAPTER VI: RECORDKEEPING AND REPORTING

REGULATION 60: CLASSIFICATION OF POLLUTANTS

Rule 601: Classification of Common and Hazardous Air Pollutants

A. The Control Officer has classified air pollutants into the categories below. In the case where no meaning is presented, the common or chemical meaning shall apply.

1. Common air pollutants

   a. nonspecific, total suspended particulate matter; or particulate matter; or total suspended particulate matter (TSP)

      Discrete particles of liquid or solid material, or combinations thereof, other than chemically uncombined water~~,~~ which are discharged into the atmosphere with or without one or more gases as carrier media.

   b. sulfur dioxide (SO_2)

   c. hydrocarbon

      Any volatile organic compound other than methane (CH_4), ethane (C_2H_6), methyl chloroform (CH_3CCl_3), methylene chloride (CH_2Cl_2), and trichloro-trifuoroethane ($C_2Cl_3F_3$).

   d. nitrogen dioxide (NO_2)

   e. carbon monoxide (CO)

   f. ozone (O_3)

   g. lead (Pb)

2. Hazardous air pollutants

   a. asbestos (AB)

   b. beryllium (Be)

   c. mercury (Hg)

   d. vinyl chloride (VC)

   e. benzene (C_6H_6)

B. Additional air pollutants may be identified as common or hazardous air pollutants after they have been similarly identified in the Code of Federal Regulations.

10.9.79

Table 603

METHODOLOGY FOR ENTERING RECORDS OF EMISSIONS INTO TSP DATA BANK

(Applicable only within TAPA geographical area)

Source Category or Project	Formula for Calculating TSP Emissions, ton/yr.
Paving of Unpaved Road[1]	0.54M (ADT)[2]
Paving and Curbing of Unpaved Road[1]	0.57M (ADT)
Curbing or Paving of Road Shoulders of Paved Road[1]	0.03M (ADT)
Vegetative Stabilization of Dust or Other Permanent Suppression of Dust Associated with Mines Tailings Piles	9.4A[3]
Paving of Unpaved Parking Lot	0.74N (L+W)[4]
Stack Emissions From Industrial Facilities	(C.O.[5])
Other Fugitive Emissions and Emissions from Mobile Sources	(C.O.[6])

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[1] Either chip seal, concrete, or asphaltic paving, provided road or lot is adequately maintained. Both sides of road are required to be paved and/or curbed.

[2] M = length of road in miles. ADT = Average Daily Traffic, vehicles/day, as specified by the Control Officer on a case-by-case basis, using measured traffic counts if supplied by the owner, operator, or lessee of the project. The Control Officer may require the owner, operator, or lessee of the project to prove the validity and overall accuracy of such traffic counts.

[3] A = surface area of pile in acres.

[4] N = average number of vehicles parked per day; L = length of lot in miles; W = width of lot in miles.

[5] Based on mass-emission sampling of the quantities of emissions from each source, if test results are available; otherwise based on the Control Officer's estimates of emissions on a case-by-case basis, taking into consideration methodology furnished by the Administrator of the Environmental Protection Agency.

[6] To be specified by the Control Officer on a case-by-case basis, using methods of estimating emissions generally available, taking into consideration methodology furnished by the Administrator of the Environmental Protection Agency.

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CHAPTER VI: RECORDKEEPING AND REPORTING

REGULATION 61: RECORDKEEPING REQUIREMENTS

Rule 611: Recordkeeping for Compliance Determinations *(Amendment to Part A)*

A. The operator of a source of air pollution shall periodically collect, record, and maintain sufficient information on his emissions operation or activity to assure that the compliance status of the operation or activity with these RULES AND REGULATIONS can be readily ascertained at any time. The information shall be retained for at least two years.

10.9.79

1. Data which may be needed for compliance determinations on continuous-flow processes or operations include the chemical composition and rates of raw material feedstocks, products, waste products, and emissions; hours of operation; emissions-control device variables such as differential pressures, temperature, and/or electrical power supplied or energy consumed; narrative descriptions of abnormal startup conditions, process upsets, and malfunctions; and prevailing meteorological conditions.
2. Data which may be needed for compliance determinations on batch-operated processes include chemical composition, quantity, time and duration of each charge of raw material feedstocks, types of product and/or waste product, and each burst or continuous flow of emissions; hours of operation; emissions-control device variables such as differential pressures, temperatures, and/or electrical power supplied or energy consumed; narrative description of abnormal process condition, process upsets, and malfunctions; and prevailing meteorological conditions.
3. A source operator subject to continuous emissions monitoring requirements or continuous process-variables monitoring requirements (Chapter V) shall collect, evaluate, and record data regarding performance testing of the systems, calibration checks, adjustments and maintenance of the systems, and any other information necessary to demonstrate and maintain the accuracy of the system as required by the Control Officer. The Control Officer shall be guided by the requirements for reporting and recordkeeping published in the applicable portions of the Code of Federal Regulations.

10·9·79

Rule 612: Recordkeeping for Emission Inventories

A. In order that the Control Officer may accurately estimate emissions from a specific source or compile a total inventory of emissions in Pima County, the source operator subject to any permit provisions may be required to collect certain information which will allow the Control Officer to estimate the types, quantities, and frequencies of emissions. Such data may include the following:

1. Source location, type, and frequency of operation,
2. Design capacity and normal or average operating rates, including process feedstocks, products, and by-products or waste products, and
3. Sizes of individual equipment and/or rated capacities, e.g., fuel burning equipment in Btu. per hour, capacities of storage vessels in gallons, and electrical energy equipment in horsepower.

10.9.79

REGULATION 62: REPORTING REQUIREMENTS

Rule 621: Reporting for Compliance Evaluations

A. When the Control Officer has reasonable cause to believe that a person is violating a provision of these RULES AND REGULATIONS or a requirement of an Operating or Conditional Permit issued according to these RULES AND REGULATIONS, he may require in writing that such person produce all existing books, records, or other documents which might reasonably contain evidence needed to determine compliance or non-compliance with these RULES AND REGULATIONS. Such information shall be supplied to the Control Officer promptly upon request or in accordance with other conditions stated herein.

10.9.79

Rule 622: Reporting as a Permit Requirement

A. As established in other RULES herein, the Control Officer may require special reporting provisions as a condition of permit, and the Hearing Board may require reporting requirements for a Conditional Permit. Such reporting requirements shall be fulfilled by the permittee according to the written conditions of the permit.

10·9·79

Rule 623: Reporting for Emission Inventories

A. When the Control Officer has need for emission data (areawide or source-specific) to compile emission inventories or control to design plans, he shall notify source operators of interest in writing, stating with specificity the type of information needed.

1. A source operator receiving such a request shall furnish the information to the Control Officer in writing, within 45 days of receipt of the request, or shall ask for additional time to obtain the information. The length of an extension shall be commensurate with the magnitude of the task of gathering the required information.

10-9-79

Rule 624: Reporting for TSP Emission Data Bank

A. The source operator of a planned new major source of total suspended particulate matter shall report to the Control Officer its planned maximum actual emission rates at the time of application for an Installation Permit as required herein.

   1. Upon request, the Control Officer shall assist a permit applicant in estimating his planned emission rates in order to satisfy this requirement.

B. The owner, operator, or lessee of any of the following projects in the Tucson Air Planning Area shall submit information needed to estimate the increase or decrease in emissions of total suspended particulate matter resulting from the project on a form provided by the Control Officer, no later than one month from the date of completion of such project:

   1. Curbing or paving of a paved road longer than 100 feet, or curbing or paving of road shoulders at an intersection,
   2. Paving of an unpaved road longer than 100 feet except private driveways,
   3. Vegetative or other permanent dust stabilization of any mine tailings pile larger than one-half acre, or creation of any new tailings pile or increase in surface area of an existing tailings pile of one-half acre or more,
   4. Paving of an unpaved parking lot having space for at least five cars, and
   5. Construction of a new road longer than 100 feet except private driveways.

10·9·79

REGULATION 63: AVAILABILITY OF INFORMATION

Rule 631: Confidentiality of Trade Secrets, Sales Data, and Proprietary Information

A. Information provided to or otherwise obtained by the Control Officer shall be available to the public except that if a source operator can show to the Control Officer's satisfaction that public disclosure of such information would divulge production or sales statistics, or proprietary information related to the unique nature of a process or product, and would thereby tend to adversely affect his competitive position, then this information shall be only for the confidential use of the Control Officer and/or his supervisors in administering these RULES AND REGULATIONS. However, this RULE shall not be construed as prohibiting the Control Officer from publishing quantitative or qualitative emission statistics.

10.9.79

REGULATION 64: PENALTY FOR NON-COMPLIANCE

Rule 641: Suppression; False Information

A. Any person who fails to respond to a request for information, or who knowingly reports false information, is subject to the same penalty as a violator of any other provision of these RULES AND REGULATIONS.

10·9·79

CHAPTER VII: VIOLATIONS AND JUDICIAL PROCEDURES

REGULATION 70: VIOLATIONS

10·9·79

Rule 701: Criminal Complaint

(Refer to ARS 36-781)

10·9·79

Rule 703: Injunction

(Refer to ARS 36-787)

10·9·79

Rule 704: Precedence of Actions

(Refer to ARS 36-788)

10·9·79

Rule 705: Penalties

(Refer to ARS 13-101, et seq., plus ARS 13-801, et seq.)

10·9·79

Rule 706: Reviews for Startup, Shutdown, or Malfunctions

A. A source operator shall notify the Control Officer of any occurrence during malfunction, startup, or shutdown in which a control standard is violated. Such notification shall identify the time, location, involved equipment,and the cause of the occurrence to the extent known. The notification shall be made as soon as possible, but in any case not later than four hours after the start of the next regular business day.

B. When startup, shutdown, or equipment malfunction causes or contributes to emissions in excess of a control standard established herein, and the Control Officer has issued a Notice of Violation for the exceedance, the alleged violator may petition the Control Officer to review the Notice of Violation. Each petition shall include as a minimum:

1. The identity of the stack and/or other emission points where the excess emissions occurred,
2. The magnitude of the excess expressed in the units of the applicable control standard, and the operating data and calculations used in determining the excess,
3. The time and duration of the excess,
4. The nature and cause of the excess,
5. If the excess emissions were the result of a malfunction, a description of the steps taken or planned to remedy the malfunction

10-9-79

and to prevent recurrence,

6. The steps taken to limit the excess emissions, and
7. Evidence that the source's air pollution control equipment, process equipment, and/or processes were at all times maintained and operated, to the maximum practicable extent, consistent with good practice for minimizing emissions.

C. A petition for review of a Notice of Violation must be delivered to the Control Officer within 72 hours of the time and date of the field-issued Notice of Violation, excluding weekends and legal holidays.

D. The Control Officer may defer prosecution of a Notice of Violation issued for an exceedance of a control standard if the following conditions are met:

6-1-81

1. The alleged violator's petition for review was prepared according to Part B of this RULE and the petition clearly demonstrates that the excess emissions were caused solely by a startup, shutdown, or equipment malfunction which was temporary, unavoidable, and not due to negligence,
2. The alleged violator's petition for review was received according to Part C of this RULE,

10-9-79

3. The Control Officer has no evidence that the excess emissions associated with the alleged violation—or emissions associated with similar, recurring violations—exceeded one or more emissions discharge standards for more than an aggregate of three minutes in any one hour, or 30 minutes in any 24-hour period, for all sources under control of the same source operator at a contiguous geographical area, and
4. It is determined that the alleged violation was not serious, that human health has not been unduly endangered either directly or indirectly, and that the alleged violator has made good-faith efforts to avoid the excess emissions or that no practical or reasonable control measures were available.

E. Nothing in this RULE shall be construed to limit the obligation of the source operator to prevent the exceedance of an ambient air quality standard or a maximum allowable increase of a pollutant in the ambient air as established herein, as the case may apply.

10·9·79

REGULATION 72: CIRCUMVENTION

Rule 721: Evasion of Basic Requirements

A. No provision, rule, or regulation herein shall authorize any practice or combination of practices designed to circumvent the requirements of these RULES AND REGULATIONS. An intent, design, or act to circumvent the requirements of these RULES AND REGULATIONS shall be a violation of these RULES AND REGULATIONS.

10-9-79

Rule 722: Concealment of Emissions

A. No person shall construct, install, erect, use, replace, modify, or operate an emission source so as to conceal an emission which would otherwise be a violation of a control standard established herein.

   1. Concealment includes the use of gaseous diluents to achieve compliance with an opacity standard or with a standard which is based on the concentration of a pollutant in the gases discharged to the atmosphere.

   2. Concealment also includes operating in a piecemeal fashion to avoid compliance with a standard that would otherwise apply to the source on the basis of its size.

10-9-79

CHAPTER VIII: EMERGENCY EPISODES AND PUBLIC AWARENESS

REGULATION 80: EMERGENCY EPISODES

Rule 801: State Jurisdiction

A. Pursuant to ARS 36-1719, the Director of the Arizona Department of Health Services and the Governor of Arizona have exclusive jurisdiction over any air pollution conditions which constitute an emergency risk to the public health. Orders of the Governor during any emergency episode condition in Pima County shall be enforced by the Control Officer.

10.9.79

Table 802

AIR POLLUTION EPISODE CRITERIA

Pollutant	Averaging Time	Episode Stage* (concentrations in µg./m.^{3}) Alert	Warning	Emergency	Significant Harm
SO_2	24 hours	800	1,600	2,100	2,620
TSP	24 hours	375	625	875	1,000
TSP x SO_2	24 hours	65,000	261,000	393,000	490,000
CO	8 hours	17,000	34,000	46,000	57,500
CO	4 hours	--	--	--	86,300
CO	1 hour	--	--	--	144,000
O_3	1 hour	400	800	1,000	1,200
NO_2	1 hour	1,130	2,260	3,000	3,750
NO_2	24 hours	282	565	750	938

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*Providing meteorological conditions are such that the pollutant concentration can be expected to remain at the designated levels for at least 12 hours.

10·9·79

Rule 802: Determination of Emergency Conditions

A. When the Control Officer determines that high concentrations of pollutants in the ambient air and/or weather conditions constitute an emergency risk to persons in the County, such determination shall be communicated promptly to the public and to the Director of the Arizona Department of Health Services.

1. Criteria used for determining an emergency shall include the air pollutant concentration levels listed in Table 802.
2. Possible episode conditions shall include the progressively deteriorating air quality levels listed as Alert, Warning, and Emergency in Table 802. These criteria have been established to prevent, avoid, or reduce the Significant Harm level of air pollution. (Significant Harm means increased morbidity or irreversible, incapacitating damage to the health of the citizenry.)
3. Weather forecasts of conditions which are likely to produce unusually high concentrations of air pollutants in a large area shall be communicated to the public when deemed appropriate by the Control Officer.

B. Upon the recommendation of the Director of the Arizona Department of Health Services, the Governor of the State may, by proclamation, declare that an air pollution emergency exists in a specific area and may order appropriate curtailments of emissions to eliminate the emergency in the affected area.

10.9.79

Rule 803: Emergency Episode Reporting

A. During any stage of an air pollution episode in the County, the Control Officer shall redirect available resources toward a prearranged plan of air quality monitoring, reporting, and communication of information to the Arizona Department of Health Services.

1. Such plan shall include (as directed by the Director of ADHS) collection and analysis of air pollutant data at intervals more frequent than normal, and continual analysis of local weather reports and forecasts.
2. A written report of the air quality levels before, during, and after the episode condition shall be forwarded to the ADHS Director within one week of the episode.

10-9-79

Table 804

POSSIBLE CONTROL ACTIONS DURING VARIOUS STAGES OF AN AIR POLLUTION EPISODE[1]

Alert Stage

1. Suspend all Open Burning Permits.
2. Limit incineration to 12 noon to 4:00 p.m.
3. Curtail operations of selected manufacturing industries.
4. Request public to eliminate unnecessary motor vehicle use.

Warning Stage

1. Prohibit open burning.
2. Prohibit incineration.
3. Reduce emissions from manufacturing industries by at least 40 percent.
4. Transfer power plant generating loads outside affected area.
5. Prohibit highway construction and dust producing construction activities.
6. Prohibit dust producing crop preparation and cultivation activities.
7. Request public to eliminate motor vehicle use.

Emergency Stage

1. Prohibit operation of selected manufacturing industries.
2. Close all commercial, governmental, and institutional establishments except public safety and welfare institutions.
3. Reduce power generating loads.
4. Halt all construction except emergency construction.
5. Prohibit motor vehicle use except that necessary for public safety and welfare.

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[1] Subject to orders by the Governor of Arizona and directed by the Director of the Arizona Department of Health Services.

10.9.79

Rule 804: Enforcement Actions

A. Depending on the severity of an air pollution episode, the Governor of the State may prohibit or restrict various emission source activities in the affected area for the duration of the episode.

   1. Such prohibitions or restrictions may include the enforcement actions listed in Table 804.

B. During any stage of an air pollution episode in the County, upon the request of the Director of the Arizona Department of Health Services, the Control Officer shall redirect available staff to assist ADHS staff in eliminating the episode condition, according to a prearranged plan.

   1. Such plan shall include increased surveillance of emission sources, possible suspensions of existing air pollution permits, and enforcement of special emission limiting actions.

   2. Mandatory prohibitions or restrictions imposed by the Director of the Arizona Department of Health Services shall be implemented by the Control Officer upon the request of the ADHS Director.

10.9.79

REGULATION 81: AVAILABILITY OF MONITORING DATA

Rule 811: Continuous Monitoring of Ambient Air Pollution

A. The Control Officer shall continually measure the concentrations of air pollutants in the ambient air as needed by the overall control program and apprise the general public of current or imminent conditions which might be hazardous to their health.

   1. Each common pollutant shall be monitored in at least one location representative of an area of high population density in the County.

B. Monitoring data shall be reduced to easily understandable terms and made available to the public upon request as soon as possible after acquisition.

   1. The latest available data shall be reported as current data, and data from any monitoring station currently in operation shall be selectively reported upon request.

10.9.79

REGULATION 82: PUBLIC AWARENESS

RULE 821: Reports to the Public

A. Violations of an ambient air standard which occurred during the preceding calendar year shall be communicated to the public in an annual report. This report shall be widely distributed, and shall include information on health hazards associated with violations and on the pollution control measures which were implemented to reduce the hazardous emission levels. This report shall also suggest procedures for preventing recurrences of violations, and ways in which the public may participate in these procedures. For example, given advance information on adverse weather conditions, the Control Officer, upon the approval of the Director of the Arizona Department of Health Services, may recommend that the public reduce motor vehicle use during selected hours.

B. The public shall be informed of average daily visibility, and average daily concentrations of three common air pollutants: TSP, CO and O_3. This information shall be made available to newspapers, television and radio stations for dissemination.

10-9-79

Rule 822: General Information

A. As resources permit, Air Quality Control District staff shall respond to telephone and written inquiries from the public regarding the field of air pollution control or the air quality in Pima County, and shall grant interviews to the news media, public or private groups.

10·9·79

Rule 823: Public Participation in Rulemaking

A. The Control Officer shall encourage the public to provide input to the rulemaking process.

   1. Extensive publicity, including prominently displayed advertisements in newspapers of wide circulation and notification by mail to interested public and private organizations, shall be given to all public hearings conducted by the Air Quality Advisory Council, the Air Quality Hearing Board, and the Board of Supervisors concerning proposed amendments to these RULES AND REGULATIONS.

B. The Control Officer shall consider public comment on methods to improve these RULES AND REGULATIONS, or to improve air quality in Pima County. For example, informal comments received from interested citizens may be filed and referred to when amending this document.

10-9-79

REGULATION 90: DELEGATIONS OF JURISDICTION

Rule 901: General Affidavit of Delegation

AFFIDAVIT

STATE OF ARIZONA)
:ss
COUNTY OF MARICOPA)

SUZANNE DANDOY, M.D., being first duly sworn, upon her oath deposes and says:

That she is now and has been since June 1975 the Director of the Department of Health Services.

That pursuant to A.R.S. § 36-1705(B) she and her predecessor have the authority to delegate jurisdiction to county air pollution control districts over those sources defined in A.R.S. § 36-1706.

That she as Director of the Department of Health Services is required by law to keep records concerning the operation of that department.

That the Director of the Department of Health Services on September 25, 1970, acting through the Director of Air Pollution Control did delegate, by registered letter, jurisdiction over elementary, high school, and nonstate operated junior college districts to the Pima County Air Pollution Control District. Such delegation is evidenced by Exhibit "A" attached hereto and incorporated herein.

That such delegation was accepted by the then Director of the Pima County Health Department as evidenced by Exhibit "B" attached hereto and incorporated herein.

That said delegation and its acceptance has remained in continuous force and effect since September 25, 1970 to the date of this affidavit.

Suzanne Dandoy MD
Suzanne Dandoy, M.D.

SUBSCRIBED AND SWORN to before me this 15 day of September, 1978.

Vicki
Notary Public

My commission expires:
June 26, 1980

10.9.79

Rule 902: Political Sub-Divisions Delegation

REGISTERED MAIL - RETURN RECEIPT REQUESTED September 25, 1970

Roy McCaldin, Ph.D., Director
Division of Environmental Health
Pima County Health Department
151 West Congress Street
Tucson, Arizona 85701

Dear Dr. McCaldin:

In response to your letter of September 16, 1970, in which you requested the delegation of authority for controlling certain sources of air pollution, it is the decision of the Director of the State Division of Air Pollution Control to delegate authority over certain types of sources falling under Section 36-1705 A.2. of the Arizona Revised Statutes. Such delegation at the present time shall include:

1. Elementary, high school and non-state operated junior college districts.
2. County and city construction and road building except that portable equipment will remain under State jurisdiction.
3. Sanitary landfills as defined under Regulation 2 and A.R.S. Statute Title 36, Chapter 1, Section 36-105.
4. County Highway Department open burning.
5. County and municipal buildings.

Delegation of the above sources is contingent upon provision of a semi-annual report to the State Division of Air Pollution Control showing the frequency of inspection and the adequacy of control of each individual source inspected by the County. This report shall include special reference to each source where there is non-conformity with applicable rules and standards and also indication of instances of non-cooperation of persons responsible for the operation of these delegated sources. Failure on the part of the County of the foregoing requirements would constitute conditions rendering the delegation of this authority void.

This delegation shall become effective upon my receipt of a certified or registered letter of acceptance and shall continue until further notice.

This agency appreciates the interest of Pima County in assuming jurisdiction over sources of air pollution in Pima County and looks forward to working with your agency for the purpose of controlling air pollution. Continued consideration will be given to delegation of authority to your agency relative to the control of air pollution sources.

Sincerely yours,

Norman E. Schell, Director
Division of Air Pollution Control

NES:es
bc: Senator Cardella
V.F.R. Griffith

AFFIDAVIT

STATE OF ARIZONA)
) ss
COUNTY OF MARICOPA)

SUZANNE DANDOY, M.D., being first duly sworn, upon her oath deposes and says:

SUZANNE DANDOY hereby certifies that she is the Director of the Arizona Department of Health Services; that she is the official custodian of the records authorized to be kept by law by the Arizona Department of Health Services; that this document, dated September 25, 1970, is a true and correct copy of a document delegating jurisdiction contained in the files of the Arizona Department of Health Services.

Suzanne Dandoy MD
SUZANNE DANDOY, M.D., M.P.H.
Director

SUBSCRIBED AND SWORN TO before me this 26th day of September, 1978.

Margaret Allen
Notary Public

My Commission Expires:
4-26-81

10.9.79

Rule 902, Continued

OCT 1970
RECEIVED

PIMA COUNTY HEALTH DEPARTMENT
151 West Congress Street
Tucson, Arizona 85701

Frederick J. Brady, M.D.
Director

Phone 792-8511

Environmental Health Services
792-8618

October 1, 1970

Mr. Norman E. Schell, Director
Division of Air Pollution Control
Arizona State Department of Health
Hayden Plaza West
4019 North 33rd Avenue
Phoenix, Arizona 85017

Dear Norm:

This is to acknowledge your letter of September 25, 1970, in which you have delegated certain air pollution control responsibility to the Pima County Health Department.

We accept the delegations and will continue to pursue air pollution control endeavors for these pollution sources.

Sincerely yours,

Roy

Roy O. McCaldin, Ph.D.
Director

ROM:al
cc: Wm. Griffith

AFFIDAVIT

STATE OF ARIZONA)
} ss
COUNTY OF MARICOPA)

SUZANNE DANDOY, M.D., being first duly sworn, upon her oath deposes and says:

SUZANNE DANDOY hereby certifies that she is the Director of the Arizona Department of Health Services; that she is the official custodian of records authorized to be kept by law by the Arizona Department of Health Services; that this document, dated October 1, 1970, is a true and correct copy of a document accepting a delegation of jurisdiction contained in the files of the Arizona Department of Health Services.

Suzanne Dandoy
SUZANNE DANDOY, M.D., M.P.H.
Director

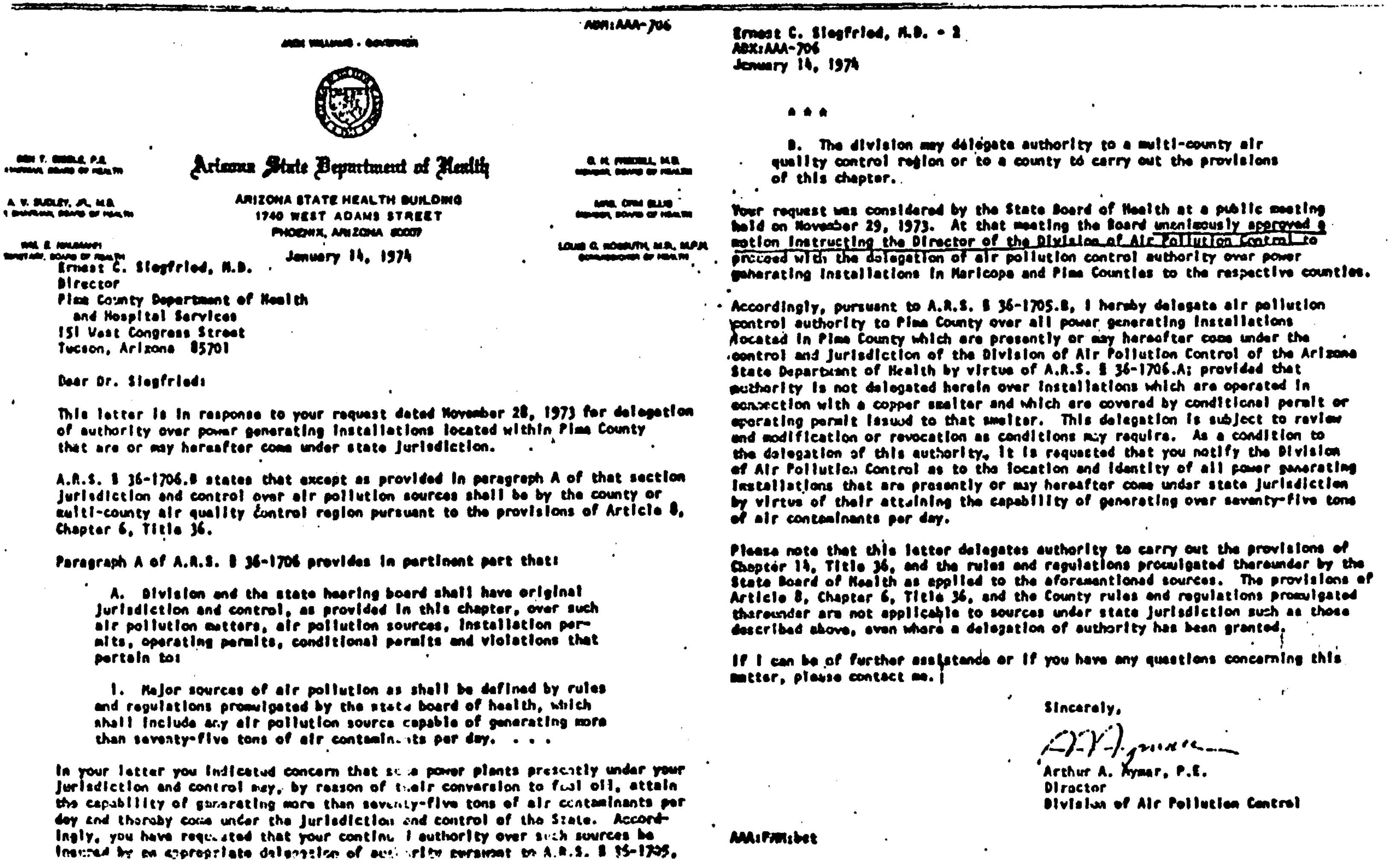
SUBSCRIBED AND SWORN TO before me this 26th day of September, 1978.

Margaret Allen
Notary Public

My Commission Expires:
4-26-81

10-9-79

Rule 903: Large Power Plants Delegation



ABX:AAA-706

JACK WILLIAMS · GOVERNOR

Arizona State Department of Health

ARIZONA STATE HEALTH BUILDING
1740 WEST ADAMS STREET
PHOENIX, ARIZONA 85007

[illegible], P.E.
CHAIRMAN, BOARD OF HEALTH

A. V. [illegible], JR., M.D.
VICE CHAIRMAN, BOARD OF HEALTH

[illegible]
SECRETARY, BOARD OF HEALTH

[illegible], M.D.
MEMBER, BOARD OF HEALTH

MRS. [illegible]
MEMBER, BOARD OF HEALTH

LOUIS C. KOSSUTH, M.D., M.P.H.
COMMISSIONER OF HEALTH

January 14, 1974

Ernest C. Siegfried, M.D.
Director
Pima County Department of Health
and Hospital Services
151 West Congress Street
Tucson, Arizona 85701

Dear Dr. Siegfried:

This letter is in response to your request dated November 28, 1973 for delegation of authority over power generating installations located within Pima County that are or may hereafter come under state jurisdiction.

A.R.S. § 36-1706.B states that except as provided in paragraph A of that section jurisdiction and control over air pollution sources shall be by the county or multi-county air quality control region pursuant to the provisions of Article 8, Chapter 6, Title 36.

Paragraph A of A.R.S. § 36-1706 provides in pertinent part that:

> A. Division and the state hearing board shall have original jurisdiction and control, as provided in this chapter, over such air pollution matters, air pollution sources, installation permits, operating permits, conditional permits and violations that pertain to:
>
> 1. Major sources of air pollution as shall be defined by rules and regulations promulgated by the state board of health, which shall include any air pollution source capable of generating more than seventy-five tons of air contaminants per day. . . .

In your letter you indicated concern that some power plants presently under your jurisdiction and control may, by reason of their conversion to fuel oil, attain the capability of generating more than seventy-five tons of air contaminants per day and thereby come under the jurisdiction and control of the State. Accordingly, you have requested that your continued authority over such sources be insured by an appropriate delegation of authority pursuant to A.R.S. § 36-1705.

Ernest C. Siegfried, M.D. - 2
ABX:AAA-706
January 14, 1974

* * *

> B. The division may delegate authority to a multi-county air quality control region or to a county to carry out the provisions of this chapter.

Your request was considered by the State Board of Health at a public meeting held on November 29, 1973. At that meeting the Board unanimously approved a motion instructing the Director of the Division of Air Pollution Control to proceed with the delegation of air pollution control authority over power generating installations in Maricopa and Pima Counties to the respective counties.

Accordingly, pursuant to A.R.S. § 36-1705.B, I hereby delegate air pollution control authority to Pima County over all power generating installations located in Pima County which are presently or may hereafter come under the control and jurisdiction of the Division of Air Pollution Control of the Arizona State Department of Health by virtue of A.R.S. § 36-1706.A; provided that authority is not delegated herein over installations which are operated in connection with a copper smelter and which are covered by conditional permit or operating permit issued to that smelter. This delegation is subject to review and modification or revocation as conditions may require. As a condition to the delegation of this authority, it is requested that you notify the Division of Air Pollution Control as to the location and identity of all power generating installations that are presently or may hereafter come under state jurisdiction by virtue of their attaining the capability of generating over seventy-five tons of air contaminants per day.

Please note that this letter delegates authority to carry out the provisions of Chapter 14, Title 36, and the rules and regulations promulgated thereunder by the State Board of Health as applied to the aforementioned sources. The provisions of Article 8, Chapter 6, Title 36, and the County rules and regulations promulgated thereunder are not applicable to sources under state jurisdiction such as those described above, even where a delegation of authority has been granted.

If I can be of further assistance or if you have any questions concerning this matter, please contact me.

Sincerely,

Arthur A. Aymar, P.E.
Director
Division of Air Pollution Control

AAA:FMN:bet

AOK:AAA-773

JACK WILLIAMS - GOVERNOR

Arizona State Department of Health

ARIZONA STATE HEALTH BUILDING
1740 WEST ADAMS STREET
PHOENIX, ARIZONA 85007

February 11, 1974

Ernest C. Siegfried, M.D., Director
Pima County Department of Health and
Hospital Services
151 West Congress Street
Tucson, Arizona 85701

Dear Dr. Siegfried:

With reference to my letter of January 14, 1974 regarding the delegation of authority over certain power generating installations located in Pima County, a question has risen as to whether under this delegation an application for a conditional permit by such an installation should be made to the appropriate County Air Pollution Control Hearing Board.

The above-referenced letter delegated complete air pollution control authority to carry out the provisions of Chapter 14, Title 36, Arizona Revised Statutes, as they apply to certain power-generating installations to Pima County Department of Health and Hospital Services. Under this delegation of authority, the County Control District, County Control Officer and County Air Pollution Control Hearing Board take the place of the Division of Air Pollution Control, the Director of the Division of Air Pollution Control and the Arizona State Air Pollution Control Hearing Board, respectively, for the purposes of administering the provisions of Chapter 14, Title 36, A.R.S. Accordingly, should it become necessary to request an application for a conditional permit for a power generating installation covered by the aforementioned delegation, it should be filed with the appropriate County Air Pollution Control Hearing Board which would then proceed in accordance with the provisions of A.R.S. §§ 36-1712 et seq.

Sincerely,

Arthur K. Aymar, P.E.
Director
Division of Air Pollution Control

AAK:aa

Rule 904: Unpaved Roads Delegation

JACK WILLIAMS - GOVERNOR

[illegible], P.E.
CHAIRMAN, BOARD OF HEALTH

A. V. [illegible], JR., M.D.
VICE CHAIRMAN, BOARD OF HEALTH

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SECRETARY, BOARD OF HEALTH

Arizona State Department of Health

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C. H. [illegible], M.D.
MEMBER, BOARD OF HEALTH

[illegible]
MEMBER, BOARD OF HEALTH

LOUIS C. KOSSUTH, M.D., M.P.H.
COMMISSIONER OF HEALTH

March 19, 1974

Mr. C. Lee Fox, Chief
Air Pollution Control District
Pima County Health Department
151 West Congress Street
Tucson, Arizona 85701

Dear Mr. Fox:

Please excuse this delayed response to your letter of February 25, 1974 requesting delegation of authority for air pollution from unpaved roads.

A.R.S. 36-1706.A.2. states that the division and the state hearing board shall have original jurisdiction and control over such air pollution matters, air pollution sources, installation permits, operating permits, conditional permits and violations that pertain to air pollution generated by operations and activities of all agencies and departments of the state and its political subdivisions.

Accordingly, pursuant to A.R.S. 36-1705.B I hereby delegate air pollution control authority to Pima County over all roads in Pima County owned or operated or maintained by political subdivisions of the State of Arizona. This delegation is subject to review and modification or revocation as conditions may require.

Please note that this letter delegates authority to carry out the provisions of Chapter 14, Title 36 as applied to the aforementioned sources.

If I can be of further assistance or if you have any questions concerning this matter, please contact me.

Sincerely,

AAAymer

Arthur A. Aymer, P.E.
Director
Division of Air Pollution Control

AAA:es

cc: Robert Taylor
L. C. Kopisch

10 9-79

REGULATION 91: REFERENCE TEST METHODS

Rule 911: Emissions-Discharge Testing for Common Air Pollutants

Method 1

SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

(42 FR, 41755, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. To aid in the representative measurement of pollutant emissions and/or total volumetric flow rate from a stationary source, a measurement site where the effluent stream is flowing in a known direction is selected, and the cross-section of the stack is divided into a number of equal areas. A traverse point is then located within each of these equal areas.

1.2 Applicability. This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when: (1) flow is cyclonic or swirling (see Section 2.4), (2) a stack is smaller than about 0.30 meter (12 in.) in diameter, or 0.071 m² (113 in.²) in cross-sectional area, or (3) the measurement site is less than two stack or duct diameters downstream or less than a half diameter upstream from a flow disturbance.

The requirements of this method must be considered before construction of a new facility from which emissions will be measured; failure to do so may require subsequent alterations to the stack or deviation from the standard procedure. Cases involving variants are subject to approval by the Administrator, U.S. Environmental Protection Agency.

2. *Procedure*

2.1 Selection of Measurement Site. Sampling or velocity measurement is performed at a site located at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, or contraction in the stack, or from a visible flame. If necessary, an alternative location may be selected, at a position at least two stack or duct diameters downstream and a half diameter upstream from any flow disturbance. For a rectangular cross section, an equivalent diameter (D_e) shall be calculated from the following equation, to determine the upstream and downstream distances:

$$D_e = \frac{2LW}{L+W}$$

where L=length and W=width.

2.2 Determining the Number of Traverse Points.

2.2.1 Particulate Traverses. When the eight- and two-diameter criterion can be met, the minimum number of traverse points shall be: (1) twelve, for circular or rectangular stacks with diameters (or equivalent diameters) greater than 0.61 meter (24 in.); (2) eight, for circular stacks with diameters between 0.30 and 0.61 meter (12-24 in.); (3) nine, for rectangular stacks with equivalent diameters between 0.30 and 0.61 meter (12-24 in.).

When the eight- and two-diameter criterion cannot be met, the minimum number of traverse points is determined from Figure 1-1. Before referring to the figure, however, determine the distances from the chosen measurement site to the nearest upstream and downstream disturbances, and divide each distance by the stack diameter or equivalent diameter, to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1-1 the minimum number of traverse points that corresponds: (1) to the number of duct diameters upstream; and (2) to the number of diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value, so that for circular stacks the number is a multiple of 4, and for rectangular stacks, the number is one of those shown in Table 1-1.

TABLE 1-1. *Cross-sectional layout for rectangular stacks*

Number of traverse points:	*Matrix layout*
9	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

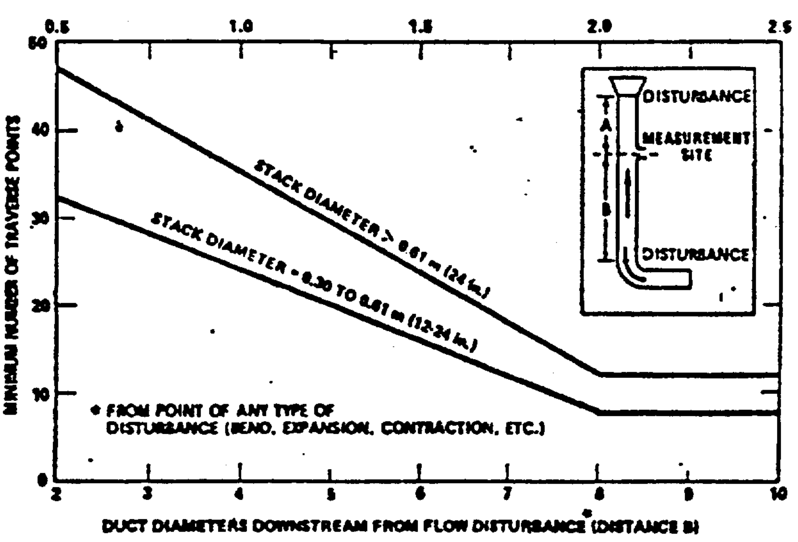


Figure 1-1. Minimum number of traverse points for particulate traverses.

Method 1, Continued

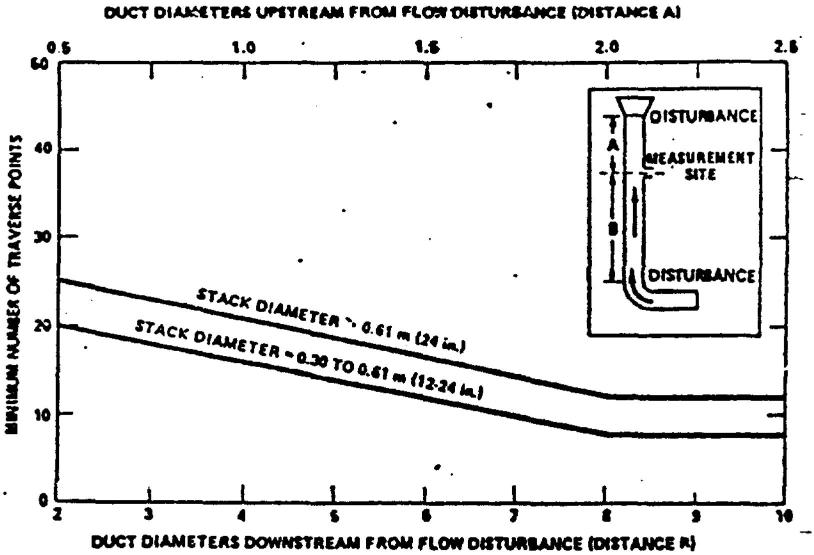


Figure 1-2. Minimum number of traverse points for velocity (nonparticulate) traverses.

2.2.2 Velocity (Non-Particulate) Traverses. When velocity or volumetric flow rate is to be determined (but not particulate matter), the same procedure as that for particulate traverses (Section 2.2.1) is followed, except that Figure 1-2 may be used instead of Figure 1-1.

2.3 Cross-Sectional Layout and Location of Traverse Points.

2.3.1 Circular Stacks. Locate the traverse points on two perpendicular diameters according to Table 1-2 and the example shown in Figure 1-3. Any equation (for examples, see Citations 2 and 3 in the Bibliography) that gives the same values as those in Table 1-2 may be used in lieu of Table 1-2.

For particulate traverses, one of the diameters must be in a plane containing the greatest expected concentration variation, e.g., after bends, one diameter shall be in the plane of the bend. This requirement becomes less critical as the distance from the disturbance increases; therefore, other diameter locations may be used, subject to approval of the Administrator.

In addition, for stacks having diameters greater than 0.61 m (24 in.) no traverse points shall be located within 2.5 centimeters (1.00 in.) of the stack walls; and for stack diameters equal to or less than 0.61 m (24 in.), no traverse points shall be located within 1.3 cm (0.50 in.) of the stack walls. To meet these criteria, observe the procedures given below.

2.3.1.1 Stacks With Diameters Greater Than 0.61 m (24 in.). When any of the traverse points as located in Section 2.3.1 fall within 2.5 cm (1.00 in.) of the stack walls, relocate them away from the stack walls to: (1) a distance of 2.5 cm (1.00 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger. These relocated traverse points (on each end of a diameter) shall be the "adjusted" traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points, both in the sampling (or velocity measurement) procedure, and in recording the data.

2.3.1.2 Stacks With Diameters Equal to or Less Than 0.61 m (24 in.). Follow the procedure in Section 2.3.1.1, noting only that any "adjusted" points should be relocated away from the stack walls to: (1) a distance of 1.3 cm (0.50 in.); or (2) a distance equal to the nozzle inside diameter, whichever is larger.

2.3.2 Rectangular Stacks. Determine the number of traverse points as explained in Sections 2.1 and 2.2 of this method. From Table 1-1, determine the grid configuration. Divide the stack cross-section into as many equal rectangular elemental areas as traverse points, and then locate a traverse point at the centroid of each equal area according to the example in Figure 1-4.

The situation of traverse points being too close to the stack walls is not expected to arise with rectangular stacks. If this problem should ever arise, the Administrator must be contacted for resolution of the matter.

2.4 Verification of Absence of Cyclonic Flow. In most stationary sources, the direction of stack gas flow is essentially parallel to the stack walls. However, cyclonic flow may exist (1) after such devices as cyclones and inertial demisters following venturi scrubbers, or (2) in stacks having tangential inlets or other duct configurations which tend to induce swirling; in these instances, the presence or absence of cyclonic flow at the sampling location must be determined. The following techniques are acceptable for this determination.

Level and zero the manometer. Connect a Type S pitot tube to the manometer. Position the Type S pitot tube at each traverse point, in succession, so that the planes of the face openings of the pitot tube are perpendicular to the stack cross-sectional plane; when the Type S pitot tube is in this position, it is at "0° reference." Note the differential pressure (Δp) reading at each traverse point. If a null (zero) pitot reading is obtained at 0° reference at a given traverse point, an acceptable flow condition exists at that point. If the pitot reading is not zero at 0° reference, rotate the pitot tube (up to ±90° yaw angle), until a null reading is obtained. Carefully determine and record the value of the rotation angle (α) to the nearest degree. After the null technique has been applied at each traverse point, calculate the average of the absolute values of α; assign α values of 0° to those points for which no rotation was required, and include these in the overall average. If the average value of α is greater than 10°, the overall flow condition in the stack is unacceptable and alternative methodology, subject to the approval of the Administrator, must be used to perform accurate sample and velocity traverses.

Method 1, Continued

Table 1-2. LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

(Percent of stack diameter from inside wall to traverse point)

Traverse point number on a diameter	Number of traverse points on a diameter											
	2	4	6	8	10	12	14	16	18	20	22	24
1	14.6	6.7	4.4	3.2	2.6	2.1	1.8	1.6	1.4	1.3	1.1	1.1
2	85.4	25.0	14.6	10.5	8.2	6.7	5.7	4.9	4.4	3.9	3.5	3.2
3		75.0	29.6	19.4	14.6	11.8	9.9	8.5	7.5	6.7	6.0	5.5
4		93.3	70.4	32.3	22.6	17.7	14.6	12.5	10.9	9.7	8.7	7.9
5			85.4	67.7	34.2	25.0	20.1	16.9	14.6	12.9	11.6	10.5
6			95.6	80.6	65.8	35.6	26.9	22.0	18.8	16.5	14.6	13.2
7				89.5	77.4	64.4	36.6	28.3	23.6	20.4	18.0	16.1
8				96.8	85.4	75.0	63.4	37.5	29.6	25.0	21.8	19.4
9					91.8	82.3	73.1	62.5	38.2	30.6	26.2	23.0
10					97.4	88.2	79.9	71.7	61.8	38.8	31.5	27.2
11						93.3	85.4	78.0	70.4	61.2	39.3	32.3
12						97.9	90.1	83.1	76.4	69.4	60.7	39.8
13							94.3	87.5	81.2	75.0	68.5	60.2
14							98.2	91.5	85.4	79.6	73.8	67.7
15								95.1	89.1	83.5	78.2	72.8
16								98.4	92.5	87.1	82.0	77.0
17									95.6	90.3	85.4	80.6
18									98.6	93.3	88.4	83.9
19										96.1	91.3	86.8
20										98.7	94.0	89.5
21											96.5	92.1
22											98.9	94.5
23												96.8
24												98.9

TRAVERSE POINT	DISTANCE, % of diameter
1	4.4
2	14.7
3	29.5
4	70.5
5	85.3
6	95.6

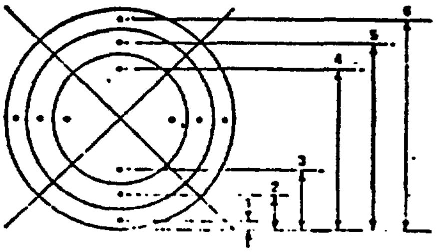


Figure 1-3. Example showing circular stack cross section divided into 12 equal areas, with location of traverse points indicated.

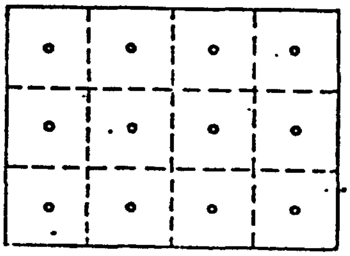


Figure 1-4. Example showing rectangular stack cross section divided into 12 equal areas, with a traverse point at centroid of each area.

8. *Bibliography*

1. Determining Dust Concentration in a Gas Stream. ASME. Performance Test Code No. 27. New York. 1957.

2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District. Los Angeles, CA. November 1963.

3. Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co. Los Angeles, CA. Bulletin WP-50. 1968.

4. Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM Standards, Part 23. ASTM Designation D-2928-71. Philadelphia, Pa. 1971.

5. Hanson, H. A., et al. Particulate Sampling Strategies for Large Power Plants Including Nonuniform Flow. USEPA, ORD, ESRL, Research Triangle Park, N.C. EPA-600/2-76-170, June 1976.

6. Entropy Environmentalists, Inc. Determination of the Optimum Number of Sampling Points: An Analysis of Method 1 Criteria. Environmental Protection Agency. Research Triangle Park, N.C. EPA Contract No. 68-01-3172, Task 7.

10-9-79

Method 2

DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (TYPE S PITOT TUBE)

(42 FR, 41758, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with a Type S (Stausscheibe or reverse type) pitot tube.

1.2 Applicability. This method is applicable for measurement of the average velocity of a gas stream and for quantifying gas flow.

This procedure is not applicable at measurement sites which fail to meet the criteria of Method 1, Section 2.1. Also, the method cannot be used for direct measurement in cyclonic or swirling gas streams; Section 2.4 of Method 1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, alternative procedures, subject to the approval of the Administrator, U.S. Environmental Protection Agency, must be employed to make accurate flow rate determinations; examples of such alternative procedures are: (1) to install straightening vanes; (2) to calculate the total volumetric flow rate stoichiometrically, or (3) to move to another measurement site at which the flow is acceptable.

2. *Apparatus*

Specifications for the apparatus are given below. Any other apparatus that has been demonstrated (subject to approval of the Administrator) to be capable of meeting the specifications will be considered acceptable.

2.1 Type S Pitot Tube. The Type S pitot tube (Figure 2-1) shall be made of metal tubing (e.g., stainless steel). It is recommended that the external tubing diameter (dimension D_t, Figure 2-2b) be between 0.48 and 0.95 centimeters ($\frac{3}{16}$ and $\frac{3}{8}$ inch). There shall be an equal distance from the base of each leg of the pitot tube to its face-opening plane (dimensions P_A and P_B, Figure 2-2b); it is recommended that this distance be between 1.05 and 1.50 times the external tubing diameter. The face openings of the pitot tube shall, preferably, be aligned as shown in Figure 2-2; however, slight misalignments of the openings are permissible (see Figure 2-3).

The Type S pitot tube shall have a known coefficient, determined as outlined in Section 4. An identification number shall be assigned to the pitot tube; this number shall be permanently marked or engraved on the body of the tube.

A standard pitot tube may be used instead of a Type S, provided that it meets the specifications of Sections 2.7 and 4.2; note, however, that the static and impact pressure holes of standard pitot tubes are susceptible to plugging in particulate-laden gas streams. Therefore, whenever a standard pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the pitot tube have not plugged up during the traverse period; this can be done by taking a velocity head (Δp) reading at the final traverse point, cleaning out the impact and static holes of the standard pitot tube by "back-purging" with pressurized air, and then taking another Δp reading. If the Δp readings made before and after the air purge are the same (± 5 percent), the traverse is acceptable. Otherwise, reject the run. Note that if Δp at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, then comparative Δp readings shall be taken, as above, for the last two back purges at which suitably high Δp readings are observed.

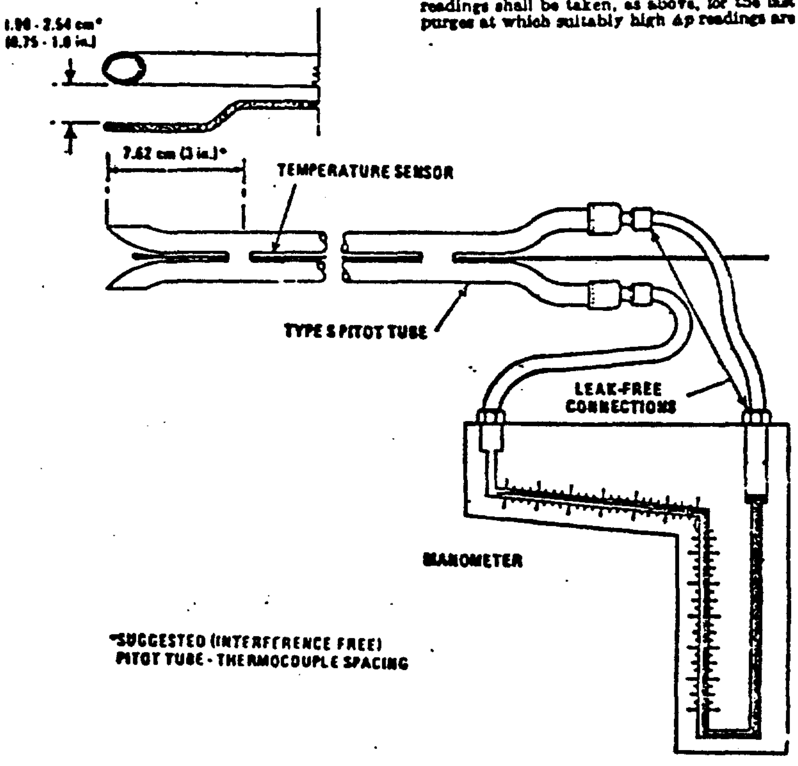


Figure 2-1. Type S pitot tube manometer assembly.

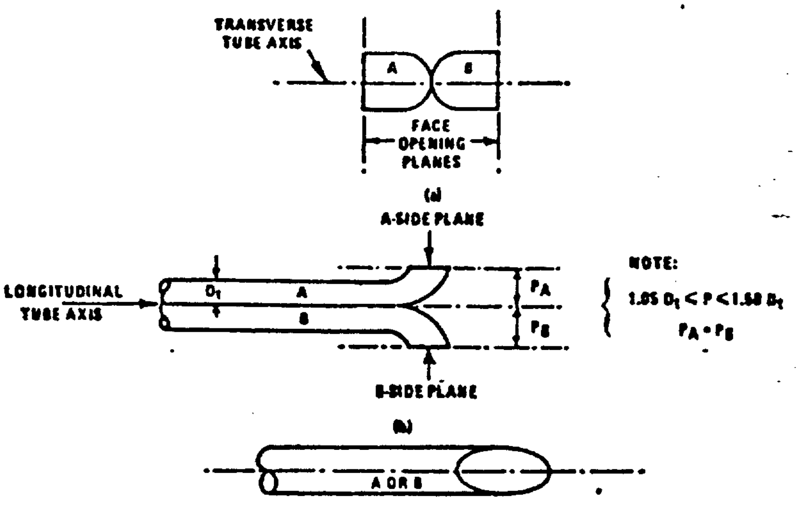


Figure 2-2. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to pitot tubes constructed this way.

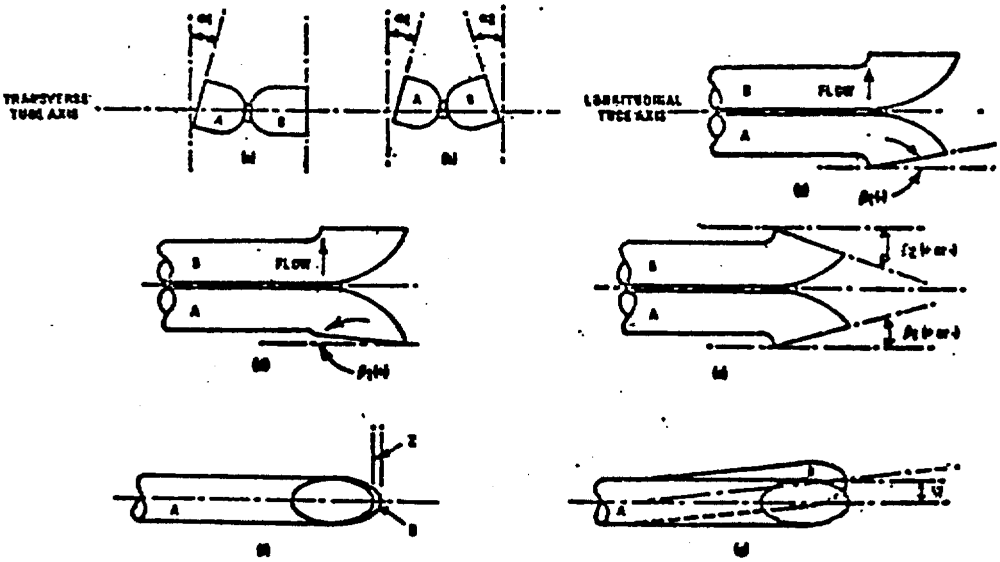


Figure 2-3. Types of face-opening misalignment that can result from field use or improper construction of Type S pitot tubes. These will not affect the baseline value of $\bar{C}_{p(s)}$ so long as α_1 and $\alpha_2 < 10^\circ$, β_1 and $\beta_2 < 5^\circ$, $z < 0.32$ cm (1/8 in.) and $w < 0.08$ cm (1/32 in.) (citation 11 in Section 6).

Method 2, Continued

2.2 Differential Pressure Gauge. An inclined manometer or equivalent device is used. Most sampling trains are equipped with a 10-in. (water column) inclined-vertical manometer, having 0.01-in. H_2O divisions on the 0- to 1-in. inclined scale, and 0.1-in. H_2O divisions on the 1- to 10-in. vertical scale. This type of manometer (or other gauge of equivalent sensitivity) is satisfactory for the measurement of Δp values as low as 1.3 mm (0.05 in.) H_2O. However, a differential pressure gauge of greater sensitivity shall be used (subject to the approval of the Administrator), if any of the following is found to be true: (1) the arithmetic average of all Δp readings at the traverse points in the stack is less than 1.3 mm (0.05 in.) H_2O; (2) for traverses of 12 or more points, more than 10 percent of the individual Δp readings are below 1.3 mm (0.05 in.) H_2O; (3) for traverses of fewer than 12 points, more than one Δp reading is below 1.3 mm (0.05 in.) H_2O. Citation 18 in Section 6 describes commercially available instrumentation for the measurement of low-range gas velocities.

As an alternative to criteria (1) through (3) above, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T=\frac{\sum_{i=1}^{n}\sqrt{\Delta p_i+K}}{\sum_{i=1}^{n}\sqrt{\Delta p_i}}$$

where:

Δp_i = Individual velocity head reading at a traverse point, mm H_2O (in. H_2O).

n = Total number of traverse points.

K = 0.13 mm H_2O when metric units are used and 0.005 in H_2O when English units are used.

If T is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

NOTE.—If differential pressure gauges other than inclined manometers are used (e.g., magnehelic gauges), their calibration must be checked after each test series. To check the calibration of a differential pressure gauge, compare Δp readings of the gauge with those of a gauge-oil manometer at a minimum of three points, approximately representing the range of Δp values in the stack. If, at each point, the values of Δp as read by the differential pressure gauge and gauge-oil manometer agree to within 5 percent, the differential pressure gauge shall be considered to be in proper calibration. Otherwise, the test series shall either be voided, or procedures to adjust the measured Δp values and final results shall be used, subject to the approval of the Administrator.

2.3 Temperature Gauge. A thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature shall be used. The temperature gauge shall be attached to the pitot tube such that the sensor tip does not touch any metal; the gauge shall be in an interference-free arrangement with respect to the pitot tube face openings (see Figure 2-1 and also Figure 2-7 in Section 4). Alternate positions may be used if the pitot tube-temperature gauge system is calibrated according to the procedure of Section 4. Provided that a difference of not more than 1 percent in the average velocity measurement is introduced, the temperature gauge need not be attached to the pitot tube; this alternative is subject to the approval of the Administrator.

2.4 Pressure Probe and Gauge. A piezometer tube and mercury- or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap of a standard type pitot tube or one leg of a Type S pitot tube with the face opening planes positioned parallel to the gas flow may also be used as the pressure probe.

2.5 Barometer. A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm (0.1 in.) Hg per 30-meter (100 foot) elevation increase, or vice-versa for elevation decrease.

2.6 Gas Density Determination Equipment. Method 3 equipment, if needed (see Section 3.6), to determine the stack gas dry molecular weight, and Reference Method 4 or Method 5 equipment for moisture content determination; other methods may be used subject to approval of the Administrator.

2.7 Calibration Pitot Tube. When calibration of the Type S pitot tube is necessary (see Section 4), a standard pitot tube is used as a reference. The standard pitot tube shall, preferably, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersburg, Maryland, or (2) by calibration against another standard pitot tube with an NBS-traceable coefficient. Alternatively, a standard pitot tube designed according to the criteria given in 2.7.1 through 2.7.5 below and illustrated in Figure 2-4 (see also Citations 7, 8, and 17 in Section 6) may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about 0.99±0.01.

2.7.1 Hemispherical (shown in Figure 2-4), ellipsoidal, or conical tip.

2.7.2 A minimum of six diameters straight run (based upon D, the external diameter of the tube) between the tip and the static pressure holes.

2.7.3 A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90 degree bend.

2.7.4 Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.

2.7.5 Ninety degree bend, with curved or mitered junction.

2.8 Differential Pressure Gauge for Type S Pitot Tube Calibration. An inclined manometer or equivalent is used. If the single-velocity calibration technique is employed (see Section 4.1.2.3), the calibration differential pressure gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in. H_2O). For multivelocity calibrations, the gauge shall be readable to the nearest 0.13 mm H_2O (0.005 in H_2O) for Δp values between 1.3 and 25 mm H_2O (0.05 and 1.0 in. H_2O), and to the nearest 1.3 mm H_2O (0.05 in. H_2O) for Δp values above 25 mm H_2O (1.0 in. H_2O). A special, more sensitive gauge will be required to read Δp values below 1.3 mm H_2O [0.05 in. H_2O] (see Citation 18 in Section 6).

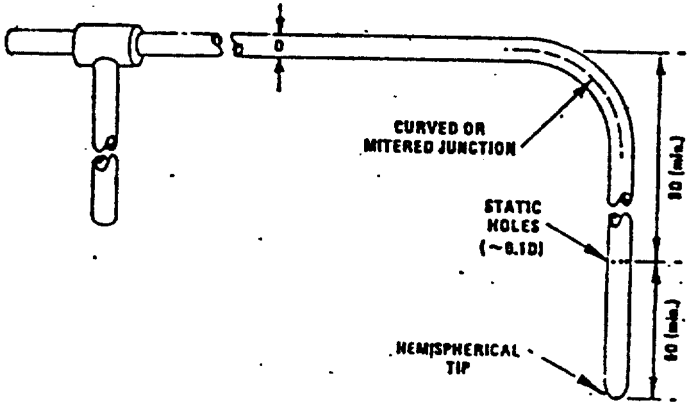


Figure 2-4. Standard pitot tube design specifications.

Method 2, Continued

3. *Procedure*

3.1 Set up the apparatus as shown in Figure 2-1. Capillary tubing or surge tanks installed between the manometer and pitot tube may be used to dampen Δp fluctuations. It is recommended, but not required, that a pretest leak-check be conducted, as follows: (1) blow through the pitot impact opening until at least 7.6 cm (3 in.) H_2O velocity pressure registers on the manometer; then, close off the impact opening. The pressure shall remain stable for at least 15 seconds; (2) do the same for the static pressure side, except using suction to obtain the minimum of 7.6 cm (3 in.) H_2O. Other leak-check procedures, subject to the approval of the Administrator, may be used.

3.2 Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse. Record all necessary data as shown in the example data sheet (Figure 2-6).

3.3 Measure the velocity head and temperature at the traverse points specified by Method 1. Ensure that the proper differential pressure gauge is being used for the range of Δp values encountered (see Section 2.2). If it is necessary to change to a more sensitive gauge, do so, and remeasure the Δp and temperature readings at each traverse point. Conduct a post-test leak-check (mandatory), as described in Section 3.1 above, to validate the traverse run.

3.4 Measure the static pressure in the stack. One reading is usually adequate.

3.5 Determine the atmospheric pressure.

PLANT ____________________

DATE ____________ RUN NO. ________

STACK DIAMETER OR DIMENSIONS, m(in.) ________

BAROMETRIC PRESSURE, mm Hg (in. Hg) ________

CROSS SECTIONAL AREA, $m^2(ft^2)$ ________

OPERATORS ________

PITOT TUBE I.D. NO. ________

AVG. COEFFICIENT, C_p = ________

LAST DATE CALIBRATED ________

SCHEMATIC OF STACK CROSS SECTION

Traverse Pt. No.	Vel. Hd., Δp mm (in.) H_2O	Stack Temperature		P_g mm Hg (in.Hg)	$\sqrt{\Delta p}$
		t_s, °C (°F)	T_s, °K (°R)		
		Average			

Figure 2-5. Velocity traverse data.

3.6 Determine the stack gas dry molecular weight. For combustion processes or processes that emit essentially CO_2, O_2, CO, and N_2, use Method 3. For processes emitting essentially air, an analysis need not be conducted; use a dry molecular weight of 29.0. For other processes, other methods, subject to the approval of the Administrator, must be used.

3.7 Obtain the moisture content from Reference Method 4 (or equivalent) or from Method 5.

3.8 Determine the cross-sectional area of the stack or duct at the sampling location. Whenever possible, physically measure the stack dimensions rather than using blueprints.

4. *Calibration*

4.1 Type S Pitot Tube. Before its initial use, carefully examine the Type S pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in *Figure* 2-2 or 2-3. The pitot tube shall not be used if it fails to meet these alignment specifications.

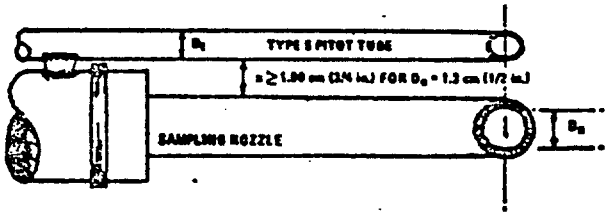
After verifying the face opening alignment, measure and record the following dimensions of the pitot tube: (a) the external tubing diameter (dimension D_t, Figure 2-2b); and (b) the base-to-opening plane distances (dimensions P_A and P_B, Figure 2-2b). If D_t is between 0.48 and 0.95 cm (3/16 and 3/8 in.) and if P_A and P_B are equal and between 1.05 and 1.50 D_t, there are two possible options: (1) the pitot tube may be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, or (2) a baseline (isolated tube) coefficient value of 0.84 may be assigned to the pitot tube. Note, however, that if the pitot tube is part of an assembly, calibration may still be required, despite knowledge of the baseline coefficient value (see Section 4.1.1).

If D_t, P_A, and P_B are outside the specified limits, the pitot tube must be calibrated as outlined in 4.1.2 through 4.1.5 below.

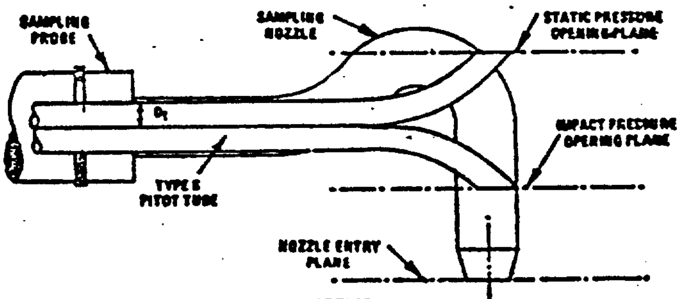
4.1.1 Type S Pitot Tube Assemblies. During sample and velocity traverses, the isolated Type S pitot tube is not always used; in many instances, the pitot tube is used in combination with other source-sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly." The presence of other sampling components can sometimes affect the baseline value of the Type S pitot tube coefficient (Citation 9 in Section 6); therefore an assigned (or otherwise known) baseline coefficient value may or may not be valid for a given assembly. The baseline and assembly coefficient values will be identical only when the relative placement of the components in the assembly is such that aerodynamic interference effects are eliminated. Figures 2-6 through 2-8 illustrate interference-free component arrangements for Type S pitot tubes having external tubing diameters between 0.48 and 0.95 cm (3/16 and 3/8 in.). Type S pitot tube assemblies that fail to meet any or all of the specifications of Figures 2-6 through 2-8 shall be calibrated according to the procedure outlined in Sections 4.1.2 through 4.1.5 below, and prior to calibration, the values of the intercomponent spacings (pitot-nozzle, pitot-thermocouple, pitot-probe sheath) shall be measured and recorded.

NOTE.—Do not use any Type S pitot tube assembly which is constructed such that the impact pressure opening plane of the pitot tube is below the entry plane of the nozzle (see Figure 2-6b).

4.1.2 Calibration Setup. If the Type S pitot tube is to be calibrated, one leg of the tube shall be permanently marked A, and the other, B. Calibration shall be done in a flow system having the following essential design features:



A. BOTTOM VIEW; SHOWING MINIMUM PITOT-NOZZLE SEPARATION.



B. SIDE VIEW; TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR ABOVE THE NOZZLE ENTRY PLANE.

Figure 2-6. Proper pitot tube - sampling nozzle configuration to prevent aerodynamic interference; buttonhook - type nozzle; centers of nozzle and pitot opening aligned; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

4.1.2.1 The flowing gas stream must be confined to a duct of definite cross-sectional area, either circular or rectangular. For circular cross-sections, the minimum duct diameter shall be 30.5 cm (12 in.); for rectangular cross-sections, the width (shorter side) shall be at least 25.4 cm (10 in.).

4.1.2.2 The cross-sectional area of the calibration duct must be constant over a distance of 10 or more duct diameters. For a rectangular cross-section, use an equivalent diameter, calculated from the following equation, to determine the number of duct diameters:

$$D_e = \frac{2LW}{(L+W)}$$

Equation 2-1

where:

D_e = Equivalent diameter
L = Length
W = Width

To ensure the presence of stable, fully developed flow patterns at the calibration site, or "test section," the site must be located at least eight diameters downstream and two diameters upstream from the nearest disturbances.

NOTE.—The eight- and two-diameter criteria are not absolute; other test section locations may be used (subject to approval of the Administrator), provided that the flow at the test site is stable and demonstrably parallel to the duct axis.

4.1.2.3 The flow system shall have the capacity to generate a test-section velocity around 915 m/min (3,000 ft/min). This velocity must be constant with time to guarantee steady flow during calibration. Note that Type S pitot tube coefficients obtained by single-velocity calibration at 915 m/min (3,000 ft/min) will generally be valid to within ±3 percent for the measurement of velocities above 305 m/min (1,000 ft/min) and to within ±5 to 6 percent for the measurement of velocities between 180 and 305 m/min (600 and 1,000 ft/min). If a more precise correlation between C_p and velocity is desired, the flow system shall have the capacity to generate at least four distinct, time-invariant test-section velocities covering the velocity range from 180 to 1,525 m/min (600 to 5,000 ft/min), and calibration data shall be taken at regular velocity intervals over this range (see Citations 9 and 14 in Section 6 for details).

4.1.2.4 Two entry ports, one each for the standard and Type S pitot tubes, shall be cut in the test section; the standard pitot entry port shall be located slightly downstream of the Type S port, so that the standard and Type S impact openings will lie in the same cross-sectional plane during calibration. To facilitate alignment of the pitot tubes during calibration, it is advisable that the test section be constructed of plexiglas or some other transparent material.

4.1.3 Calibration Procedure. Note that this procedure is a general one and must not be used without first referring to the special considerations presented in Section 4.1.5. Note also that this procedure applies only to single-velocity calibration. To obtain calibration data for the A and B sides of the Type S pitot tube, proceed as follows:

4.1.3.1 Make sure that the manometer is properly filled and that the oil is free from contamination and is of the proper density. Inspect and leak-check all pitot lines; repair or replace if necessary.

4.1.3.2 Level and zero the manometer. Turn on the fan and allow the flow to stabilize. Seal the Type S entry port.

4.1.3.3 Ensure that the manometer is level and zeroed. Position the standard pitot tube at the calibration point (determined as outlined in Section 4.1.5.1), and align the tube so that its tip is pointed directly into the flow. Particular care should be taken in aligning the tube to avoid yaw and pitch angles. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.4 Read Δp_{std} and record its value in a data table similar to the one shown in Figure 2-9. Remove the standard pitot tube from the duct and disconnect it from the manometer. Seal the standard entry port.

4.1.3.5 Connect the Type S pitot tube to the manometer. Open the Type S entry port. Check the manometer level and zero. Insert and align the Type S pitot tube so that its A side impact opening is at the same point as was the standard pitot tube and is pointed directly into the flow. Make sure that the entry port surrounding the tube is properly sealed.

4.1.3.6 Read Δp_s and enter its value in the data table. Remove the Type S pitot tube from the duct and disconnect it from the manometer.

4.1.3.7 Repeat steps 4.1.3.3 through 4.1.3.6 above until three pairs of Δp readings have been obtained.

4.1.3.8 Repeat steps 4.1.3.3 through 4.1.3.7 above for the B side of the Type S pitot tube.

4.1.3.9 Perform calculations, as described in Section 4.1.4 below.

4.1.4 Calculations.

4.1.4.1 For each of the six pairs of Δp readings (i.e., three from side A and three from side B) obtained in Section 4.1.3 above, calculate the value of the Type S pitot tube coefficient as follows:

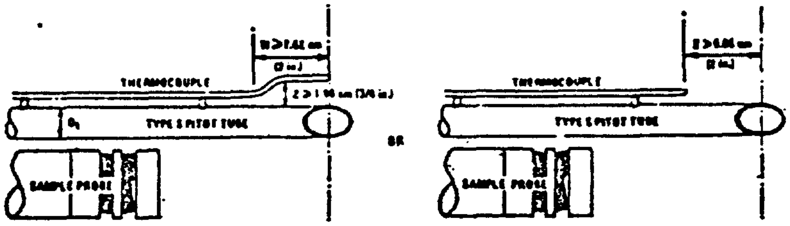


Figure 2-7. Proper thermocouple placement to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

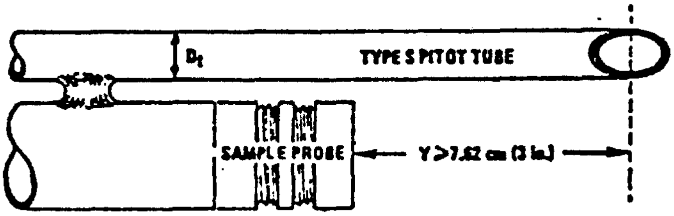


Figure 2-8. Minimum pitot-sample probe separation needed to prevent interference; D_t between 0.48 and 0.95 cm (3/16 and 3/8 in.).

PITOT TUBE IDENTIFICATION NUMBER: ____________ DATE: ________

CALIBRATED BY: ________________________

	"A" SIDE CALIBRATION			
RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_p(A)$
1				
2				
3				
		$\bar{C}_p$ (SIDE A)		

	"B" SIDE CALIBRATION			
RUN NO.	Δp_{std} cm H_2O (in. H_2O)	$\Delta p_{(s)}$ cm H_2O (in. H_2O)	$C_{p(s)}$	DEVIATION $C_{p(s)} - \bar{C}_p(B)$
1				
2				
3				
		$\bar{C}_p$ (SIDE B)		

$$\text{AVERAGE DEVIATION} = \sigma\,(\text{A OR B}) = \frac{\sum_{1}^{3} \left| C_p(s) - \bar{C}_p(\text{A OR B}) \right|}{3} \longleftarrow \text{MUST BE} \leq 0.01$$

$$\left| \bar{C}_p\,(\text{SIDE A}) - \bar{C}_p\,(\text{SIDE B}) \right| \longleftarrow \text{MUST BE} \leq 0.01$$

Figure 2-9. Pitot tube calibration data.

$$C_{p(s)} = C_{p(std)} \sqrt{\frac{\Delta p_{std}}{\Delta p_s}}$$

Equation 2-2

where:

$C_{p(s)}$ = Type S pitot tube coefficient

$C_{p(std)}$ = Standard pitot tube coefficient; use 0.99 if the coefficient is unknown and the tube is designed according to the criteria of Sections 2.7.1 to 2.7.5 of this method.

Δp_{std} = Velocity head measured by the standard pitot tube, cm H_2O (in. H_2O)

Δp_s = Velocity head measured by the Type S pitot tube, cm H_2O (in. H_2O)

4.1.4.2 Calculate $\bar{C}_p$ (side A), the mean A-side coefficient, and $\bar{C}_p$ (side B), the mean B-side coefficient; calculate the difference between these two average values.

4.1.4.3 Calculate the deviation of each of the three A-side values of $C_{p(s)}$ from $\bar{C}_p$ (side A), and the deviation of each B-side value of $C_{p(s)}$ from $\bar{C}_p$ (side B). Use the following equation:

$$\text{Deviation} = C_{p(s)} - \bar{C}_p(\text{A or B})$$

Equation 2-3

4.1.4.4 Calculate σ, the average deviation from the mean, for both the A and B sides of the pitot tube. Use the following equation:

$$\sigma\,(\text{side A or B}) = \frac{\sum_{1}^{3} |C_{p(s)} - \bar{C}_p(A \text{ or } B)|}{3}$$

Equation 2-4

4.1.4.5 Use the Type S pitot tube only if the values of σ (side A) and σ (side B) are less than or equal to 0.01 and if the absolute value of the difference between $\overline{C}_p$ (A) and $\overline{C}_p$ (B) is 0.01 or less.

4.1.5 Special considerations.

4.1.5.1 Selection of calibration point.

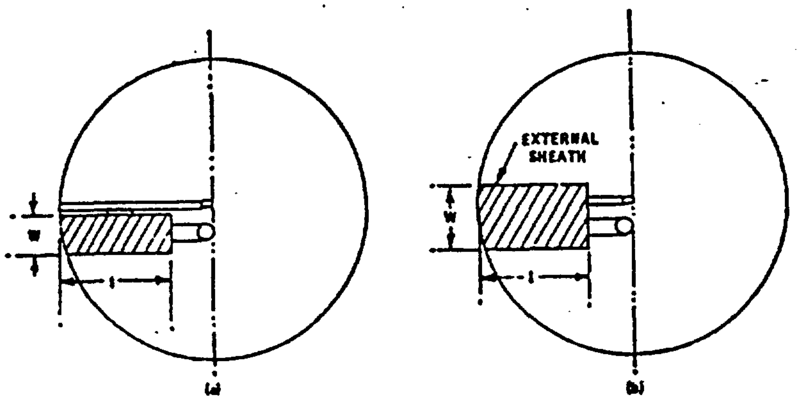
4.1.5.1.1 When an isolated Type S pitot tube is calibrated, select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The Type S pitot coefficients so obtained, i.e., $\overline{C}_p$ (side A) and $\overline{C}_p$ (side B), will be valid, so long as either: (1) the isolated pitot tube is used; or (2) the pitot tube is used with other components (nozzle, thermocouple, sample probe) in an arrangement that is free from aerodynamic interference effects (see Figures 2-6 through 2-8).

4.1.5.1.2 For Type S pitot tube-thermocouple combinations (without sample probe), select a calibration point at or near the center of the duct, and follow the procedures outlined in Sections 4.1.3 and 4.1.4 above. The coefficients so obtained will be valid so long as the pitot tube-thermocouple combination is used by itself or with other components in an interference-free arrangement (Figures 2-6 and 2-8).

4.1.5.1.3 For assemblies with sample probes, the calibration point should be located at or near the center of the duct; however, insertion of a probe sheath into a small duct may cause significant cross-sectional area blockage and yield incorrect coefficient values (Citation 9 in Section 6). Therefore, to minimize the blockage effect, the calibration point may be a few inches off-center if necessary. The actual blockage effect will be negligible when the theoretical blockage, as determined by a projected-area model of the probe sheath, is 2 percent or less of the duct cross-sectional area for assemblies without external sheaths (Figure 2-10a), and 3 percent or less for assemblies with external sheaths (Figure 2-10b).

4.1.5.2 For those probe assemblies in which pitot tube-nozzle interference is a factor (i.e., those in which the pitot-nozzle separation distance fails to meet the specification illustrated in Figure 2-6a), the value of $C_{p(s)}$ depends upon the amount of free-space between the tube and nozzle, and therefore is a function of nozzle size. In these instances, separate calibrations shall be performed with each of the commonly used nozzle sizes in place. Note that the single-velocity calibration technique is acceptable for this purpose, even though the larger nozzle sizes (>0.635 cm or ¼ in.) are not ordinarily used for isokinetic sampling at velocities around 915 m/min (3,000 ft/min), which is the calibration velocity; note also that it is not necessary to draw an isokinetic sample during calibration (see Citation 19 in Section 6).

4.1.5.3 For a probe assembly constructed such that its pitot tube is always used in the same orientation, only one side of the pitot tube need be calibrated (the side which will face the flow). The pitot tube must still meet the alignment specifications of Figure 2-2 or 2-3, however, and must have an average deviation (σ) value of 0.01 or less (see Section 4.1.4.4).



$$\text{ESTIMATED SHEATH BLOCKAGE (\%)} = \left[\frac{l \times W}{\text{DUCT AREA}}\right] \times 100$$

Figure 2-10. Projected-area models for typical pitot tube assemblies.

4.1.6 Field Use and Recalibration.

4.1.6.1 Field Use.

4.1.6.1.1 When a Type S pitot tube (isolated tube or assembly) is used in the field, the appropriate coefficient value (whether assigned or obtained by calibration) shall be used to perform velocity calculations. For calibrated Type S pitot tubes, the A side coefficient shall be used when the A side of the tube faces the flow, and the B side coefficient shall be used when the B side faces the flow; alternatively, the arithmetic average of the A and B side coefficient values may be used, irrespective of which side faces the flow.

4.1.6.1.2 When a probe assembly is used to sample a small duct (12 to 36 in. in diameter), the probe sheath sometimes blocks a significant part of the duct cross-section, causing a reduction in the effective value of $\overline{C}_{p(s)}$. Consult Citation 9 in Section 6 for details. Conventional pitot-sampling probe assemblies are not recommended for use in ducts having inside diameters smaller than 12 inches (Citation 16 in Section 6).

4.1.6.2 Recalibration.

4.1.6.2.1 Isolated Pitot Tubes. After each field use, the pitot tube shall be carefully reexamined in top, side, and end views. If the pitot face openings are still aligned within the specifications illustrated in Figure 2-2 or 2-3, it can be assumed that the baseline coefficient of the pitot tube has not changed. If, however, the tube has been damaged to the extent that it no longer meets the specifications of Figure 2-2 or 2-3, the damage shall either be repaired to restore proper alignment of the face openings or the tube shall be discarded.

4.1.6.2.2 Pitot Tube Assemblies. After each field use, check the face opening alignment of the pitot tube, as in Section 4.1.6.2.1; also, remeasure the intercomponent spacings of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, it can be assumed that the coefficient of the assembly has not changed. If the face opening alignment is no longer within the specifications of Figures 2-2 or 2-3, either repair the damage or replace the pitot tube (calibrating the new assembly, if necessary). If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

4.2 Standard pitot tube (if applicable). If a standard pitot tube is used for the velocity traverse, the tube shall be constructed according to the criteria of Section 2.7 and shall be assigned a baseline coefficient value of 0.99. If the standard pitot tube is used as part of an assembly, the tube shall be in an interference-free arrangement (subject to the approval of the Administrator).

4.3 Temperature Gauges. After each field use, calibrate dial thermometers, liquid-filled bulb thermometers, thermocouple-potentiometer systems, and other gauges at a temperature within 10 percent of the average absolute stack temperature. For temperatures up to 405° C (761° F), use an ASTM mercury-in-glass reference thermometer, or equivalent, as a reference; alternatively, either a reference thermocouple and potentiometer (calibrated by NBS) or thermometric fixed points, e.g.,

Method 2, Continued

ice bath and boiling water (corrected for barometric pressure) may be used. For temperatures above 405° C (761° F), use an NBS-calibrated reference thermocouple-potentiometer system or an alternate reference, subject to the approval of the Administrator.

If, during calibration, the absolute temperatures measured with the gauge being calibrated and the reference gauge agree within 1.5 percent, the temperature data taken in the field shall be considered valid. Otherwise, the pollutant emission test shall either be considered invalid or adjustments (if appropriate) of the test results shall be made, subject to the approval of the Administrator.

4.4 Barometer. Calibrate the barometer used against a mercury barometer.

5. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

5.1 Nomenclature.

A = Cross-sectional area of stack, m² (ft²).
B_{ws} = Water vapor in the gas stream (from Method 5 or Reference Method 4), proportion by volume.
C_p = Pitot tube coefficient, dimensionless.
K_p = Pitot tube constant,

$$34.97 \frac{\text{m}}{\text{sec}} \left[\frac{(g/g\text{-mole})(\text{mm Hg})}{(°\text{K})(\text{mm H}_2\text{O})}\right]^{1/2}$$

for the metric system and

$$85.49 \frac{\text{ft}}{\text{sec}} \left[\frac{(\text{lb/lb-mole})(\text{in. Hg})}{(°\text{R})(\text{in. H}_2\text{O})}\right]^{1/2}$$

for the English system.

M_d = Molecular weight of stack gas, dry basis (see Section 3.6) g/g-mole (lb/lb-mole).
M_s = Molecular weight of stack gas, wet basis, g/g-mole (lb/lb-mole).

$= M_d(1-B_{ws})+18.0\,B_{ws}$ Equation 2-5

P_{bar} = Barometric pressure at measurement site, mm Hg (in. Hg).
P_g = Stack static pressure, mm Hg (in. Hg).
P_s = Absolute stack gas pressure, mm Hg (in. Hg).

$= P_{bar}+P_g$ Equation 2-6

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
Q_{sd} = Dry volumetric stack gas flow rate corrected to standard conditions, dscm/hr (dscf/hr).
t_s = Stack temperature, °C (°F).
T_s = Absolute stack temperature, °K (°R).

$= 273+t_s$ for metric Equation 2-7

$= 460+t_s$ for English Equation 2-8

T_{std} = Standard absolute temperature, 293 °K (528° R)
v_s = Average stack gas velocity, m/sec (ft/sec).
Δp = Velocity head of stack gas, mm H₂O (in. H₂O).
3,600 = Conversion factor, sec/hr.
18.0 = Molecular weight of water, g/g-mole (lb-lb-mole).

5.2 Average stack gas velocity.

$$v_s = K_p C_p (\sqrt{\Delta p})_{avg} \sqrt{\frac{T_{s(avg)}}{P_s M_s}}$$

Equation 2-9

5.3 Average stack gas dry volumetric flow rate.

$$Q_{sd} = 3{,}600(1-B_{ws})v_s A \left(\frac{T_{std}}{T_{s(avg)}}\right)\left(\frac{P_s}{P_{std}}\right)$$

Equation 2-10

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Method 3

GAS ANALYSIS FOR CARBON DIOXIDE, EXCESS AIR, AND DRY MOLECULAR WEIGHT

(42 FR, 41768, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted from a stack, by one of the following methods: (1) single-point, grab sampling; (2) single-point, integrated sampling; or (3) multi-point, integrated sampling. The gas sample is analyzed for percent carbon dioxide (CO_2), percent oxygen (O_2), and, if necessary, percent carbon monoxide (CO). If a dry molecular weight determination is to be made, either an Orsat or a Fyrite[1] analyzer may be used for the analysis; for excess air or emission rate correction factor determination, an Orsat analyzer must be used.

1.2 Applicability. This method is applicable for determining CO_2 and O_2 concentrations, excess air, and dry molecular weight of a sample from a gas stream of a fossil-fuel combustion process. The method may also be applicable to other processes where it has been determined that compounds other than CO_2, O_2, CO, and nitrogen (N_2) are not present in concentrations sufficient to affect the results.

Other methods, as well as modifications to the procedure described herein, are also applicable for some or all of the above determinations. Examples of specific methods and modifications include: (1) a multi-point sampling method using an Orsat analyzer to analyze individual grab samples obtained at each point; (2) a method using CO_2 or O_2 and stoichiometric calculations to determine dry molecular weight and excess air; (3) assigning a value of 30.0 for dry molecular weight, in lieu of actual measurements, for processes burning natural gas, coal, or oil. These methods and modifications may be used, but are subject to the approval of the Administrator.

2. *Apparatus*

As an alternative to the sampling apparatus and systems described herein, other sampling systems (e.g., liquid displacement) may be used provided such systems are capable of obtaining a representative sample and maintaining a constant sampling rate, and are otherwise capable of yielding acceptable results. Use of such systems is subject to the approval of the Administrator.

2.1 Grab Sampling (Figure 3-1).

2.1.1 Probe. The probe should be made of stainless steel or borosilicate glass tubing and should be equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Any other material inert to O_2, CO_2, CO, and N_2 and resistant to temperature at sampling conditions may be used for the probe; examples of such material are aluminum, copper, quartz glass and Teflon.

2.1.2 Pump. A one-way squeeze bulb, or equivalent, is used to transport the gas sample to the analyzer.

2.2 Integrated Sampling (Figure 3-2).

2.2.1 Probe. A probe such as that described in Section 2.1.1 is suitable.

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

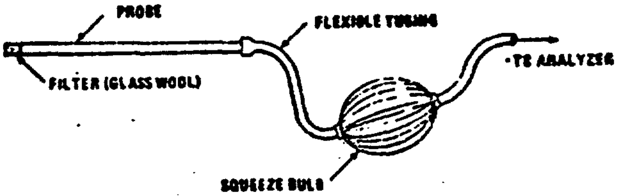

Figure 3-1. Grab sampling train.

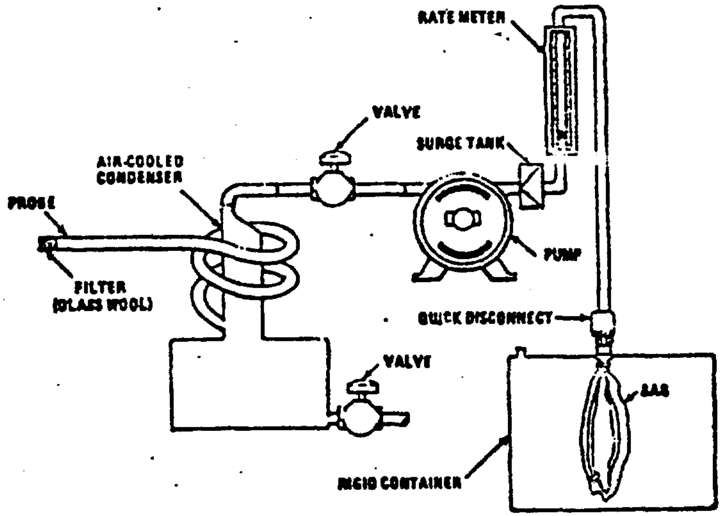

Figure 3-2. Integrated gas-sampling train.

Method 3, Continued

2.2.2 Condenser. An air-cooled or water-cooled condenser, or other condenser that will not remove O_2, CO_2, CO, and N_2, may be used to remove excess moisture which would interfere with the operation of the pump and flow meter.

2.2.3 Valve. A needle valve is used to adjust sample gas flow rate.

2.2.4 Pump. A leak-free, diaphragm-type pump, or equivalent, is used to transport sample gas to the flexible bag. Install a small surge tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.2.5 Rate Meter. The rotameter, or equivalent rate meter, used should be capable of measuring flow rate to within ±2 percent of the selected flow rate. A flow rate range of 500 to 1000 cm^3/min is suggested.

2.2.6 Flexible Bag. Any leak-free plastic (e.g., Tedlar, Mylar, Teflon) or plastic-coated aluminum (e.g., aluminized Mylar) bag, or equivalent, having a capacity consistent with the selected flow rate and time length of the test run, may be used. A capacity in the range of 55 to 90 liters is suggested.

To leak-check the bag, connect it to a water manometer and pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O). Allow to stand for 10 minutes. Any displacement in the water manometer indicates a leak. An alternative leak-check method is to pressurize the bag to 5 to 10 cm H_2O (2 to 4 in. H_2O) and allow to stand overnight. A deflated bag indicates a leak.

2.2.7 Pressure Gauge. A water-filled U-tube manometer, or equivalent, of about 28 cm (12 in.) is used for the flexible bag leak-check.

2.2.8 Vacuum Gauge. A mercury manometer, or equivalent, of at least 760 mm Hg (30 in. Hg) is used for the sampling train leak-check.

2.3 Analysis. For Orsat and Fyrite analyzer maintenance and operation procedures, follow the instructions recommended by the manufacturer, unless otherwise specified herein.

2.3.1 Dry Molecular Weight Determination. An Orsat analyzer or Fyrite type combustion gas analyzer may be used.

2.3.2 Emission Rate Correction Factor or Excess Air Determination. An Orsat analyzer must be used. For low CO_2 (less than 4.0 percent) or high O_2 (greater than 15.0 percent) concentrations, the measuring burette of the Orsat must have at least 0.1 percent subdivisions.

3. *Dry Molecular Weight Determination*

Any of the three sampling and analytical procedures described below may be used for determining the dry molecular weight.

3.1 Single-Point, Grab Sampling and Analytical Procedure.

3.1.1 The sampling point in the duct shall either be at the centroid of the cross section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

3.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. If an Orsat analyzer is used, it is recommended that the analyzer be leaked-checked by following the procedure in Section 5; however, the leak-check is optional.

3.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer and immediately analyze it for percent CO_2 and percent O_2. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO_2 and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.1.4 Repeat the sampling, analysis, and calculation procedures, until the dry molecular weights of any three grab samples differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (lb/lb-mole).

3.2 Single-Point, Integrated Sampling and Analytical Procedure.

3.2.1 The sampling point in the duct shall be located as specified in Section 3.1.1.

3.2.2 Leak-check (optional) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (optional) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum should remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

3.2.3 Sample at a constant rate. The sampling run should be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collection of at least 30 liters (1.00 ft^3) of sample gas is recommended; however, smaller volumes may be collected, if desired.

3.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. Within 8 hours after the sample is taken, analyze it for percent CO_2 and percent O_2 using either an Orsat analyzer or a Fyrite-type combustion gas analyzer. If an Orsat analyzer is used, it is recommended that the Orsat leak-check described in Section 5 be performed before this determination; however, the check is optional. Determine the percentage of the gas that is N_2 and CO by subtracting the sum of the percent CO and percent O_2 from 100 percent. Calculate the dry molecular weight as indicated in Section 6.3.

3.2.5 Repeat the analysis and calculation procedures until the individual dry molecular weights for any three analyses differ from their mean by no more than 0.3 g/g-mole (0.3 lb/lb-mole). Average these three molecular weights, and report the results to the nearest 0.1 g/g-mole (0.1 lb/lb-mole).

3.3 Multi-Point, Integrated Sampling and Analytical Procedure.

3.3.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less then 0.61 m (24 in.), a minimum of nine shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.), and a minimum of twelve traverse points shall be used for all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to approval of the Administrator.

3.3.2 Follow the procedures outlined in Sections 3.2.2 through 3.2.5, except for the following: traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

TIME	TRAVERSE PT.	Q lpm	% DEV.[a]
	AVERAGE		

$$^{a}\% \text{ DEV} = \left(\frac{Q - Q_{avg}}{Q_{avg}}\right) 100 \quad (\text{MUST BE} \leq 10\%)$$

Figure 3-3. Sampling rate data.

Method 3, Continued

4. *Emission Rate Correction Factor or Excess Air Determination*

NOTE.—A Fyrite-type combustion gas analyzer is not acceptable for excess air or emission rate correction factor determination, unless approved by the Administrator. If both percent CO_2 and percent O_2 are measured, the analytical results of any of the three procedures given below may also be used for calculating the dry molecular weight.

Each of the three procedures below shall be used only when specified in an applicable subpart of the standards. The use of these procedures for other purposes must have specific prior approval of the Administrator.

4.1 Single-Point, Grab Sampling and Analytical Procedure.

4.1.1 The sampling point in the duct shall either be at the centroid of the cross-section or at a point no closer to the walls than 1.00 m (3.3 ft), unless otherwise specified by the Administrator.

4.1.2 Set up the equipment as shown in Figure 3-1, making sure all connections ahead of the analyzer are tight and leak-free. Leak-check the Orsat analyzer according to the procedure described in Section 5. This leak-check is mandatory.

4.1.3 Place the probe in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Draw a sample into the analyzer. For emission rate correction factor determination, immediately analyze the sample, as outlined in Sections 4.1.4 and 4.1.5, for percent CO_2 or percent O_2. If excess air is desired, proceed as follows: (1) immediately analyze the sample, as in Sections 4.1.4 and 4.1.5, for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; and (3) calculate percent excess air as outlined in Section 6.2.

4.1.4 To ensure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.1.5 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. NOTE.—Since this single-point, grab sampling and analytical procedure is normally conducted in conjunction with a single-point, grab sampling and analytical procedure for a pollutant, only one analysis is ordinarily conducted. Therefore, great care must be taken to obtain a valid sample and analysis. Although in most cases only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.2 Single-Point, Integrated Sampling and Analytical Procedure.

4.2.1 The sampling point in the duct shall be located as specified in Section 4.1.1.

4.2.2 Leak-check (mandatory) the flexible bag as in Section 2.2.6. Set up the equipment as shown in Figure 3-2. Just prior to sampling, leak-check (mandatory) the train by placing a vacuum gauge at the condenser inlet, pulling a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet at the quick disconnect, and then turning off the pump. The vacuum shall remain stable for at least 0.5 minute. Evacuate the flexible bag. Connect the probe and place it in the stack, with the tip of the probe positioned at the sampling point; purge the sampling line. Next, connect the bag and make sure that all connections are tight and leak free.

4.2.3 Sample at a constant rate, or as specified by the Administrator. The sampling run must be simultaneous with, and for the same total length of time as, the pollutant emission rate determination. Collect at least 30 liters (1.00 ft^3) of sample gas. Smaller volumes may be collected, subject to approval of the Administrator.

4.2.4 Obtain one integrated flue gas sample during each pollutant emission rate determination. For emission rate correction factor determination, analyze the sample within 4 hours after it is taken for percent CO_2 or percent O_2 (as outlined in Sections 4.2.5 through 4.2.7). The Orsat analyzer must be leak-checked (see Section 5) before the analysis. If excess air is desired, proceed as follows: (1) within 4 hours after the sample is taken, analyze it (as in Sections 4.2.5 through 4.2.7) for percent CO_2, O_2, and CO; (2) determine the percentage of the gas that is N_2 by subtracting the sum of the percent CO_2, percent O_2, and percent CO from 100 percent; (3) calculate percent excess air, as outlined in Section 6.2.

4.2.5 To ensure complete absorption of the CO_2, O_2, or if applicable, CO, make repeated passes through each absorbing solution until two consecutive readings are the same. Several passes (three or four) should be made between readings. (If constant readings cannot be obtained after three consecutive readings, replace the absorbing solution.)

4.2.6 Repeat the analysis until the following criteria are met:

4.2.6.1 For percent CO_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when CO_2 is greater than 4.0 percent or (b) 0.2 percent by volume when CO_2 is less than or equal to 4.0 percent. Average the three acceptable values of percent CO_2 and report the results to the nearest 0.1 percent.

4.2.6.2 For percent O_2, repeat the analytical procedure until the results of any three analyses differ by no more than (a) 0.3 percent by volume when O_2 is less than 15.0 percent or (b) 0.2 percent by volume when O_2 is greater than 15.0 percent. Average the three acceptable values of percent O_2 and report the results to the nearest 0.1 percent.

4.2.6.3 For percent CO, repeat the analytical procedure until the results of any three analyses differ by no more than 0.3 percent. Average the three acceptable values of percent CO and report the results to the nearest 0.1 percent.

4.2.7 After the analysis is completed, leak-check (mandatory) the Orsat analyzer once again, as described in Section 5. For the results of the analysis to be valid, the Orsat analyzer must pass this leak test before and after the analysis. Note: Although in most instances only CO_2 or O_2 is required, it is recommended that both CO_2 and O_2 be measured, and that Citation 5 in the Bibliography be used to validate the analytical data.

4.3 Multi-Point, Integrated Sampling and Analytical Procedure.

4.3.1 Both the minimum number of sampling points and the sampling point location shall be as specified in Section 3.3.1 of this method. The use of fewer points than specified is subject to the approval of the Administrator.

4.3.2 Follow the procedures outlined in Sections 4.2.2 through 4.2.7, except for the following: Traverse all sampling points and sample at each point for an equal length of time. Record sampling data as shown in Figure 3-3.

5. *Leak-Check Procedure for Orsat Analyzers*

Moving an Orsat analyzer frequently causes it to leak. Therefore, an Orsat analyzer should be thoroughly leak-checked on site before the flue gas sample is introduced into it. The procedure for leak-checking an Orsat analyzer is:

5.1.1 Bring the liquid level in each pipette up to the reference mark on the capillary tubing and then close the pipette stopcock.

5.1.2 Raise the leveling bulb sufficiently to bring the confining liquid meniscus onto the graduated portion of the burette and then close the manifold stopcock.

5.1.3 Record the meniscus position.

5.1.4 Observe the meniscus in the burette and the liquid level in the pipette for movement over the next 4 minutes.

5.1.5 For the Orsat analyzer to pass the leak-check, two conditions must be met.

5.1.5.1 The liquid level in each pipette must not fall below the bottom of the capillary tubing during this 4-minute interval.

5.1.5.2 The meniscus in the burette must not change by more than 0.2 ml during this 4-minute interval.

5.1.6 If the analyzer fails the leak-check procedure, all rubber connections and stopcocks should be checked until the cause of the leak is identified. Leaking stopcocks must be disassembled, cleaned, and regreased. Leaking rubber connections must be replaced. After the analyzer is reassembled, the leak-check procedure must be repeated.

Method 3, Continued

6. *Calculations*

6.1 Nomenclature.

M_d = Dry molecular weight, g/g-mole (lb/lb-mole).
%EA = Percent excess air.
$\%CO_2$ = Percent CO_2 by volume (dry basis).
$\%O_2$ = Percent O_2 by volume (dry basis).
%CO = Percent CO by volume (dry basis).
$\%N_2$ = Percent N_2 by volume (dry basis).
0.264 = Ratio of O_2 to N_2 in air, v/v.
0.280 = Molecular weight of N_2 or CO, divided by 100.
0.320 = Molecular weight of O_2 divided by 100.
0.440 = Molecular weight of CO_2 divided by 100.

6.2 Percent Excess Air. Calculate the percent excess air (if applicable), by substituting the appropriate values of percent O_2, CO, and N_2 (obtained from Section 4.1.3 or 4.2.4) into Equation 3-1.

$$\%EA = \left[\frac{\%O_2 - 0.5\%CO}{0.264\,\%N_2 - (\%O_2 - 0.5\,\%CO)}\right]100$$

Equation 3-1

NOTE.—The equation above assumes that ambient air is used as the source of O_2 and that the fuel does not contain appreciable amounts of N_2 (as do coke oven or blast furnace gases). For those cases when appreciable amounts of N_2 are present (coal, oil, and natural gas do not contain appreciable amounts of N_2) or when oxygen enrichment is used, alternate methods, subject to approval of the Administrator, are required.

* * *

6.3 Dry Molecular Weight. Use Equation 3-2 to calculate the dry molecular weight of the stack gas

$$M_d = 0.440(\%CO_2) + 0.320(\%O_2) + 0.280(\%N_2 + \%CO)$$

Equation 3-2

NOTE.—The above equation does not consider argon in air (about 0.9 percent, molecular weight of 37.7). A negative error of about 0.4 percent is introduced. The tester may opt to include argon in the analysis using procedures subject to approval of the Administrator.

7. *Bibliography*

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1-19-79

Method 4

DETERMINATION OF MOISTURE IN STACK GASES
(42 FR, 41771, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted at a constant rate from the source; moisture is removed from the sample stream and determined either volumetrically or gravimetrically.

1.2 Applicability. This method is applicable for determining the moisture content of stack gas.

Two procedures are given. The first is a reference method, for accurate determinations of moisture content (such as are needed to calculate emission data). The second is an approximation method, which provides estimates of percent moisture to aid in setting isokinetic sampling rates prior to a pollutant emission measurement run. The approximation method described herein is only a suggested approach; alternative means for approximating the moisture content, e.g., drying tubes, wet bulb-dry bulb techniques, condensation techniques, stoichiometric calculations, previous experience, etc., are also acceptable.

The reference method is often conducted simultaneously with a pollutant emission measurement run; when it is, calculation of percent isokinetic, pollutant emission rate, etc., for the run shall be based upon the results of the reference method or its equivalent; these calculations shall not be based upon the results of the approximation method, unless the approximation method is shown, to the satisfaction of the Administrator, U.S. Environmental Protection Agency, to be capable of yielding results within 1 percent H_2O of the reference method.

NOTE.—The reference method may yield questionable results when applied to saturated gas streams or to streams that contain water droplets. Therefore, when these conditions exist or are suspected, a second determination of the moisture content shall be made simultaneously with the reference method, as follows: Assume that the gas stream is saturated. Attach a temperature sensor [capable of measuring to ±1° C (2° F)] to the reference method probe. Measure the stack gas temperature at each traverse point (see Section 2.2.1) during the reference method traverse; calculate the average stack gas temperature. Next, determine the moisture percentage, either by: (1) using a psychrometric chart and making appropriate corrections if stack pressure is different from that of the chart, or (2) using saturation vapor pressure tables. In cases where the psychrometric chart or the saturation vapor pressure tables are not applicable (based on evaluation of the process), alternate methods, subject to the approval of the Administrator, shall be used.

2. *Reference Method*

The procedure described in Method 5 for determining moisture content is acceptable as a reference method.

2.1 Apparatus. A schematic of the sampling train used in this reference method is shown in Figure 4-1. All components shall be maintained and calibrated according to the procedure outlined in Method 5.

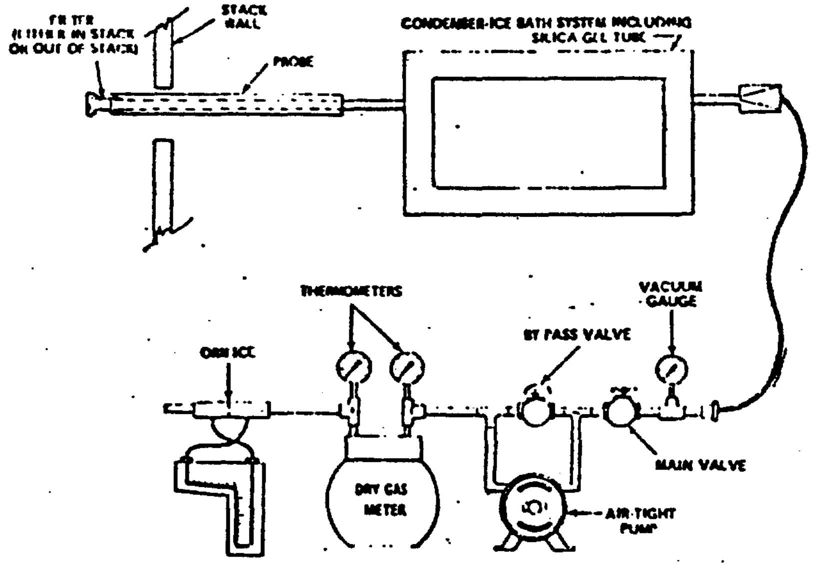

Figure 4-1. Moisture sampling train-reference method.

2.1.1 Probe. The probe is constructed of stainless steel or glass tubing, sufficiently heated to prevent water condensation, and is equipped with a filter, either in-stack (e.g., a plug of glass wool inserted into the end of the probe) or heated out-stack (e.g., as described in Method 5), to remove particulate matter.

When stack conditions permit, other metals or plastic tubing may be used for the probe, subject to the approval of the Administrator.

2.1.2 Condenser. The condenser consists of four impingers connected in series with ground glass, leak-free fittings or any similarly leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with a 1.3 centimeter (½ inch) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator.

The first two impingers shall contain known volumes of water, the third shall be empty, and the fourth shall contain a known weight of 6- to 16-mesh indicating type silica gel, or equivalent desiccant. If the silica gel has been previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. A thermometer, capable of measuring temperature to within 1° C (2° F), shall be placed at the outlet of the fourth impinger, for monitoring purposes.

Alternatively, any system may be used (subject to the approval of the Administrator) that cools the sample gas stream and allows measurement of both the water that has been condensed and the moisture leaving the condenser, each to within 1 ml or 1 g. Acceptable means are to measure the condensed water, either gravimetrically or volumetrically, and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures, or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap, with exit gases kept below 20° C (68° F), and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump, to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

2.1.3 Cooling System. An ice bath container and crushed ice (or equivalent) are used to aid in condensing moisture.

2.1.4 Metering System. This system includes a vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment as shown in Figure 4-1. Other metering systems, capable of maintaining a constant sampling rate and determining sample gas volume, may be used, subject to the approval of the Administrator.

2.1.5 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg) may be used. In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.6 Graduated Cylinder and/or Balance. These items are used to measure condensed water and moisture caught in the silica gel to within 1 ml or 0.5 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. These balances are suitable for use here.

2.2 Procedure. The following procedure is written for a condenser system (such as the impinger system described in Section 2.1.2) incorporating volumetric analysis to measure the condensed moisture, and silica gel and gravimetric analysis to measure the moisture leaving the condenser.

2.2.1 Unless otherwise specified by the Administrator, a minimum of eight traverse points shall be used for circular stacks having diameters less than 0.61 m (24 in.), a minimum of nine points shall be used for rectangular stacks having equivalent diameters less than 0.61 m (24 in.), and a minimum of twelve travers points shall be used in all other cases. The traverse points shall be located according to Method 1. The use of fewer points is subject to the approval of the Administrator. Select a suitable probe and probe length such that all traverse points can be sampled. Consider sampling from opposite sides of the stack (four total sampling ports) for large stacks, to permit use of shorter probe lengths. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point. Place known volumes of water in the first two impingers. Weigh and record the weight of the silica gel to the nearest 0.5 g, and transfer the silica gel to the fourth impinger; alternatively, the silica gel may first be transferred to the impinger, and the weight of the silica gel plus impinger recorded.

2.2.2 Select a total sampling time such that a minimum total gas volume of 0.60 scm (21 scf) will be collected, at a rate no greater than 0.021 m³/min (0.75 cfm). When both moisture content and pollutant emission rate are to be determined, the moisture determination shall be simultaneous with, and for the same total length of time as, the pollutant emission rate run, unless otherwise specified in an applicable subpart of the standards.

2.2.3 Set up the sampling train as shown in Figure 4-1. Turn on the probe heater and (if applicable) the filter heating system to temperatures of about 120° C (248° F), to prevent water condensation ahead of the condenser; allow time for the temperatures to stabilize. Place crushed ice in the ice bath container. It is recommended, but not required, that a leak check be done, as follows: Disconnect the probe from the first impinger or (if applicable) from the filter holder. Plug the inlet to the first impinger (or filter holder) and pull a 380 mm (15 in.) Hg vacuum; a lower vacuum may be used, provided that it is not exceeded during the test. A leakage rate in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, is unacceptable. Following the leak check, reconnect the probe to the sampling train.

2.2.4 During the sampling run, maintain a sampling rate within 10 percent of constant rate, or as specified by the Administrator. For each run, record the data required on the example data sheet shown in Figure 4-2. Be sure to record the dry gas meter reading at the beginning and end of each sampling time increment and whenever sampling is halted. Take other appropriate readings at each sample point, at least once during each time increment.

2.2.5 To begin sampling, position the probe tip at the first traverse point. Immediately start the pump and adjust the flow to the desired rate. Traverse the cross section, sampling at each traverse point for an equal length of time. Add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the silica gel outlet.

2.2.6 After collecting the sample, disconnect the probe from the filter holder (or from the first impinger) and conduct a leak check (mandatory) as described in Section 2.2.3. Record the leak rate. If the leakage rate exceeds the allowable rate, the tester shall either reject the test results or shall correct the sample volume as in Section 6.3 of Method 5. Next, measure the volume of the moisture condensed to the nearest ml. Determine the increase in weight of the silica gel (or silica gel plus impinger) to the nearest 0.5 g. Record this information (see example data sheet, Figure 4-2) and calculate the moisture percentage, as described in 2.3 below.

2.3 Calculations. Carry out the following calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

Method 4, Continued

PLANT ______________________
LOCATION ______________________
OPERATOR ______________________
DATE ______________________
RUN NO. ______________________
AMBIENT TEMPERATURE ______________________
BAROMETRIC PRESSURE ______________________
PROBE LENGTH m(ft) ______________________

SCHEMATIC OF STACK CROSS SECTION

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	STACK TEMPERATURE °C (°F)	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER (ΔH), mm(in.) H_2O	METER READING GAS SAMPLE VOLUME m^3 (ft^3)	ΔV_m m^3 (ft^3)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
						INLET ($T_{m_{in}}$), °C (°F)	OUTLET ($T_{m_{out}}$), °C (°F)	
TOTAL						Avg.	Avg.	
AVERAGE						Avg.		

Figure 4-2. Field moisture determination—reference method.

	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
DIFFERENCE		

Figure 4-3. Analytical data - reference method.

2.2.1 Nomenclature.

B_{ws} = Proportion of water vapor, by volume, in the gas stream.

M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).

P_m = Absolute pressure (for this method, same as barometric pressure) at the dry gas meter, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 (mm Hg) (m^3)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft^3)/(lb-mole) (°R) for English units.

T_m = Absolute temperature at meter, °K (°R).

T_{std} = Standard absolute temperature, 293° K (528° R).

V_m = Dry gas volume measured by dry gas meter, dcm (dcf).

ΔV_m = Incremental dry gas volume measured by dry gas meter at each traverse point, dcm (dcf).

$V_{m(std)}$ = Dry gas volume measured by the dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{wc(std)}$ = Volume of water vapor condensed corrected to standard conditions, scm (scf).

$V_{wsg(std)}$ = Volume of water vapor collected in silica gel corrected to standard conditions, scm (scf).

V_f = Final volume of condenser water, ml.

V_i = Initial volume, if any, of condenser water, ml.

W_f = Final weight of silica gel or silica gel plus impinger, g.

W_i = Initial weight of silica gel or silica gel plus impinger, g.

Y = Dry gas meter calibration factor.

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

2.2.2 Volume of water vapor condensed.

$$V_{wc(std)} = \frac{(V_f - V_i)\rho_w R T_{std}}{P_{std} M_w} = K_1 (V_f - V_i)$$

Equation 4-1

where:

K_1 = 0.001333 m^3/ml for metric units

= 0.04707 ft^3/ml for English units

2.2.3 Volume of water vapor collected in silica gel.

$$V_{wsg(std)} = \frac{(W_f - W_i) R T_{std}}{P_{std} M_w} = K_2 (W_f - W_i)$$

Equation 4-2

where:

K_2 = 0.001335 m^3/g for metric units

= 0.04715 ft^3/g for English units

2.2.4 Sample gas volume.

$$V_{m(std)} = V_m Y \frac{(P_m)(T_{std})}{(P_{std})(T_m)} = K_3 Y \frac{V_m P_m}{T_m}$$

Equation 4-3

where:

$K_1 = 0.3858$ °K/mm Hg for metric units
$= 17.64$ °R/in. Hg for English units

NOTE.—If the post-test leak rate (Section 2.2.6) exceeds the allowable rate, correct the value of V_m in Equation 4-3, as described in Section 6.3 of Method 5.

2.3.5 Moisture Content.

$$B_{ws} = \frac{V_{wc\,(std)} + V_{wsg\,(std)}}{V_{wc\,(std)} + V_{wsg\,(std)} + V_{m\,(std)}}$$

Equation 4-4

NOTE.—In saturated or moisture droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one using a value based upon the saturated conditions (see Section 1.2), and another based upon the results of the impinger analysis. The lower of these two values of B_{ws} shall be considered correct.

2.3.6 Verification of constant sampling rate. For each time increment, determine the ΔV_m. Calculate the average. If the value for any time increment differs from the average by more than 10 percent, reject the results and repeat the run.

3. *Approximation Method*

The approximation method described below is presented only as a suggested method (see Section 1.2).

3.1 Apparatus.

3.1.1 Probe. Stainless steel or glass tubing, sufficiently heated to prevent water condensation and equipped with a filter (either in-stack or heated out-stack) to remove particulate matter. A plug of glass wool, inserted into the end of the probe, is a satisfactory filter.

3.1.2 Impingers. Two midget impingers, each with 30 ml capacity, or equivalent.

3.1.3 Ice Bath. Container and ice, to aid in condensing moisture in impingers.

3.1.4 Drying Tube. Tube packed with new or regenerated 6- to 16-mesh indicating-type silica gel (or equivalent desiccant), to dry the sample gas and to protect the meter and pump.

3.1.5 Valve. Needle valve, to regulate the sample gas flow rate.

3.1.6 Pump. Leak-free, diaphragm type, or equivalent, to pull the gas sample through the train.

3.1.7 Volume meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2%, and calibrated over the range of flow rates and conditions actually encountered during sampling.

3.1.8 Rate Meter. Rotameter, to measure the flow range from 0 to 3 lpm (0 to 0.11 cfm).

3.1.9 Graduated Cylinder. 25 ml.

3.1.10 Barometer. Mercury, aneroid, or other barometer, as described in Section 2.1.5 above.

3.1.11 Vacuum Gauge. At least 760 mm Hg (30 in. Hg) gauge, to be used for the sampling leak check.

3.2 Procedure.

3.2.1 Place exactly 5 ml distilled water in each impinger. Assemble the apparatus without the probe as shown in Figure 4-4. Leak check the train by placing a vacuum gauge at the inlet to the first impinger and drawing a vacuum of at least 250 mm Hg (10 in. Hg), plugging the outlet of the rotameter, and then turning off the pump. The vacuum shall remain constant for at least one minute. Carefully release the vacuum gauge before unplugging the rotameter end.

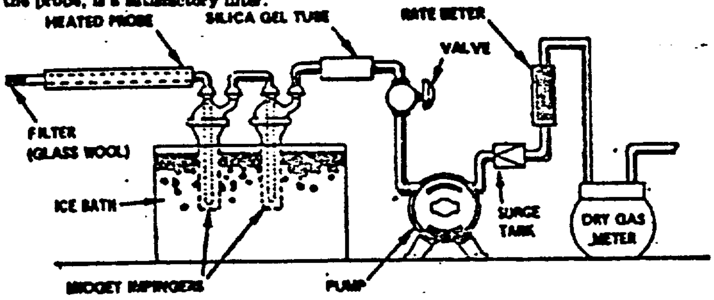

Figure 4-4. Moisture-sampling train - approximation method.

LOCATION ______________________ COMMENTS
TEST ______________________
DATE ______________________
OPERATOR ______________________

BAROMETRIC PRESSURE ______________________

CLOCK TIME	GAS VOLUME THROUGH METER, (Vm), m^3 (ft^3)	RATE METER SETTING m^3/min. (ft^3/min.)	METER TEMPERATURE, °C (°F)

Figure 4-5. Field moisture determination - approximation method.

2.2.2 Connect the probe, insert it into the stack, and sample at a constant rate of 2 lpm (0.071 cfm). Continue sampling until the dry gas meter registers about 30 liters (1.1 ft³) or until visible liquid droplets are carried over from the first impinger to the second. Record temperature, pressure, and dry gas meter readings as required by Figure 4-5.

2.2.3 After collecting the sample, combine the contents of the two impingers and measure the volume to the nearest 0.5 ml.

2.3 Calculations. The calculation method presented is designed to estimate the moisture in the stack gas; therefore, other data, which are only necessary for accurate moisture determinations, are not collected. The following equations adequately estimate the moisture content, for the purpose of determining isokinetic sampling rate settings.

2.3.1 Nomenclature.

B_{wm} = Approximate proportion, by volume, of water vapor in the gas stream leaving the second impinger, 0.025.
B_{ws} = Water vapor in the gas stream, proportion by volume.
M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole)
P_m = Absolute pressure (for this method, same as barometric pressure) at the dry gas meter.
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
R = Ideal gas constant, 0.06236 (mm Hg) (m³)/(g-mole) (°K) for metric units and 21.85 (in. Hg) (ft³)/lb-mole) (°R) for English units.
T_m = Absolute temperature at meter, °K (°R)
T_{std} = Standard absolute temperature, 293° K (528° R)
V_f = Final volume of impinger contents, ml.
V_i = Initial volume of impinger contents, ml.
V_m = Dry gas volume measured by dry gas meter, dcm (dcf).
$V_{m(std)}$ = Dry gas volume measured by dry gas meter, corrected to standard conditions, dscm (dscf).
$V_{wc(std)}$ = Volume of water vapor condensed, corrected to standard conditions, scm (scf).
ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

2.3.2 Volume of water vapor collected.

$$V_{wc} = \frac{(V_f - V_i)\rho_w R T_{std}}{P_{std} M_w}$$
$$= K_1 (V_f - V_i)$$

Equation 4-5

where:
K_1 = 0.001333 m³/ml for metric units
= 0.04707 ft³/ml for English units.

2.3.3 Gas volume.

$$V_{m(std)} = V_m \left(\frac{P_m}{P_{std}}\right) \left(\frac{T_{std}}{T_m}\right)$$
$$= K_2 \frac{V_m P_m}{T_m}$$

Equation 4-6

where:
K_2 = 0.3858 °K/mm Hg for metric units
= 17.64 °R/in. Hg for English units

2.3.4 Approximate moisture content.

$$B_{ws} = \frac{V_{wc}}{V_{wc} + V_{m(std)}} + B_{wm}$$
$$= \frac{V_{wc}}{V_{wc} + V_{m(std)}} + (0.025)$$

Equation 4-7

: : :

: : :

4. *Calibration*

4.1 For the reference method, calibrate equipment as specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); and Section 5.7 (barometer). The recommended leak check of the metering system (Section 5.6 of Method 5) also applies to the reference method. For the approximation method, use the procedures outlined in Section 5.1.1 of Method 6 to calibrate the metering system, and the procedure of Method 5, Section 5.7 to calibrate the barometer.

5. *Bibliography*

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2. Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District, Los Angeles, Calif. November, 1963.

3. Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co., Los Angeles, Calif. Bulletin WP-50. 1968.

Method 5

DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

(42 FR, 41776, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at a temperature in the range of 120±14° C (248±25° F) or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator, U.S. Environmental Protection Agency, for a particular application. The particulate mass, which includes any material that condenses at or above the filtration temperature, is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources.

2. *Apparatus*

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 5-1. Complete construction details are given in APTD-0581 (Citation 2 in Section 7); commercial models of this train are also available. For changes from APTD-0581 and for allowable modifications of the train shown in Figure 5-1, see the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576 (Citation 3 in Section 7). Since correct usage is important in obtaining valid results, all users should read APTD-0576 and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

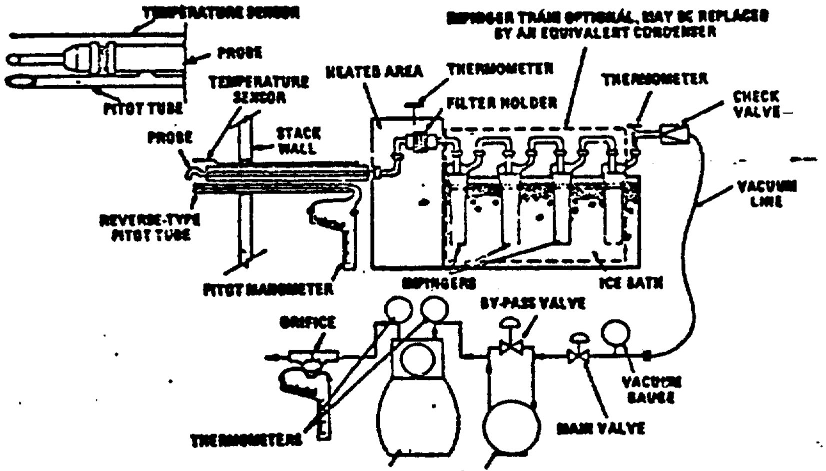

Figure 5-1. Particulate sampling train.

2.1.1 Probe Nozzle. Stainless steel (316) or glass with sharp, tapered leading edge. The angle of taper shall be ≤30° and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing; other materials of construction may be used, subject to the approval of the Administrator.

A range of nozzle sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm (⅛ to ½ in.)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm (1/16 in.). Each nozzle shall be calibrated according to the procedures outlined in Section 5.

2.1.2 Probe Liner. Borosilicate or quartz glass tubing with a heating system capable of maintaining a gas temperature at the exit end during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. (The tester may opt to operate the equipment at a temperature lower than that specified.) Since the actual temperature at the outlet of the probe is not usually monitored during sampling, probes constructed according to APTD-0581 and utilizing the calibration curves of APTD-0576 (or calibrated according to the procedure outlined in APTD-0576) will be considered acceptable.

Either borosilicate or quartz glass probe liners may be used for stack temperatures up to about 480° C (900° F); quartz liners shall be used for temperatures between 480 and 900° C (900 and 1,650° F). Both types of liners may be used at higher temperatures than specified for short periods of time, subject to the approval of the Administrator. The softening temperature for borosilicate is 820° C (1,508° F), and for quartz it is 1,500° C (2,732° F).

Whenever practical, every effort should be made to use borosilicate or quartz glass probe liners. Alternatively, metal liners (e.g., 316 stainless steel, Incoloy 825,[1] or other corrosion resistant metals) made of seamless tubing may be used, subject to the approval of the Administrator.

2.1.3 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator. The pitot tube shall be attached to the probe (as shown in Figure 5-1) to allow constant monitoring of the stack gas velocity. The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane (see Method 2, Figure 2-6b) during sampling. The Type S pitot tube assembly shall have a known coefficient, determined as outlined in Section 4 of Method 2.

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

Method 5, Continued

2.1.4 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other materials of construction (e.g., stainless steel, Teflon, Viton) may be used, subject to approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The holder shall be attached immediately at the outlet of the probe (or cyclone, if used).

2.1.6 Filter Heating System. Any heating system capable of maintaining a temperature around the filter holder during sampling of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator for a particular application. Alternatively, the tester may opt to operate the equipment at a temperature lower than that specified. A temperature gauge capable of measuring temperature to within 3° C (5.4° F) shall be installed so that the temperature around the filter holder can be regulated and monitored during sampling. Heating systems other than the one shown in APTD-0581 may be used.

2.1.7 Condenser. The following system shall be used to determine the stack gas moisture content: Four impingers connected in series with leak-free ground glass fittings or any similar leak-free non-contaminating fittings. The first, third, and fourth impingers shall be of the Greenburg-Smith design, modified by replacing the tip with 1.3 cm (½ in.) ID glass tube extending to about 1.3 cm (½ in.) from the bottom of the flask. The second impinger shall be of the Greenburg-Smith design with the standard tip. Modifications (e.g., using flexible connections between the impingers, using materials other than glass, or using flexible vacuum lines to connect the filter holder to the condenser) may be used, subject to the approval of the Administrator. The first and second impingers shall contain known quantities of water (Section 4.1.3), the third shall be empty, and the fourth shall contain a known weight of silica gel, or equivalent desiccant. A thermometer, capable of measuring temperature to within 1° C (2° F) shall be placed at the outlet of the fourth impinger for monitoring purposes.

Alternatively, any system that cools the sample gas stream and allows measurement of the water condensed and moisture leaving the condenser, each to within 1 ml or 1 g may be used, subject to the approval of the Administrator. Acceptable means are to measure the condensed water either gravimetrically or volumetrically and to measure the moisture leaving the condenser by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample gas stream through a tared silica gel (or equivalent desiccant) trap with exit gases kept below 20° C (68° F) and determining the weight gain.

If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel (or equivalent) still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

NOTE.—If a determination of the particulate matter collected in the impingers is desired in addition to moisture content, the impinger system described above shall be used, without modification. Individual States or control agencies requiring this information shall be contacted as to the sample recovery and analysis of the impinger contents.

2.1.8 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 5-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

2.1.9 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.10 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3. The temperature sensor shall, preferably, be permanently attached to the pitot tube or sampling probe in a fixed configuration, such that the tip of the sensor extends beyond the leading edge of the probe sheath and does not touch any metal. Alternatively, the sensor may be attached just prior to use in the field. Note, however, that if the temperature sensor is attached in the field, the sensor must be placed in an interference-free arrangement with respect to the Type S pitot tube openings (see Method 2, Figure 2-7). As a second alternative, if a difference of not more than 1 percent in the average velocity measurement is to be introduced, the temperature gauge need not be attached to the probe or pitot tube. (This alternative is subject to the approval of the Administrator.)

2.2 Sample Recovery. The following items are needed.

2.2.1 Probe-Liner and Probe-Nozzle Brushes. Nylon bristle brushes with stainless steel wire handles. The probe brush shall have extensions (at least as long as the probe) of stainless steel, Nylon, Teflon, or similarly inert material. The brushes shall be properly sized and shaped to brush out the probe liner and nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistent, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples, glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable for use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Air-tight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

2.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

2.3 Analysis. For analysis, the following equipment is needed.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 g.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. *Reagents*

3.1 Sampling. The reagents used in sampling are as follows:

3.1.1 Filters. Glass fiber filters, without organic binder, exhibiting at least 99.95 percent efficiency (≤0.05 percent penetration) on 0.3-micron dioctyl phthalate smoke particles. The filter efficiency test shall be conducted in accordance with ASTM standard method D 2986-71. Test data from the supplier's quality control program are sufficient for this purpose.

* * *

3.1.2. Silica Gel. Indicating type, 6 to 16 mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Water. When analysis of the material caught in the impingers is required, distilled water shall be used. Run blanks prior to field use to eliminate a high blank on test samples.

3.1.4 Crushed Ice.

3.1.5 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

3.2 Sample Recovery. Acetone—reagent grade, ≤0.001 percent residue, in glass bottles—is required. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers; thus, acetone blanks shall be run prior to field use and only acetone with low blank values (≤0.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis. Two reagents are required for the analysis:

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. *Procedure*

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. All the components shall be maintained and calibrated according to the procedure described in APTD-0576, unless otherwise specified herein.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper diameter on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at 20±5.6° C (68±10° F) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., <0.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105° C (220° F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particulate sample run.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a suitable probe liner and probe length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 min (or some greater time interval as specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

Place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as to prevent the sample gas stream from circumventing the filter. Check the filter for tears after assembly is completed.

When glass liners are used, install the selected nozzle using a Viton A O-ring when stack temperatures are less than 260° C (500° F) and an asbestos string gasket when temperatures are higher. See APTD-0576 for details. Other connecting systems using either 316 stainless steel or Teflon ferrules may be used. When metal liners are used, install the nozzle as above or by a leak-free direct mechanical connection. Mark the probe with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Set up the train as in Figure 5-1, using (if necessary) a very light coat of silicone grease on all ground glass joints, greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease. Subject to the approval of the Administrator, a glass cyclone may be used between the probe and filter holder when the total particulate catch is expected to exceed 100 mg or when water droplets are present in the stack gas.

Place crushed ice around the impingers.

4.1.4 Leak-Check Procedures.

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, turn on and set the filter and probe heating systems at the desired operating temperatures. Allow time for the temperatures to stabilize. If a Viton A O-ring or other leak-free connection is used in assembling the probe nozzle to the probe liner, leak-check the train at the sampling site by plugging the nozzle and pulling a 380 mm Hg (15 in. Hg) vacuum.

NOTE.—A lower vacuum may be used, provided that it is not exceeded during the test.

If an asbestos string is used, do not connect the probe to the train during the leak-check. Instead, leak-check the train by first plugging the inlet to the filter holder (cyclone, if applicable) and pulling a 380 mm Hg (15 in. Hg) vacuum (see Note immediately above). Then connect the probe to the train and leak-check at about 25 mm Hg (1 in. Hg) vacuum; alternatively, the probe may be leak-checked with the rest of the sampling train, in one step, at 380 mm Hg (15 in. Hg) vacuum. Leakage rates in excess of 4 percent of the average sampling rate or 0.00057 m³/min (0.02 cfm), whichever is less, are unacceptable.

Method 5, Continued

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with bypass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the bypass valve until the desired vacuum is reached. Do not reverse direction of bypass valve; this will cause water to back up into the filter holder. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe, filter holder, or cyclone (if applicable) and immediately turn off the vacuum pump. This prevents the water in the impingers from being forced backward into the filter holder and silica gel from being entrained backward into the third impinger.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain an isokinetic sampling rate (within 10 percent of true isokinetic unless otherwise specified by the Administrator) and a temperature around the filter of 120±14° C (248±25° F), or such other temperature as specified by an applicable subpart of the standards or approved by the Administrator.

For each run, record the data required on a data sheet such as the one shown in Figure 5-2. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted.

Take other readings required by Figure 5-2 at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling deposited material. To begin sampling, remove the nozzle cap, verify that the filter and probe heating systems are up to temperature, and that the pitot tube and probe are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment of the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85±0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29±4. APTD-0576 details the procedure for using the nomographs. If C_p and M_d are outside the above stated ranges do not use the nomographs unless appropriate steps (see Citation 7 in Section 7) are taken to compensate for the deviations.

PLANT
LOCATION
OPERATOR
DATE
RUN NO.
SAMPLE BOX NO.
METER BOX NO.
METER ΔH@
C FACTOR
PITOT TUBE COEFFICIENT, C_p

SCHEMATIC OF STACK CROSS SECTION

AMBIENT TEMPERATURE
BAROMETRIC PRESSURE
ASSUMED MOISTURE, %
PROBE LENGTH, m (ft)
NOZZLE IDENTIFICATION NO.
AVERAGE CALIBRATED NOZZLE DIAMETER, cm (in.)
PROBE HEATER SETTING
LEAK RATE, m³/min (cfm)
PROBE LINER MATERIAL
STATIC PRESSURE, mm Hg (in. Hg)
FILTER NO.

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	VACUUM mm Hg (in. Hg)	STACK TEMPERATURE (T_s) °C (°F)	VELOCITY HEAD (ΔP_s) mm (in.) H_2O	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER mm H_2O (in. H_2O)	GAS SAMPLE VOLUME m³ (ft³)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		FILTER HOLDER TEMPERATURE, °C (°F)	TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
							INLET °C (°F)	OUTLET °C (°F)		
TOTAL							Avg.	Avg.		
AVERAGE							Avg.			

Figure 5-2. Particulate field data.

Method 5, Continued

When the stack is under significant negative pressure (height of impinger stem), take care to close the coarse adjust valve before inserting the probe into the stack to prevent water from backing into the filter holder. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Traverse the stack cross-section, as required by Method 1 or as specified by the Administrator, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe through the portholes; this minimizes the chance of extracting deposited material.

During the test run, make periodic adjustments to keep the temperature around the filter holder at the proper level; add more ice and, if necessary, salt to maintain a temperature of less than 20° C (68° F) at the condenser/silica gel outlet. Also, periodically check the level and zero of the manometer.

If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sample run. It is recommended that another complete filter assembly be used rather than attempting to change the filter itself. Before a new filter assembly is installed, conduct a leak-check (see Section 4.1.4.2). The total particulate weight shall include the summation of all filter assembly catches.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator.

Note that when two or more trains are used, separate analyses of the front-half and (if applicable) impinger catches from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case, the front-half catches from the individual trains may be combined (as may the impinger catches) and one analysis of front-half catch and one analysis of impinger catch may be performed. Consult with the Administrator for details concerning the calculation of results when two or more trains are used.

At the end of the sample run, turn off the coarse adjust valve, remove the probe and nozzle from the stack, turn off the pump, record the final dry gas meter reading, and conduct a post-test leak-check, as outlined in Section 4.1.4.3. Also, leak-check the pitot lines as described in Method 2, Section 3.1; the lines must pass this leak-check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Calculations, Section 6) to determine whether the run was valid or another test run should be made. If there was difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe is removed from the stack at the end of the sampling period. Allow the probe to cool.

When the probe can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, thus drawing water from the impingers into the filter holder.

Before moving the sample train to the cleanup site, remove the probe from the sample train, wipe off the silicone grease, and cap the open outlet of the probe. Be careful not to lose any condensate that might be present. Wipe off the silicone grease from the filter inlet where the probe was fastened and cap it. Remove the umbilical cord from the last impinger and cap the impinger. If a flexible line is used between the first impinger or condenser and the filter holder, disconnect the line at the filter holder and let any condensed water or liquid drain into the impingers or condenser. After wiping off the silicone grease, cap off the filter holder outlet and impinger inlet. Either ground-glass stoppers, plastic caps, or serum caps may be used to close these openings.

Transfer the probe and filter-impinger assembly to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, probe fitting, probe liner, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow the Administrator's directions on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a nylon bristle brush. Brush until the acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse the inside parts of the Swagelok fitting with acetone in a similar way until no visible particles remain.

Rinse the probe liner with acetone by tilting and rotating the probe while squirting acetone into its upper end so that all inside surfaces will be wetted with acetone. Let the acetone drain from the lower end into the sample container. A funnel (glass or polyethylene) may be used to aid in transferring liquid washes to the container. Follow the acetone rinse with a probe brush. Hold the probe in an inclined position, squirt acetone into the upper end as the probe brush is being pushed with a twisting action through the probe; hold a sample container underneath the lower end of the probe, and catch any acetone and particulate matter which is brushed from the probe. Run the brush through the probe three times or more until no visible particulate matter is carried out with the acetone or until none remains in the probe liner on visual inspection. With stainless steel or other metal probes, run the brush through in the above prescribed manner at least six times since metal probes have small crevices in which particulate matter can be entrapped. Rinse the brush with acetone, and quantitatively collect these washings in the sample container. After the brushing, make a final acetone rinse of the probe as described above.

It is recommended that two people be used to clean the probe to minimize sample losses. Between sampling runs, keep brushes clean and protected from contamination.

After ensuring that all joints have been wiped clean of silicone grease, clean the inside of the front half of the filter holder by rubbing the surfaces with a nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make a final rinse of the brush and filter holder. Carefully rinse out the glass cyclone, also (if applicable). After all acetone washings and particulate matter have been collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occurred during transport. Label the container to clearly identify its contents.

Container No. 3. Note the color of the indicating silica gel to determine if it has been completely spent and make a notation of its condition. Transfer the silica gel from the fourth impinger to its original container and seal. A funnel may make it easier to pour the silica gel without spilling. A rubber policeman may be used as an aid in removing the silica gel from the impinger. It is not necessary to remove the small amount of dust particles that may adhere to the impinger wall and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for container No. 3 in Section 4.3.

* * *

* * *

Method 5, Continued

Impinger Water. Treat the impingers as follows: Make a notation of any color or film in the liquid catch. Measure the liquid which is in the first three impingers to within ±1 ml by using a graduated cylinder or by weighing it to within ±0.5 g by using a balance (if one is available). Record the volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas.

Discard the liquid after measuring and recording the volume or weight, unless analysis of the impinger catch is required (see Note, Section 2.1.7).

If a different type of condenser is used, measure the amount of moisture condensed either volumetrically or gravimetrically.

Whenever possible, containers should be shipped in such a way that they remain upright at all times.

4.3 Analysis. Record the data required on a sheet such as the one shown in *Figure 5-3.* Handle each sample container as follows:

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Plant ______________________________

Date ______________________________

Run No. ______________________________

Filter No. ______________________________

Amount liquid lost during transport ______________________________

Acetone blank volume, ml ______________________________

Acetone wash volume, ml ______________________________

Acetone blank concentration, mg/mg (equation 5-4) ______________________________

Acetone wash blank, mg (equation 5-5) ______________________________

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED, mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			
		Less acetone blank	
		Weight of particulate matter	

	VOLUME OF LIQUID WATER COLLECTED		
	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g	
FINAL			
INITIAL			
LIQUID COLLECTED			
TOTAL VOLUME COLLECTED		g*	ml

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER (1g/ml).

$$\frac{\text{INCREASE, g}}{1\ \text{g/ml}} = \text{VOLUME WATER, ml}$$

Figure 5-3. Analytical data.

Alternatively, the sample may be oven dried at 105° C (220° F) for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at 105° C (220° F) for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ±1 ml or gravimetrically to ±0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance. This step may be conducted in the field.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE.—At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

5. *Calibration*

Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

5.2 Pitot Tube. The Type S pitot tube assembly shall be calibrated according to the procedure outlined in Section 4 of Method 2.

5.3 Metering System. Before its initial use in the field, the metering system shall be calibrated according to the procedure outlined in APTD-0576. Instead of physically adjusting the dry gas meter dial readings to correspond to the wet test meter readings, calibration factors may be used to mathematically correct the gas meter dial readings to the proper values. Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057 m³/min (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divide the difference by 10, to get the leak rate. The leak rate should not exceed 0.00057 m³/min (0.02 cfm).

After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the calibration factor. If the calibration has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as outlined in APTD-0576.

Alternative procedures, e.g., using the orifice meter coefficients, may be used, subject to the approval of the Administrator.

NOTE.—If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Probe Heater Calibration. The probe heating system shall be calibrated before its initial use in the field according to the procedure outlined in APTD-0576. Probes constructed according to APTD-0581 need not be calibrated if the calibration curves in APTD-0576 are used.

5.5 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.6 Leak Check of Metering System Shown in Figure 5-1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 5-4): Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

5.7 Barometer. Calibrate against a mercury barometer.

6. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

6.1 Nomenclature

A_n = Cross-sectional area of nozzle, m² (ft²).
B_{ws} = Water vapor in the gas stream, proportion by volume.
C_a = Acetone blank residue concentrations, mg/g.
c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (g/dscf).
I = Percent of isokinetic sampling.
L_a = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change; equal to 0.00057 m³/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.
L_i = Individual leakage rate observed during the leak check conducted prior to the "i^{th}" component change (i=1, 2, 3 . . . . n), m³/min (cfm).
L_p = Leakage rate observed during the post-test leak check, m³/min (cfm).
m_n = Total amount of particulate matter collected, mg.
M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).
m_a = Mass of residue of acetone after evaporation, mg.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_s = Absolute stack gas pressure, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
R = Ideal gas constant, 0.06236 mm Hg-m³/°K-g-mole (21.85 in. Hg-ft³/°R-lb-mole).
T_m = Absolute average dry gas meter temperature (see Figure 5-2), °K (°R).
T_s = Absolute average stack gas temperature (see Figure 5-2), °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of acetone blank, ml.
V_{aw} = Volume of acetone used in wash, ml.
V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.
V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).
$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).
V_s = Stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 5, m/sec (ft/sec).

* * *

Method 5, Continued

W_a = Weight of residue in acetone wash, mg.

Y = Dry gas meter calibration factor.

ΔH = Average pressure differential across the orifice meter (see Figure 5-2), mm H_2O (in. H_2O).

ρ_a = Density of acetone, mg/ml (see label on bottle).

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

θ = Total sampling time, min.

θ_1 = Sampling time interval, from the beginning of a run until the first component change, min.

θ_i = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.

θ_p = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.

13.6 = Specific gravity of mercury.

60 = Sec/min.

100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 5-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C, 760 mm Hg or 68° F, 29.92 in. Hg) by using Equation 5-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right) \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right]$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

where:

K_1 = 0.3858 °K/mm Hg for metric units

= 17.64 °R/in. Hg for English units

Equation 5-1

NOTE.—Equation 5-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak checks conducted prior to component changes) exceeds L_a. If L_p or L_i exceeds L_a, Equation 5-1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 5-1 with the expression:

$$V_m - (L_p - L_a)\theta]$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 5-1 by the expression:

$$\left[V_m - (L_1 - L_a)\theta_1 - \sum_{i=2}^{n} (L_i - L_a)\theta_i - (L_p - L_a)\theta_p\right]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_a.

6.4 Volume of water vapor.

Equation 5-2

$$V_{w(std)} = V_{1c}\left(\frac{\rho_w}{M_w}\right)\left(\frac{RT_{std}}{P_{std}}\right) = K_2 V_{1c}$$

where:

K_2 = 0.001333 m³/ml for metric units

= 0.04707 ft³/ml for English units.

6.5 Moisture Content.

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}$$

where:

Equation 5-3

K_3 = 0.003454 mm Hg-m³/ml-°K for metric units.

= 0.002009 in. Hg-ft³/ml-°R for English units.

NOTE.—In saturated or water droplet-laden gas streams, two calculations of the moisture content of the stack gas shall be made, one from the impinger analysis (Equation 5-3), and a second from the assumption of saturated conditions. The lower of the two values of B_{ws} shall be considered correct. The procedure for determining the moisture content based upon assumption of saturated conditions is given in the Note of Section 1.2 of Method 4. For the purposes of this method, the average stack gas temperature from Figure 5-2 may be used to make this determination, provided that the accuracy of the in-stack temperature sensor is ± 1° C (2° F).

6.6 Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a}$$

Equation 5-4

6.7 Acetone Wash Blank.

$$W_a = C_a V_{aw} \rho_a$$

Equation 5-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 5-3). NOTE.—Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$$c_s = (0.001\ g/mg)\ (m_n/V_{m(std)})$$

Equation 5-6

6.10 Conversion Factors:

From	To	Multiply by
scf	m³	0.02832
g/ft³	gr/ft³	15.43
g/ft³	lb/ft³	2.205×10⁻³
g/ft³	g/m³	35.31

6.11 Isokinetic Variation.

6.11.1 Calculation From Raw Data.

$$I = \frac{100\ T_s [K_3 V_{1c} + (V_m/T_m)(P_{bar} + \Delta H/13.6)]}{60\ \theta v_s P_s A_n}$$

Equation 5-7

6.11.2 Calculation From Intermediate Values.

$$I = \frac{T_s V_{m(std)} P_{std} 100}{T_{std} v_s \theta A_n P_s 60 (1 - B_{ws})}$$

$$= K_4 \frac{T_s V_{m(std)}}{P_s V_s A_n \theta (1 - B_{ws})}$$

where:

K_4 = 4.320 for metric units

= 0.09450 for English units.

Equation 5-8

6.12 Acceptable Results. If 90 percent ≤ I ≤ 110 percent, the results are acceptable. If the results are low in comparison to the standard and I is beyond the acceptable range, or, if I is less than 90 percent, the Administrator may opt to accept the results. Use Citation 4 to make judgments. Otherwise, reject the results and repeat the test.

Method 5, Continued

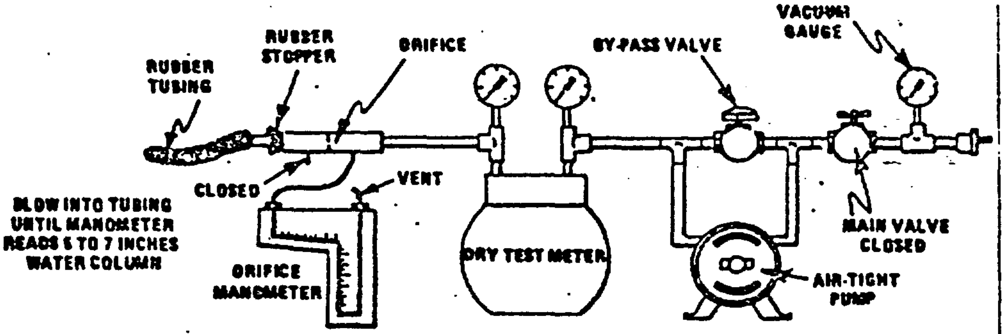

Figure 5-4. Leak check of meter box.

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127

Method 6

DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

(42 FR, 41782, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted from the sampling point in the stack. The sulfuric acid mist (including sulfur trioxide) and the sulfur dioxide are separated. The sulfur dioxide fraction is measured by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfur dioxide emissions from stationary sources. The minimum detectable limit of the method has been determined to be 3.4 milligrams (mg) of SO_2/m^3 (2.12×10^{-7} lb/ft³). Although no upper limit has been established, tests have shown that concentrations as high as 80,000 mg/m³ of SO_2 can be collected efficiently in two midget impingers, each containing 15 milliliters of 3 percent hydrogen peroxide, at a rate of 1.0 lpm for 20 minutes. Based on theoretical calculations, the upper concentration limit in a 20-liter sample is about 93,300 mg/m³.

Possible interferents are free ammonia, water-soluble cations, and fluorides. The cations and fluorides are removed by glass wool filters and an isopropanol bubbler, and hence do not affect the SO_2 analysis. When samples are being taken from a gas stream with high concentrations of very fine metallic fumes (such as in inlets to control devices), a high-efficiency glass fiber filter must be used in place of the glass wool plug (i.e., the one in the probe) to remove the cation interferents.

Free ammonia interferes by reacting with SO_2 to form particulate sulfite and by reacting with the indicator. If free ammonia is present (this can be determined by knowledge of the process and noticing white particulate matter in the probe and isopropanol bubbler), alternative methods, subject to the approval of the Administrator, U.S. Environmental Protection Agency, are required.

2. *Apparatus*

2.1 Sampling. The sampling train is shown in Figure 6-1, and component parts are discussed below. The tester has the option of substituting sampling equipment described in Method 8 in place of the midget impinger equipment of Method 6. However, the Method 8 train must be modified to include a heated filter between the probe and isopropanol impinger, and the operation of the sampling train and sample analysis must be at the flow rates and solution volumes defined in Method 8.

The tester also has the option of determining SO_2 simultaneously with particulate matter and moisture determinations by (1) replacing the water in a Method 5 impinger system with 3 percent peroxide solution, or (2) by replacing the Method 5 water impinger system with a Method 8 isopropanol-filter-peroxide system. The analysis for SO_2 must be consistent with the procedure in Method 8.

2.1.1 Probe. Borosilicate glass, or stainless steel (other materials of construction may be used, subject to the approval of the Administrator), approximately 6-mm inside diameter, with a heating system to prevent water condensation and a filter (either in-stack or heated out-stack) to remove particulate matter, including sulfuric acid mist. A plug of glass wool is a satisfactory filter.

2.1.2 Bubbler and Impingers. One midget bubbler, with medium-coarse glass frit and borosilicate or quartz glass wool packed in top (see Figure 6-1) to prevent sulfuric acid mist carryover, and three 30-ml midget impingers. The bubbler and midget impingers must be connected in series with leak-free glass connectors. Silicone grease may be used, if necessary, to prevent leakage.

At the option of the tester, a midget impinger may be used in place of the midget bubbler.

Other collection absorbers and flow rates may be used, but are subject to the approval of the Administrator. Also, collection efficiency must be shown to be at least 99 percent for each test run and must be documented in the report. If the efficiency is found to be acceptable after a series of three tests, further documentation is not required. To conduct the efficiency test, an extra absorber must be added and analyzed separately. This extra absorber must not contain more than 1 percent of the total SO_2.

2.1.3 Glass Wool. Borosilicate or quartz.

2.1.4 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease may be used, if necessary.

2.1.5 Temperature Gauge. Dial thermometer, or equivalent, to measure temperature of gas leaving impinger train to within 1° C (2° F.)

2.1.6 Drying Tube. Tube packed with 6- to 16-mesh indicating type silica gel, or equivalent, to dry the gas sample and to protect the meter and pump. If the silica gel has been used previously, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to approval of the Administrator.

2.1.7 Valve. Needle valve, to regulate sample gas flow rate.

2.1.8 Pump. Leak-free diaphragm pump, or equivalent, to pull gas through the train. Install a small tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

2.1.9 Rate Meter. Rotameter, or equivalent, capable of measuring flow rate to within 2 percent of the selected flow rate of about 1000 cc/min.

2.1.10 Volume Meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2 percent, calibrated at the selected flow rate and conditions actually encountered during sampling, and equipped with a temperature gauge (dial thermometer, or equivalent) capable of measuring temperature to within 3° C (5.4° F).

2.1.11 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.12 Vacuum Gauge. At least 760 mm Hg (30 in. Hg) gauge, to be used for leak check of the sampling train.

2.2 Sample Recovery.

2.2.1 Wash bottles. Polyethylene or glass, 500 ml, two.

2.2.2 Storage Bottles. Polyethylene, 100 ml, to store impinger samples (one per sample).

2.3 Analysis.

2.3.1 Pipettes. Volumetric type, 5-ml, 20-ml (one per sample), and 25-ml sizes.

2.3.2 Volumetric Flasks. 100-ml size (one per sample) and 1000-ml size.

2.3.3 Burettes. 5- and 50-ml sizes.

2.3.4 Erlenmeyer Flasks. 250 ml-size (one for each sample, blank, and standard).

2.3.5 Dropping Bottle. 125-ml size, to add indicator.

2.3.6 Graduated Cylinder. 100-ml size.

2.3.7 Spectrophotometer. To measure absorbance at 352 nanometers.

3. *Reagents*

Unless otherwise indicated, all reagents must conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society. Where such specifications are not available, use the best available grade.

3.1 Sampling.

3.1.1 Water. Deionized, distilled to conform to ASTM specification D1193-74, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.1.2 Isopropanol, 80 percent. Mix 80 ml of isopropanol with 20 ml of deionized, distilled water. Check each lot of isopropanol for peroxide impurities as follows: shake 10 ml of isopropanol with 10 ml of freshly prepared 10 percent potassium iodide solution. Prepare a blank by similarly treating 10 ml of distilled water. After 1 minute, read the absorbance at 352 nanometers on a spectrophotometer. If absorbance exceeds 0.1, reject alcohol for use.

Peroxides may be removed from isopropanol by redistilling or by passage through a column of activated alumina; however, reagent grade isopropanol with suitably low peroxide levels may be obtained from commercial sources. Rejection of contaminated lots may, therefore, be a more efficient procedure.

3.1.3 Hydrogen Peroxide, 3 Percent. Dilute 30 percent hydrogen peroxide 1:9 (v/v) with deionized, distilled water (30 ml is needed per sample). Prepare fresh daily.

3.1.4 Potassium Iodide Solution, 10 Percent. Dissolve 10.0 grams KI in deionized, distilled water and dilute to 100 ml. Prepare when needed.

3.2 Sample Recovery.

3.2.1 Water. Deionized, distilled, as in 3.1.1.

3.2.2 Isopropanol, 80 Percent. Mix 80 ml of isopropanol with 20 ml of deionized, distilled water.

3.3 Analysis.

3.3.1 Water. Deionized, distilled, as in 3.1.1.

3.3.2 Isopropanol, 100 percent.

3.3.3 Thorin Indicator. 1-(o-arsonophenylazo)-2-naphthol-3,6-disulfonic acid, disodium salt, or equivalent. Dissolve 0.20 g in 100 ml of deionized, distilled water.

3.3.4 Barium Perchlorate Solution, 0.0100 N. Dissolve 1.95 g of barium perchlorate trihydrate [$Ba(ClO_4)_2 \cdot 3H_2O$] in 200 ml distilled water and dilute to 1 liter with isopropanol. Alternatively, 1.22 g of [$BaCl_2 \cdot 2H_2O$] may be used instead of the perchlorate. Standardize as in Section 5.5.

3.3.5 Sulfuric Acid Standard, 0.0100 N. Purchase or standardize to ±0.0002 N against 0.0100 N NaOH which has previously been standardized against potassium acid phthalate (primary standard grade).

4. *Procedure.*

4.1 Sampling.

4.1.1 Preparation of collection train. Measure 15 ml of 80 percent isopropanol into the midget bubbler and 15 ml of 3 percent hydrogen peroxide into each of the first two midget impingers. Leave the final midget impinger dry. Assemble the train as shown in Figure 6-1. Adjust probe heater to a temperature sufficient to prevent water condensation. Place crushed ice and water around the impingers.

4.1.2 Leak-check procedure. A leak check prior to the sampling run is optional; however, a leak check after the sampling run is mandatory. The leak-check procedure is as follows:

With the probe disconnected, place a vacuum gauge at the inlet to the bubbler and pull a vacuum of 250 mm (10 in.) Hg; plug or pinch off the outlet of the flow meter, and then turn off the pump. The vacuum shall remain stable for at least 30 seconds. Carefully release the vacuum gauge before releasing the flow meter end to prevent back flow of the impinger fluid.

Other leak-check procedures may be used, subject to the approval of the Administrator, U.S. Environmental Protection Agency. The procedure used in Method 5 is not suitable for diaphragm pumps.

4.1.3 Sample collection. Record the initial dry gas meter reading and barometric pressure. To begin sampling, position the tip of the probe at the sampling point, connect the probe to the bubbler, and start the pump. Adjust the sample flow to a constant rate of approximately 1.0 liter/min as indicated by the rotameter. Maintain this constant rate (±10 percent) during the entire sampling run. Take readings (dry gas meter, temperatures at dry gas meter and at impinger outlet and rate meter) at least every 5 minutes. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 20° C (68° F) or less. At the conclusion of each run, turn off the pump, remove probe from the stack, and record the final readings. Conduct a leak check as in Section 4.1.2. (This leak check is mandatory.) If a leak is found, void the test run. Drain the ice bath, and purge the remaining part of the train by drawing clean ambient air through the system for 15 minutes at the sampling rate.

Clean ambient air can be provided by passing air through a charcoal filter or through an extra midget impinger with 15 ml of 3 percent H_2O_2. The tester may opt to simply use ambient air, without purification.

4.2 Sample Recovery. Disconnect the impingers after purging. Discard the contents of the midget bubbler. Pour the contents of the midget impingers into a leak-free polyethylene bottle for shipment. Rinse the three midget impingers and the connecting tubes with deionized, distilled water, and add the washings to the same storage container. Mark the fluid level. Seal and identify the sample container.

4.3 Sample Analysis. Note level of liquid in container, and confirm whether any sample was lost during shipment; note this on analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results.

Transfer the contents of the storage container to a 100-ml volumetric flask and dilute to exactly 100 ml with deionized, distilled water. Pipette a 20-ml aliquot of this solution into a 250-ml Erlenmeyer flask, add 80 ml of 100 percent isopropanol and two to four drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat and average the titration volumes. Run a blank with each series of samples. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is larger.

(NOTE.—Protect the 0.0100 N barium perchlorate solution from evaporation at all times.)

5. *Calibration*

5.1 Metering System.

5.1.1 Initial Calibration. Before its initial use in the field, first leak check the metering system (drying tube, needle valve, pump, rotameter, and dry gas meter) as

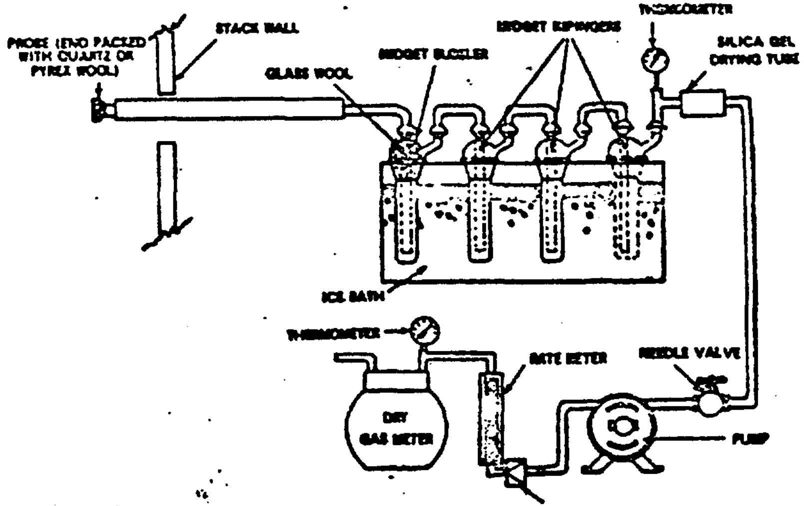

Figure 6-1. SO_2 sampling train.

follows: place a vacuum gauge at the inlet to the drying tube and pull a vacuum of 250 mm (10 in.) Hg; plug or pinch off the outlet of the flow meter, and then turn off the pump. The vacuum shall remain stable for at least 30 seconds. Carefully release the vacuum gauge before releasing the flow meter end.

Next, calibrate the metering system (at the sampling flow rate specified by the method) as follows: connect an appropriately sized wet test meter (e.g., 1 liter per revolution) to the inlet of the drying tube. Make three independent calibration runs, using at least five revolutions of the dry gas meter per run. Calculate the calibration factor, Y (wet test meter calibration volume divided by the dry gas meter volume, both volumes adjusted to the same reference temperature and pressure), for each run, and average the results. If any Y value deviates by more than 2 percent from the average, the metering system is unacceptable for use. Otherwise, use the average as the calibration factor for subsequent test runs.

5.1.2 Post-Test Calibration Check. After each field test series, conduct a calibration check as in Section 5.1.1 above, except for the following variations: (a) the leak check is not to be conducted, (b) three, or more revolutions of the dry gas meter may be used, and (c) only two independent runs need be made. If the calibration factor does not deviate by more than 5 percent from the initial calibration factor (determined in Section 5.1.1), then the dry gas meter volumes obtained during the test series are acceptable. If the calibration factor deviates by more than 5 percent, recalibrate the metering system as in Section 5.1.1, and for the calculations, use the calibration factor (initial or recalibration) that yields the lower gas volume for each test run.

5.2 Thermometers. Calibrate against mercury-in-glass thermometers.

5.3 Rotameter. The rotameter need not be calibrated but should be cleaned and maintained according to the manufacturer's instruction.

5.4 Barometer. Calibrate against a mercury barometer.

5.5 Barium Perchlorate Solution. Standardize the barium perchlorate solution against 25 ml of standard sulfuric acid to which 100 ml of 100 percent isopropanol has been added.

6. *Calculations*

Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

6.1 Nomenclature.

C_{SO_2} = Concentration of sulfur dioxide, dry basis corrected to standard conditions, mg/dscm (lb/dscf).
N = Normality of barium perchlorate titrant, milliequivalents/ml.
P_{bar} = Barometric pressure at the exit orifice of the dry gas meter, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
T_m = Average dry gas meter absolute temperature, °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of sample aliquot titrated, ml.
V_m = Dry gas volume as measured by the dry gas meter, dcm (dcf).
$V_{m(std)}$ = Dry gas volume measured by the dry gas meter, corrected to standard conditions, dscm (dscf).
V_{soln} = Total volume of solution in which the sulfur dioxide sample is contained, 100 ml.
V_t = Volume of barium perchlorate titrant used for the sample, ml (average of replicate titrations).
V_{tb} = Volume of barium perchlorate titrant used for the blank, ml.
Y = Dry gas meter calibration factor.
32.03 = Equivalent weight of sulfur dioxide.

6.2 Dry sample gas volume, corrected to standard conditions.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right)\left(\frac{P_{bar}}{P_{std}}\right) = K_1 Y \frac{V_m P_{bar}}{T_m}$$

Equation 6-1

where:

K_1 = 0.3858 °K/mm Hg for metric units.
= 17.64 °R/in. Hg for English units.

6.3 Sulfur dioxide concentration.

$$C_{SO_2} = K_2 \frac{(V_t - V_{tb})\, N \left(\frac{V_{soln}}{V_a}\right)}{V_{m(std)}}$$

Equation 6-2

where:
K_2 = 32.03 mg/meq. for metric units.
= 7.061×10⁻⁵ lb/meq. for English units.

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Method 7

DETERMINATION OF NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES

(42 FR, 41784, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. A grab sample is collected in an evacuated flask containing a dilute sulfuric acid-hydrogen peroxide absorbing solution, and the nitrogen oxides, except nitrous oxide, are measured colorimetrically using the phenoldisulfonic acid (PDS) procedure.

1.2 Applicability. This method is applicable to the measurement of nitrogen oxides emitted from stationary sources. The range of the method has been determined to be 2 to 400 milligrams NO_x (as NO_2) per dry standard cubic meter, without having to dilute the sample.

2. *Apparatus*

2.1 Sampling (see Figure 7-1). Other grab sampling systems or equipment, capable of measuring sample volume to within ±2.0 percent and collecting a sufficient sample volume to allow analytical reproducibility to within ±5 percent, will be considered acceptable alternatives, subject to approval of the Administrator, U.S. Environmental Protection Agency. The following equipment is used in sampling:

2.1.1 Probe. Borosilicate glass tubing, sufficiently heated to prevent water condensation and equipped with an in-stack or out-stack filter to remove particulate matter (a plug of glass wool is satisfactory for this purpose). Stainless steel or Teflon[1] tubing may also be used for the probe. Heating is not necessary if the probe remains dry during the purging period.

2.1.2 Collection Flask. Two-liter borosilicate, round bottom flask, with short neck and 24/40 standard taper opening, protected against implosion or breakage.

2.1.3 Flask Valve. T-bore stopcock connected to a 24/40 standard taper joint.

2.1.4 Temperature Gauge. Dial-type thermometer, or other temperature gauge, capable of measuring 1° C (2° F) intervals from −5 to 50° C (25 to 125° F).

2.1.5 Vacuum Line. Tubing capable of withstanding a vacuum of 75 mm Hg (3 in. Hg) absolute pressure, with "T" connection and T-bore stopcock.

2.1.6 Vacuum Gauge. U-tube manometer, 1 meter (36 in.), with 1-mm (0.1-in.) divisions, or other gauge capable of measuring pressure to within ±2.5 mm Hg (0.10 in. Hg).

2.1.7 Pump. Capable of evacuating the collection flask to a pressure equal to or less than 75 mm Hg (3 in. Hg) absolute.

2.1.8 Squeeze Bulb. One-way.

2.1.9 Volumetric Pipette. 25 ml.

2.1.10 Stopcock and Ground Joint Grease. A high-vacuum, high-temperature chlorofluorocarbon grease is required. Halocarbon 25-5S has been found to be effective.

2.1.11 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase, or vice versa for elevation decrease.

2.2 Sample Recovery. The following equipment is required for sample recovery:

2.2.1 Graduated Cylinder. 50 ml with 1-ml divisions.

2.2.2 Storage Containers. Leak-free polyethylene bottles.

2.2.3 Wash Bottle. Polyethylene or glass.

2.2.4 Glass Stirring Rod.

2.2.5 Test Paper for Indicating pH. To cover the pH range of 7 to 14.

2.3 Analysis. For the analysis, the following equipment is needed:

2.3.1 Volumetric Pipettes. Two 1 ml, two 2 ml, one 3 ml, one 4 ml, two 10 ml, and one 25 ml for each sample and standard.

: : :

: : :

2.3.2 Porcelain Evaporating Dishes. 175- to 250-ml capacity with lip for pouring, one for each sample and each standard. The Coors No. 45006 (shallow-form, 195 ml) has been found to be satisfactory. Alternatively, polymethyl pentene beakers (Nalge No. 1203, 150 ml), or glass beakers (150 ml) may be used. When glass beakers are used, etching of the beakers may cause solid matter to be present in the analytical step; the solids should be removed by filtration (see Section 4.3).

2.3.3 Steam Bath. Low-temperature ovens or thermostatically controlled hot plates kept below 70° C (160° F) are acceptable alternatives.

2.3.4 Dropping Pipette or Dropper. Three required.

2.3.5 Polyethylene Policeman. One for each sample and each standard.

2.3.6 Graduated Cylinder. 100 ml with 1-ml divisions.

2.3.7 Volumetric Flasks. 50 ml (one for each sample), 100 ml (one for each sample and each standard, and one for the working standard KNO_3 solution), and 1000 ml (one).

2.3.8 Spectrophotometer. To measure absorbance at 410 nm.

2.3.9 Graduated Pipette. 10 ml with 0.1-ml divisions.

2.3.10 Test Paper for Indicating pH. To cover the pH range of 7 to 14.

2.3.11 Analytical Balance. To measure to within 0.1 mg.

3. *Reagents*

Unless otherwise indicated, it is intended that all reagents conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available; otherwise, use the best available grade.

3.1 Sampling. To prepare the absorbing solution, cautiously add 2.8 ml concentrated H_2SO_4 to 1 liter of deionized, distilled water. Mix well and add 6 ml of 3 percent hydrogen peroxide, freshly prepared from 30 percent hydrogen peroxide solution. The absorbing solution should be used within 1 week of its preparation. Do not expose to extreme heat or direct sunlight.

3.2 Sample Recovery. Two reagents are required for sample recovery:

3.2.1 Sodium Hydroxide (1N). Dissolve 40 g NaOH in deionized, distilled water and dilute to 1 liter.

3.2.2 Water. Deionized, distilled to conform to ASTM specification D1193-74, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.3 Analysis. For the analysis, the following reagents are required:

3.3.1 Fuming Sulfuric Acid. 15 to 18 percent by weight free sulfur trioxide. HANDLE WITH CAUTION.

3.3.2 Phenol. White solid.

3.3.3 Sulfuric Acid. Concentrated, 95 percent minimum assay. HANDLE WITH CAUTION.

3.3.4 Potassium Nitrate. Dried at 105 to 110° C (220 to 230° F) for a minimum of 2 hours just prior to preparation of standard solution.

3.3.5 Standard KNO_3 Solution. Dissolve exactly 2.198 g of dried potassium nitrate (KNO_3) in deionized, distilled water and dilute to 1 liter with deionized, distilled water in a 1,000-ml volumetric flask.

3.3.6 Working Standard KNO_3 Solution. Dilute 10 ml of the standard solution to 100 ml with deionized distilled water. One milliliter of the working standard solution is equivalent to 100 μg nitrogen dioxide (NO_2).

3.3.7 Water. Deionized, distilled as in Section 3.2.2.

3.3.8 Phenoldisulfonic Acid Solution. Dissolve 25 g of pure white phenol in 150 ml concentrated sulfuric acid on a steam bath. Cool, add 75 ml fuming sulfuric acid, and heat at 100° C (212° F) for 2 hours. Store in a dark, stoppered bottle.

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

4. *Procedures*

4.1 Sampling.

4.1.1 Pipette 25 ml of absorbing solution into a sample flask, retaining a sufficient quantity for use in preparing the calibration standards. Insert the flask valve stopper into the flask with the valve in the "purge" position. Assemble the sampling train as shown in Figure 7-1 and place the probe at the sampling point. Make sure that all fittings are tight and leak-free, and that all ground glass joints have been properly greased with a high-vacuum, high-temperature chlorofluorocarbon-based stopcock grease. Turn the flask valve and the pump valve to their "evacuate" positions. Evacuate the flask to 75 mm Hg (3 in. Hg) absolute pressure, or less. Evacuation to a pressure approaching the vapor pressure of water at the existing temperature is desirable. Turn the pump valve to its "vent" position and turn off the pump. Check for leakage by observing the manometer for any pressure fluctuation. (Any variation greater than 10 mm Hg (0.4 in. Hg) over a period of 1 minute is not acceptable, and the flask is not to be used until the leakage problem is corrected. Pressure in the flask is not to exceed 75 mm Hg (3 in. Hg) absolute at the time sampling is commenced.) Record the volume of the flask and valve (V_f), the flask temperature (T_i), and the barometric pressure. Turn the flask valve counterclockwise to its "purge" position and do the same with the pump valve. Purge the probe and the vacuum tube using the squeeze bulb. If condensation occurs in the probe and the flask valve area, heat the probe and purge until the condensation disappears. Next, turn the pump valve to its "vent" position. Turn the flask valve clockwise to its "evacuate" position and record the difference in the mercury levels in the manometer. The absolute internal pressure in the flask (P_i) is equal to the barometric pressure less the manometer reading. Immediately turn the flask valve to the "sample" position and permit the gas to enter the flask until pressures in the flask and sample line (i.e., duct, stack) are equal. This will usually require about 15 seconds; a longer period indicates a "plug" in the probe, which must be corrected before sampling is continued. After collecting the sample, turn the flask valve to its "purge" position and disconnect the flask from the sampling train. Shake the flask for at least 5 minutes.

4.1.2 If the gas being sampled contains insufficient oxygen for the conversion of NO to NO_2 (e.g., an applicable subpart of the standard may require taking a sample of a calibration gas mixture of NO in N_2), then oxygen shall be introduced into the flask to permit this conversion. Oxygen may be introduced into the flask by one of three methods; (1) Before evacuating the sampling flask, flush with pure cylinder oxygen, then evacuate flask to 75 mm Hg (3 in. Hg) absolute pressure or less; or (2) inject oxygen into the flask after sampling; or (3) terminate sampling with a minimum of 50 mm Hg (2 in. Hg) vacuum remaining in the flask, record this final pressure, and then vent the flask to the atmosphere until the flask pressure is almost equal to atmospheric pressure.

4.2 Sample Recovery. Let the flask set for a minimum of 16 hours and then shake the contents for 2 minutes. Connect the flask to a mercury filled U-tube manometer. Open the valve from the flask to the manometer and record the flask temperature (T_f), the barometric pressure, and the difference between the mercury levels in the manometer. The absolute internal pressure in the flask (P_f) is the barometric pressure less the manometer reading. Transfer the contents of the flask to a leak-free polyethylene bottle. Rinse the flask twice with 5-ml portions of deionized, distilled water and add the rinse water to the bottle. Adjust the pH to between 9 and 12 by adding sodium hydroxide (1 N), dropwise (about 25 to 35 drops). Check the pH by dipping a stirring rod into the solution and then touching the rod to the pH test paper. Remove as little material as possible during this step. Mark the height of the liquid level so that the container can be checked for leakage after transport. Label the container to clearly identify its contents. Seal the container for shipping.

4.3 Analysis. Note the level of the liquid in container and confirm whether or not any sample was lost during shipment; note this on the analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Immediately prior to analysis, transfer the contents of the shipping container to a 50-ml volumetric flask, and rinse the container twice with 5-ml portions of deionized, distilled water. Add the rinse water to the flask and dilute to the mark with deionized, distilled water; mix thoroughly. Pipette a 25-ml aliquot into the porcelain evaporating dish. Return any unused portion of the sample to the polyethylene storage bottle. Evaporate the 25-ml aliquot to dryness on a steam bath and allow to cool. Add 2 ml phenoldisulfonic acid solution to the dried residue and triturate thoroughly with a polyethyl-

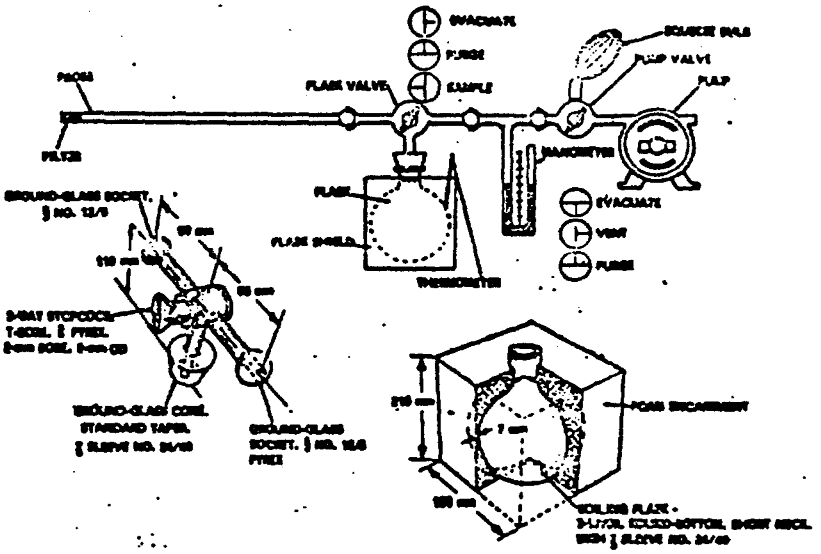

Figure 7-1. Sampling train, flask valve, and flask.

use policeman. Make sure the solution contacts all the residue. Add 1 ml deionized, distilled water and four drops of concentrated sulfuric acid. Heat the solution on a steam bath for 3 minutes with occasional stirring. Allow the solution to cool, add 20 ml deionized, distilled water, mix well by stirring, and add concentrated ammonium hydroxide, dropwise, with constant stirring, until the pH is 10 (as determined by pH paper). If the sample contains solids, these must be removed by filtration (centrifugation is an acceptable alternative, subject to the approval of the Administrator), as follows: filter through Whatman No. 41 filter paper into a 100-ml volumetric flask; rinse the evaporating dish with three 5-ml portions of deionized, distilled water; filter these three rinses. Wash the filter with at least three 15-ml portions of deionized, distilled water. Add the filter washings to the contents of the volumetric flask and dilute to the mark with deionized, distilled water. If solids are absent, the solution can be transferred directly to the 100-ml volumetric flask and diluted to the mark with deionized, distilled water. Mix the contents of the flask thoroughly, and measure the absorbance at the optimum wavelength used for the standards (Section 5.2.1), using the blank solution as a zero reference. Dilute the sample and the blank with equal volumes of deionized, distilled water if the absorbance exceeds A_4, the absorbance of the 400 μg NO_2 standard (see Section 5.2.2).

5. *Calibration*

5.1 Flask Volume. The volume of the collection flask-flask valve combination must be known prior to sampling. Assemble the flask and flask valve and fill with water, to the stopcock. Measure the volume of water to ±10 ml. Record this volume on the flask.

5.2 Spectrophotometer Calibration.

5.2.1 Optimum Wavelength Determination. For both fixed and variable wavelength spectrophotometers, calibrate against standard certified wavelength of 410 nm, every 6 months. Alternatively, for variable wave length spectrophotometers, scan the spectrum between 400 and 415 nm using a 200 μg NO_2 standard solution (see Section 5.2.2). If a peak does not occur, the spectrophotometer is probably malfunctioning, and should be repaired. When a peak is obtained within the 400 to 415 nm range, the wavelength at which this peak occurs shall be the optimum wavelength for the measurement of absorbance for both the standards and samples.

5.2.2 Determination of Spectrophotometer Calibration Factor K_c. Add 0.0, 1.0, 2.0, 3.0, and 4.0 ml of the KNO_3 working standard solution (1 ml = 100 μg NO_2) to a series of five porcelain evaporating dishes. To each, add 25 ml of absorbing solution, 10 ml deionized, distilled water, and sodium hydroxide (1N), dropwise, until the pH is between 9 and 12 (about 25 to 35 drops each). Beginning with the evaporation step, follow the analysis procedure of Section 4.3, until the solution has been transferred to the 100 ml volumetric flask and diluted to the mark. Measure the absorbance of each solution, at the optimum wavelength, as determined in Section 5.2.1. This calibration procedure must be repeated on each day that samples are analyzed. Calculate the spectrophotometer calibration factor as follows:

$$K_c = 100\,\frac{A_1+2A_2+3A_3+4A_4}{A_1^2+A_2^2+A_3^2+A_4^2}$$

Equation 7-1

where:

K_c = Calibration factor

A_1 = Absorbance of the 100-μg NO_2 standard

A_2 = Absorbance of the 200-μg NO_2 standard

A_3 = Absorbance of the 300-μg NO_2 standard

A_4 = Absorbance of the 400-μg NO_2 standard

5.3 Barometer. Calibrate against a mercury barometer.

5.4 Temperature Gauge. Calibrate dial thermometers against mercury-in-glass thermometers.

5.5 Vacuum Gauge. Calibrate mechanical gauges, if used, against a mercury manometer such as that specified in 2.1.6.

5.6 Analytical Balance. Calibrate against standard weights.

6. *Calculations*

Carry out the calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculations.

6.1 Nomenclature.

A = Absorbance of sample.

C = Concentration of NO_x as NO_2, dry basis, corrected to standard conditions, mg/dscm (lb/dscf).

F = Dilution factor (i.e., 25/5, 25/10, etc., required only if sample dilution was needed to reduce the absorbance into the range of calibration).

K_c = Spectrophotometer calibration factor.

m = Mass of NO_x as NO_2 in gas sample, μg.

P_f = Final absolute pressure of flask, mm Hg (in. Hg).

P_i = Initial absolute pressure of flask, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

T_f = Final absolute temperature of flask, °K (°R).

T_i = Initial absolute temperature of flask, °K (°R).

T_{std} = Standard absolute temperature, 293° K (528° R)

V_{sc} = Sample volume at standard conditions (dry basis), ml.

V_f = Volume of flask and valve, ml.

V_a = Volume of absorbing solution, 25 ml.

2 = 50/25, the aliquot factor. (If other than a 25-ml aliquot was used for analysis, the corresponding factor must be substituted).

6.2 Sample volume, dry basis, corrected to standard conditions.

$$V_{sc} = \frac{T_{std}}{P_{std}}\,(V_f - V_a)\left[\frac{P_f}{T_f} - \frac{P_i}{T_i}\right]$$

$$= K_1 (V_f - 25\text{ ml})\left[\frac{P_f}{T_f} - \frac{P_i}{T_i}\right]$$

where: Equation 7-2

$$K_1 = 0.3858\,\frac{°K}{\text{mm Hg}} \text{ for metric units}$$

$$= 17.64\,\frac{°R}{\text{in. Hg}} \text{ for English units}$$

6.3 Total μg NO_2 per sample.

$$m = 2\,K_c\,A\,F \qquad \text{Equation 7-3}$$

NOTE.—If other than a 25-ml aliquot is used for analysis, the factor 2 must be replaced by a corresponding factor.

6.4 Sample concentration, dry basis, corrected to standard conditions.

$$C = K_2\,\frac{m}{V_{sc}} \qquad \text{Equation 7-4}$$

where:

$$K_2 = 10^3\,\frac{\text{mg/m}^3}{\mu\text{g/ml}} \text{ for metric units}$$

$$= 6.243\times10^{-5}\,\frac{\text{lb/scf}}{\mu\text{g/ml}} \text{ for English units}$$

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Method 8

DETERMINATION OF SULFURIC ACID MIST AND SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

(42 FR, 41876, August 18, 1977)

1. *Principle and Applicability*

1.1 Principle. A gas sample is extracted isokinetically from the stack. The sulfuric acid mist (including sulfur trioxide) and the sulfur dioxide are separated, and both fractions are measured separately by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfuric acid mist (including sulfur trioxide, and in the absence of other particulate matter) and sulfur dioxide emissions from stationary sources. Collaborative tests have shown that the minimum detectable limits of the method are 0.05 milligrams/cubic meter (0.03×10^{-7} pounds/cubic foot) for sulfur trioxide and 1.2 mg/m³ (0.74×10^{-7} lb/ft³) for sulfur dioxide. No upper limits have been established. Based on theoretical calculations for 200 milliliters of 3 percent hydrogen peroxide solution, the upper concentration limit for sulfur dioxide in a 1.0 m³ (35.3 ft³) gas sample is about 12,500 mg/m³ (7.7×10^{-4} lb/ft³). The upper limit can be extended by increasing the quantity of peroxide solution in the impingers.

Possible interfering agents of this method are fluorides, free ammonia, and dimethyl aniline. If any of these interfering agents are present (this can be determined by knowledge of the process), alternative methods, subject to the approval of the Administrator, are required.

Filterable particulate matter may be determined along with SO_3 and SO_2 (subject to the approval of the Administrator); however, the procedure used for particulate matter must be consistent with the specifications and procedures given in Method 5.

2. *Apparatus*

2.1 Sampling. A schematic of the sampling train used in this method is shown in Figure 8-1; it is similar to the Method 5 train except that the filter position is different and the filter holder does not have to be heated. Commercial models of this train are available. For those who desire to build their own, however, complete construction details are described in APTD-0581. Changes from the APTD-0581 document and allowable modifications to Figure 8-1 are discussed in the following subsections.

The operating and maintenance procedures for the sampling train are described in APTD-0576. Since correct usage is important in obtaining valid results, all users should read the APTD-0576 document and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. Further details and guidelines on operation and maintenance are given in Method 5 and should be read and followed whenever they are applicable.

2.1.1 Probe Nozzle. Same as Method 5, Section 2.1.1.

2.1.2 Probe Liner. Borosilicate or quartz glass, with a heating system to prevent visible condensation during sampling. Do not use metal probe liners.

2.1.3 Pitot Tube. Same as Method 5, Section 2.1.3.

2.1.4 Differential Pressure Gauge. Same as Method 5, Section 2.1.4.

2.1.5 Filter Holder. Borosilicate glass, with a glass frit filter support and a silicone rubber gasket. Other gasket materials, e.g., Teflon or Viton, may be used subject to the approval of the Administrator. The holder design shall provide a positive seal against leakage from the outside or around the filter. The filter holder shall be placed between the first and second impingers. Note: Do not heat the filter holder.

2.1.6 Impingers—Four, as shown in Figure 8-1. The first and third shall be of the Greenburg-Smith design with standard tips. The second and fourth shall be of the Greenburg-Smith design, modified by replacing the insert with an approximately 13 millimeter (0.5 in.) ID glass tube, having an unconstricted tip located 13 mm (0.5 in.) from the bottom of the flask. Similar collection systems, which have been approved by the Administrator, may be used.

2.1.7 Metering System. Same as Method 5, Section 2.1.8.

2.1.8 Barometer. Same as Method 5, Section 2.1.9.

2.1.9 Gas Density Determination Equipment. Same as Method 5, Section 2.1.10.

2.1.10 Temperature Gauge. Thermometer, or equivalent, to measure the temperature of the gas leaving the impinger train to within 1° C (2° F).

2.2 Sample Recovery.

2.2.1 Wash Bottles. Polyethylene or glass, 500 ml (two).

2.2.2 Graduated Cylinders. 250 ml, 1 liter. (Volumetric flasks may also be used.)

2.2.3 Storage Bottles. Leak-free polyethylene bottles, 1000 ml size (two for each sampling run).

2.2.4 Trip Balance. 500-gram capacity, to measure to ±0.5 g (necessary only if a moisture content analysis is to be done).

2.3 Analysis.

2.3.1 Pipettes. Volumetric 25 ml, 100 ml.

2.3.2 Burrette. 50 ml.

2.3.3 Erlenmeyer Flask. 250 ml. (one for each sample blank and standard).

2.3.4 Graduated Cylinder. 100 ml.

2.3.5 Trip Balance. 500 g capacity, to measure to ±0.5 g.

2.3.6 Dropping Bottle. To add indicator solution, 125-ml size.

3. *Reagents*

Unless otherwise indicated, all reagents are to conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Otherwise, use the best available grade.

3.1 Sampling.

3.1.1 Filters. Same as Method 5, Section 3.1.1.

3.1.2 Silica Gel. Same as Method 5, Section 3.1.2.

3.1.3 Water. Deionized, distilled to conform to ASTM specification D1193-74, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

3.1.4 Isopropanol, 80 Percent. Mix 800 ml of isopropanol with 200 ml of deionized, distilled water.

NOTE.—Experience has shown that only A.C.S. grade isopropanol is satisfactory. Tests have shown that isopropanol obtained from commercial sources occasionally has peroxide impurities that will cause erroneously high sulfuric acid mist measurement. Use the following test for detecting peroxides in each lot of isopropanol: Shake 10 ml of the isopropanol with 10 ml of freshly prepared 10 percent potassium iodide solution. Prepare a blank by similarly treating 10 ml of distilled water. After 1 minute, read the absorbance on a spectrophotometer at 352 nanometers. If the absorbance exceeds 0.1, the isopropanol shall not be used. Peroxides may be removed from isopropanol by redistilling, or by passage through a column of activated alumina. However, reagent-grade isopropanol with suitably low peroxide levels is readily available from commercial sources; therefore, rejection of contaminated lots may be more efficient than following the peroxide removal procedure.

3.1.5 Hydrogen Peroxide, 3 Percent. Dilute 100 ml of 30 percent hydrogen peroxide to 1 liter with deionized, distilled water. Prepare fresh daily.

3.1.6 Crushed Ice.

3.2 Sample Recovery.

3.2.1 Water. Same as 3.1.3.

3.2.2 Isopropanol, 80 Percent. Same as 3.1.4.

3.3 Analysis.

3.3.1 Water. Same as 3.1.3.

3.3.2 Isopropanol, 100 Percent.

3.3.3 Thorin Indicator. 1-(o-arsonophenylazo)-2-naphthol-3, 6-disulfonic acid, disodium salt, or equivalent. Dissolve 0.20 g in 100 ml of deionized, distilled water.

3.3.4 Barium Perchlorate (0.0100 Normal). Dissolve 1.95 g of barium perchlorate trihydrate ($Ba(ClO_4)_2 \cdot 3H_2O$) in 200 ml deionized, distilled water, and dilute to 1 liter with isopropanol; 1.22 g of barium chloride dihydrate ($BaCl_2 \cdot 2H_2O$) may be used instead of the barium perchlorate. Standardize with sulfuric acid as in Section 5.2. This solution must be protected against evaporation at all times.

Méthod 8, Continued

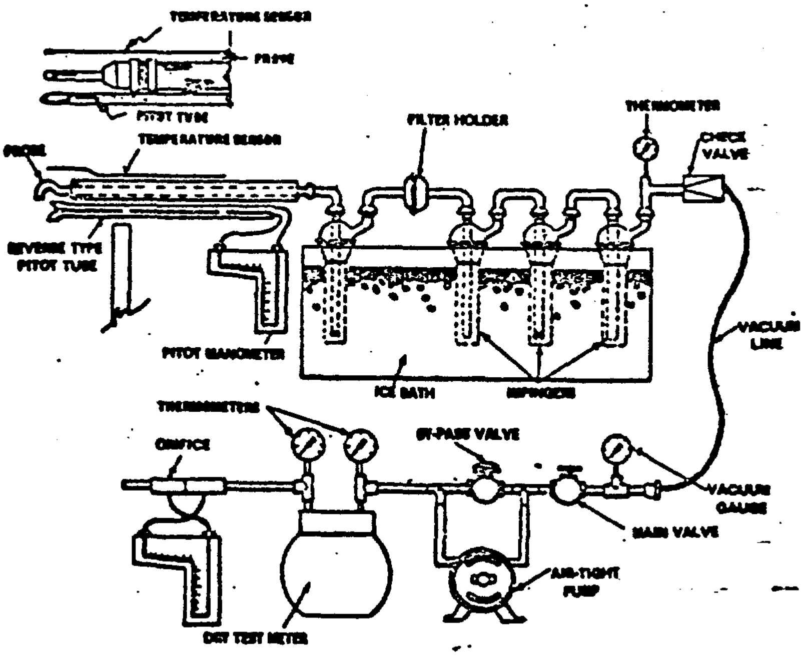

Figure 8-1. Sulfuric acid mist sampling train.

3.3.5 Sulfuric Acid Standard (0.0100 N). Purchase or standardize to ±0.0002 N against 0.0100 N NaOH that has previously been standardized against primary standard potassium acid phthalate.

4. *Procedure*

4.1 Sampling.

4.1.1 Pretest Preparation. Follow the procedure outlined in Method 5, Section 4.1.1; filters should be inspected, but need not be desiccated, weighed, or identified. If the effluent gas can be considered dry, i.e., moisture free, the silica gel need not be weighed.

4.1.2 Preliminary Determinations. Follow the procedure outlined in Method 5, Section 4.1.2.

4.1.3 Preparation of Collection Train. Follow the procedure outlined in Method 5, Section 4.1.3 (except for the second paragraph and other obviously inapplicable parts) and use Figure 8-1 instead of Figure 5-1. Replace the second paragraph with: Place 100 ml of 80 percent isopropanol in the first impinger, 100 ml of 3 percent hydrogen peroxide in both the second and third impingers; retain a portion of each reagent for use as a blank solution. Place about 200 g of silica gel in the fourth impinger.

NOTE.—If moisture content is to be determined by impinger analysis, weigh each of the first three impingers (plus absorbing solution) to the nearest 0.5 g and record these weights. The weight of the silica gel (or silica gel plus container) must also be determined to the nearest 0.5 g and recorded.

4.1.4 Pretest Leak-Check Procedure. Follow the basic procedure outlined in Method 5, Section 4.1.4.1, noting that the probe heater shall be adjusted to the minimum temperature required to prevent condensation, and also that verbage such as, "* * * plugging the inlet to the filter holder * * *," shall be replaced by, "* * * plugging the inlet to the first impinger * * *." The pretest leak-check is optional.

4.1.5 Train Operation. Follow the basic procedures outlined in Method 5, Section 4.1.5, in conjunction with the following special instructions. Data shall be recorded on a sheet similar to the one in Figure 8-2. The sampling rate shall not exceed 0.030 m³/min (1.0 cfm) during the run. Periodically during the test, observe the connecting line between the probe and first impinger for signs of condensation. If it does occur, adjust the probe heater setting upward to the minimum temperature required to prevent condensation. If component changes become necessary during a run, a leak-check shall be done immediately before each change, according to the procedure outlined in Section 4.1.4.2 of Method 5 (with appropriate modifications, as mentioned in Section 4.1.4 of this method); record all leak rates. If the leakage rate(s) exceed the specified rate, the tester shall either void the run or shall plan to correct the sample volume as outlined in Section 6.3 of Method 5. Immediately after component changes, leak-checks are optional. If these leak-checks are done, the procedure outlined in Section 4.1.4.1 of Method 5 (with appropriate modifications) shall be used.

After turning off the pump and recording the final readings at the conclusion of each run, remove the probe from the stack. Conduct a post-test (mandatory) leak-check as in Section 4.1.4.3 of Method 5 (with appropriate modification) and record the leak rate. If the post-test leakage rate exceeds the specified acceptable rate, the tester shall either correct the sample volume, as outlined in Section 6.3 of Method 5, or shall void the run.

Drain the ice bath and, with the probe disconnected, purge the remaining part of the train, by drawing clean ambient air through the system for 15 minutes at the average flow rate used for sampling.

NOTE.—Clean ambient air can be provided by passing air through a charcoal filter. At the option of the tester, ambient air (without cleaning) may be used.

4.1.6 Calculation of Percent Isokinetic. Follow the procedure outlined in Method 5, Section 4.1.6.

4.2 Sample Recovery.

4.2.1 Container No. 1. If a moisture content analysis

Method 8; Continued

is to be done, weigh the first impinger plus contents to the nearest 0.5 g and record this weight.

Transfer the contents of the first impinger to a 250-ml graduated cylinder. Rinse the probe, first impinger, all connecting glassware before the filter, and the front half of the filter holder with 80 percent isopropanol. Add the rinse solution to the cylinder. Dilute to 250 ml with 80 percent isopropanol. Add the filter to the solution, mix, and transfer to the storage container. Protect the solution against evaporation. Mark the level of liquid on the container and identify the sample container.

4.2.2 Container No. 2. If a moisture content analysis is to be done, weigh the second and third impingers (plus contents) to the nearest 0.5 g and record these weights. Also, weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g.

Transfer the solutions from the second and third impingers to a 1000-ml graduated cylinder. Rinse all connecting glassware (including back half of filter holder) between the filter and silica gel impinger with deionized, distilled water, and add this rinse water to the cylinder. Dilute to a volume of 1000 ml with deionized, distilled water. Transfer the solution to a storage container. Mark the level of liquid on the container. Seal and identify the sample container.

4.3 Analysis.

Note the level of liquid in containers 1 and 2, and confirm whether or not any sample was lost during shipment; note this on the analytical data sheet. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results.

4.3.1 Container No. 1. Shake the container holding the isopropanol solution and the filter. If the filter breaks up, allow the fragments to settle for a few minutes before removing a sample. Pipette a 100-ml aliquot of this solution into a 250-ml Erlenmeyer flask, add 2 to 4 drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat the titration with a second aliquot of sample and average the titration values. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is greater.

4.3.2 Container No. 2. Thoroughly mix the solution in the container holding the contents of the second and third impingers. Pipette a 10-ml aliquot of sample into a 250-ml Erlenmeyer flask. Add ml of isopropanol, 2 to 4 drops of thorin indicator, and titrate to a pink endpoint using 0.0100 N barium perchlorate. Repeat the titration with a second aliquot of sample and average the titration values. Replicate titrations must agree within 1 percent or 0.2 ml, whichever is greater.

4.3.3 Blanks. Prepare blanks by adding 2 to 4 drops of thorin indicator to 100 ml of 80 percent isopropanol. Titrate the blanks in the same manner as the samples.

5. Calibration

5.1 Calibrate equipment using the procedures specified in the following sections of Method 5: Section 5.3 (metering system); Section 5.5 (temperature gauges); Section 5.7 (barometer). Note that the recommended leak-check of the metering system, described in Section 5.6 of Method 5, also applies to this method.

5.2 Standardize the barium perchlorate solution with 25 ml of standard sulfuric acid, to which 100 ml of 100 percent isopropanol has been added.

: : :

: : :

PLANT ______

LOCATION ______

OPERATOR ______

DATE ______

RUN NO. ______

SAMPLE BOX NO. ______

METER BOX NO. ______

METER ΔH@ ______

C FACTOR ______

PITOT TUBE COEFFICIENT, Cp ______

SCHEMATIC OF STACK CROSS SECTION

STATIC PRESSURE, mm Hg (in. Hg) ______

AMBIENT TEMPERATURE ______

BAROMETRIC PRESSURE ______

ASSUMED MOISTURE, % ______

PROBE LENGTH, m (ft) ______

NOZZLE IDENTIFICATION NO. ______

AVERAGE CALIBRATED NOZZLE DIAMETER, cm (in.) ______

PROBE HEATER SETTING ______

LEAK RATE, m³/min, (cfm) ______

PROBE LINER MATERIAL ______

FILTER NO. ______

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	VACUUM mm Hg (in. Hg)	STACK TEMPERATURE (Ts), °C (°F)	VELOCITY HEAD (ΔPs), mm H₂O (in. H₂O)	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER, mm H₂O (in. H₂O)	GAS SAMPLE VOLUME, m³ (ft³)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
							INLET, °C (°F)	OUTLET, °C (°F)	
TOTAL							Avg	Avg	
AVERAGE							Avg		

Figure 8-2. Field data.

: : :

6. *Calculations*

Note.—Carry out calculations retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after final calculation.

6.1 Nomenclature.

A_n = Cross-sectional area of nozzle, m² (ft²).
B_{ws} = Water vapor in the gas stream, proportion by volume.
$C_{H_2SO_4}$ = Sulfuric acid (including SO_3) concentration, g/dscm (lb/dscf).
C_{SO_2} = Sulfur dioxide concentration, g/dscm (lb/dscf).
I = Percent of isokinetic sampling.
N = Normality of barium perchlorate titrant, g equivalents/liter.
P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).
P_s = Absolute stack gas pressure, mm Hg (in. Hg).
P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).
T_m = Average absolute dry gas meter temperature (see Figure 8-2), °K (°R).
T_s = Average absolute stack gas temperature (see Figure 8-2), °K (°R).
T_{std} = Standard absolute temperature, 293° K (528° R).
V_a = Volume of sample aliquot titrated, 100 ml for H_2SO_4 and 10 ml for SO_2.
V_{lc} = Total volume of liquid collected in impingers and silica gel, ml.
V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).
$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter corrected to standard conditions, dscm (dscf).
v_s = Average stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 8, m/sec (ft/sec).
V_{soln} = Total volume of solution in which the sulfuric acid or sulfur dioxide sample is contained, 250 ml or 1,000 ml, respectively.
V_t = Volume of barium perchlorate titrant used for the sample, ml.
V_{tb} = Volume of barium perchlorate titrant used for the blank, ml.
Y = Dry gas meter calibration factor.
ΔH = Average pressure drop across orifice meter, mm (in.) H_2O.
θ = Total sampling time, min.
13.6 = Specific gravity of mercury.
60 = sec/min.
100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 8-2).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C and 760 mm Hg or 68° F and 29.92 in. Hg) by using Equation 8-1.

$$V_{m(std)} = V_m Y \left(\frac{T_{std}}{T_m}\right) \frac{P_{bar} + \left(\frac{\Delta H}{13.6}\right)}{P_{std}}$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 8-1

where:
K_1 = 0.3858 °K/mm Hg for metric units.
= 17.64 °R/in. Hg for English units.

Note.—If the leak rate observed during any mandatory leak-checks exceeds the specified acceptable rate, the tester shall either correct the value of V_m in Equation 8-1 (as described in Section 6.3 of Method 5), or shall invalidate the test run.

6.4 Volume of Water Vapor and Moisture Content. Calculate the volume of water vapor using Equation 5-2 of Method 5; the weight of water collected in the impingers and silica gel can be directly converted to milliliters (the specific gravity of water is 1 g/ml). Calculate the moisture content of the stack gas, using Equation 5-3 of Method 5. The "Note" in Section 6.5 of Method 5 also applies to this method. Note that if the effluent gas stream can be considered dry, the volume of water vapor and moisture content need not be calculated.

6.5 *Sulfuric acid mist (including SO_3) concentration.*

$$C_{H_2SO_4} = K_2 \frac{N(V_t - V_{tb})\left(\frac{V_{soln}}{V_a}\right)}{V_{m(std)}}$$

Equation 8-2

where:
K_2 = 0.04904 g/milliequivalent for metric units.
= 1.081×10^{-4} lb/meq for English units.

6.6 Sulfur dioxide concentration.

$$C_{SO_2} = K_3 \frac{N(V_t - V_{tb})\left(\frac{V_{soln}}{V_a}\right)}{V_{m(std)}}$$

Equation 8-3

where:
K_3 = 0.03203 g/meq for metric units.
= 7.061×10^{-5} lb/meq for English units.

6.7 Isokinetic Variation.

6.7.1 Calculation from raw data.

$$I = \frac{100\, T_s [K_4 V_{lc} + (V_m / T_m) P_{bar} + \Delta H/13.6)]}{60\, \theta V_s P_s A_n}$$

Equation 8-4

where:
K_4 = 0.003464 mm Hg-m³/ml-°K for metric units.
= 0.002676 in. Hg-ft³/ml-°R for English units.

6.7.2 Calculation from intermediate values.

$$I = \frac{T_s V_{m(std)} P_{std} 100}{T_{std} v_s \theta A_n P_s 60 (1 - B_{ws})}$$

$$= K_5 \frac{T_s V_{m(std)}}{P_s v_s A_n \theta (1 - B_{ws})}$$

Equation 8-5

where:
K_5 = 4.320 for metric units.
= 0.09450 for English units.

6.8 Acceptable Results. If 90 percent ≤ I ≤ 110 percent, the results are acceptable. If the results are low in comparison to the standards and I is beyond the acceptable range, the Administrator may opt to accept the results. Use Citation 4 in the Bibliography of Method 5 to make judgments. Otherwise, reject the results and repeat the test.

7. *Bibliography*

1. Atmospheric Emissions from Sulfuric Acid Manufacturing Processes. U.S. DHEW, PHS, Division of Air Pollution. Public Health Service Publication No. 999-AP-13. Cincinnati, Ohio. 1965.

2. Corbett, P. F. The Determination of SO_2 and SO_3 in Flue Gases. Journal of the Institute of Fuel. 24:237-243. 1961.

3. Martin, Robert M. Construction Details of Isokinetic Source Sampling Equipment. Environmental Protection Agency. Research Triangle Park, N.C. Air Pollution Control Office Publication No. APTD-0581. April, 1971.

4. Patton, W. F. and J. A. Brink, Jr. New Equipment and Techniques for Sampling Chemical Process Gases. Journal of Air Pollution Control Association. 13:162. 1963.

5. Rom, J. J. Maintenance, Calibration, and Operation of Isokinetic Source-Sampling Equipment. Office of Air Programs, Environmental Protection Agency. Research Triangle Park, N.C. APTD-0576. March, 1972.

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7. Annual Book of ASTM Standards. Part 31; Water, Atmospheric Analysis. pp. 40-42. American Society for Testing and Materials. Philadelphia, Pa. 1974.

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(Secs. 111, 114, 301(a), Clean Air Act, sec. 4(a) of Pub. L. 91-604, 84 Stat. 1683; sec. 4(a) of Pub. L. 91-604, 84 Stat. 1687; sec. 2 of Pub. L. 90-148, 81 Stat. 504 [42 U.S.C. 1857c-6, 1857c-9, 1857g(a)].)

[FR Doc.77-13608 Filed 8-17-77;8:45 am]

Method 9

VISUAL DETERMINATION OF THE OPACITY OF EMISSIONS FROM STATIONARY SOURCES

(40 CFR 60, Appendix A, July 1, 1976)

Many stationary sources discharge visible emissions into the atmosphere; these emissions are usually in the shape of a plume. This method involves the determination of plume opacity by qualified observers. The method includes procedures for the training and certification of observers, and procedures to be used in the field for determination of plume opacity. The appearance of a plume as viewed by an observer depends upon a number of variables, some of which may be controllable and some of which may not be controllable in the field. Variables which can be controlled to an extent to which they no longer exert a significant influence upon plume appearance include: Angle of the observer with respect to the plume; angle of the observer with respect to the sun; point of observation of attached and detached steam plume; and angle of the observer with respect to a plume emitted from a rectangular stack with a large length to width ratio. The method includes specific criteria applicable to these variables.

Other variables which may not be controllable in the field are luminescence and color contrast between the plume and the background against which the plume is viewed. These variables exert an influence upon the appearance of a plume as viewed by an observer, and can affect the ability of the observer to accurately assign opacity values to the observed plume. Studies of the theory of plume opacity and field studies have demonstrated that a plume is most visible and presents the greatest apparent opacity when viewed against a contrasting background. It follows from this, and is confirmed by field trials, that the opacity of a plume, viewed under conditions where a contrasting background is present can be assigned with the greatest degree of accuracy. However, the potential for a positive error is also the greatest when a plume is viewed under such contrasting conditions. Under conditions presenting a less contrasting background, the apparent opacity of a plume is less and approaches zero as the color and luminescence contrast decrease toward zero. As a result, significant negative bias and negative errors can be made when a plume is viewed under less contrasting conditions. A negative bias decreases rather than increases the possibility that a plant operator will be cited for a violation of opacity standards due to observer error.

Studies have been undertaken to determine the magnitude of positive errors which can be made by qualified observers while reading plumes under contrasting conditions and using the procedures set forth in this method. The results of these studies (field trials) which involve a total of 769 sets of 25 readings each are as follows:

(1) For black plumes (133 sets at a smoke generator), 100 percent of the sets were read with a positive error[1] of less than 7.5 percent opacity; 99 percent were read with a positive error of less than 5 percent opacity.

(2) For white plumes (170 sets at a smoke generator, 168 sets at a coal-fired power plant, 298 sets at a sulfuric acid plant), 99 percent of the sets were read with a positive error of less than 7.5 percent opacity; 95 percent were read with a positive error of less than 5 percent opacity.

The positive observational error associated with an average of twenty-five readings is therefore established. The accuracy of the method must be taken into account when determining possible violations of applicable opacity standards.

1. *Principle and applicability.*

1.1 Principle. The opacity of emissions from stationary sources is determined visually by a qualified observer.

1.2 Applicability. This method is applicable for the determination of the opacity of emissions from stationary sources pursuant to § 60.11(b) and for qualifying observers for visually determining opacity of emissions.

2. *Procedures.* The observer qualified in accordance with paragraph 3 of this method shall use the following procedures for visually determining the opacity of emissions:

2.1 Position. The qualified observer shall stand at a distance sufficient to provide a clear view of the emissions with the sun oriented in the 140° sector to his back. Consistent with maintaining the above requirement, the observer shall, as much as possible, make his observations from a position such that his line of vision is approximately perpendicular to the plume direction, and when observing opacity of emissions from rectangular outlets (e.g. roof monitors, open baghouses, noncircular stacks), approximately perpendicular to the longer axis of the outlet. The observer's line of sight should not include more than one plume at a time when multiple stacks are involved, and in any case the observer should make his observations with his line of sight perpendicular to the longer axis of such a set of multiple stacks (e.g. stub stacks on baghouses).

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[1] For a set, positive error=average opacity determined by observers' 25 observations—average opacity determined from transmissometer's 25 recordings.

2.2 Field records. The observer shall record the name of the plant, emission location, type facility, observer's name and affiliation, and the date on a field data sheet (Figure 9-1). The time, estimated distance to the emission location, approximate wind direction, estimated wind speed, description of the sky condition (presence and color of clouds), and plume background are recorded on a field data sheet at the time opacity readings are initiated and completed.

2.3 Observations. Opacity observations shall be made at the point of greatest opacity in that portion of the plume where condensed water vapor is not present. The observer shall not look continuously at the plume, but instead shall observe the plume momentarily at 15-second intervals.

2.3.1 Attached steam plumes. When condensed water vapor is present within the plume as it emerges from the emission outlet, opacity observations shall be made beyond the point in the plume at which condensed water vapor is no longer visible. The observer shall record the approximate distance from the emission outlet to the point in the plume at which the observations are made.

2.3.2 Detached steam plume. When water vapor in the plume condenses and becomes visible at a distinct distance from the emission outlet, the opacity of emissions should be evaluated at the emission outlet prior to the condensation of water vapor and the formation of the steam plume.

2.4 Recording observations. Opacity observations shall be recorded to the nearest 5 percent at 15-second intervals on an observational record sheet. (See Figure 9-2 for an example.) A minimum of 24 observations shall be recorded. Each momentary observation recorded shall be deemed to represent the average opacity of emissions for a 15-second period.

2.5 Data Reduction. Opacity shall be determined as an average of 24 consecutive observations recorded at 15-second intervals. Divide the observations recorded on the record sheet into sets of 24 consecutive observations. A set is composed of any 24 consecutive observations. Sets need not be consecutive in time and in no case shall two sets overlap. For each set of 24 observations, calculate the average by summing the opacity of the 24 observations and dividing this sum by 24. If an applicable standard specifies an averaging time requiring more than 24 observations, calculate the average for all observations made during the specified time period. Record the average opacity on a record sheet. (See Figure 9-1 for an example.)

3. *Qualifications and testing.*

3.1 Certification requirements. To receive certification as a qualified observer, a candidate must be tested and demonstrate the ability to assign opacity readings in 5 percent increments to 25 different black plumes and 25 different white plumes, with an error not to exceed 15 percent opacity on any one reading and an average error not to exceed 7.5 percent opacity in each category. Candidates shall be tested according to the procedures described in paragraph 3.2. Smoke generators used pursuant to paragraph 3.2 shall be equipped with a smoke meter which meets the requirements of paragraph 3.3.

The certification shall be valid for a period of 6 months, at which time the qualification procedure must be repeated by any observer in order to retain certification.

3.2 Certification procedure. The certification test consists of showing the candidate a complete run of 50 plumes—25 black plumes and 25 white plumes—generated by a smoke generator. Plumes within each set of 25 black and 25 white runs shall be presented in random order. The candidate assigns an opacity value to each plume and records his observation on a suitable form. At the completion of each run of 50 readings, the score of the candidate is determined. If a candidate fails to qualify, the complete run of 50 readings must be repeated in any retest. The smoke test may be administered as part of a smoke school or training program, and may be preceded by training or familiarization runs of the smoke generator during which candidates are shown black and white plumes of known opacity.

3.3 Smoke generator specifications. Any smoke generator used for the purposes of paragraph 3.2 shall be equipped with a smoke meter installed to measure opacity across the diameter of the smoke generator stack. The smoke meter output shall display in-stack opacity based upon a pathlength equal to the stack exit diameter, on a full 0 to 100 percent chart recorder scale. The smoke meter optical design and performance shall meet the specifications shown in Table 9-1. The smoke meter shall be calibrated as prescribed in paragraph 3.3.1 prior to the conduct of each smoke reading test. At the completion of each test, the zero and span drift shall be checked and if the drift exceeds ±1 percent opacity, the condition shall be corrected prior to conducting any subsequent test runs. The smoke meter shall be demonstrated, at the time of installation, to meet the specifications listed in Table 9-1. This demonstration shall be repeated following any subsequent repair or replacement of the photocell or associated electronic circuitry including the chart recorder or output meter, or every 6 months, whichever occurs first.

Parameter:	*Specification*
a. Light source	Incandescent lamp operated at nominal rated voltage.
b. Spectral response of photocell.	Photopic (daylight spectral response of the human eye—reference 4.3).
c. Angle of view	15° maximum total angle.
d. Angle of projection.	15° maximum total angle.
e. Calibration error.	±3% opacity, maximum.
f. Zero and span drift.	±1% opacity, 30 minutes.
g. Response time	≤5 seconds.

Method 9, Continued

FIGURE 9-1

RECORD OF VISUAL DETERMINATION OF OPACITY

PAGE____of____

COMPANY____________

LOCATION____________

TEST NUMBER____________

DATE ____________

TYPE FACILITY____________

CONTROL DEVICE____________

HOURS OF OBSERVATION____________

OBSERVER____________

OBSERVER CERTIFICATION DATE____________

OBSERVER AFFILIATION____________

POINT OF EMISSIONS____________

HEIGHT OF DISCHARGE POINT____________

	Initial			Final
CLOCK TIME				
OBSERVER LOCATION Distance to Discharge				
Direction from Discharge				
Height of Observation Point				
BACKGROUND DESCRIPTION				
WEATHER CONDITIONS Wind Direction				
Wind Speed				
Ambient Temperature				
SKY CONDITIONS (clear, overcast, % clouds, etc.)				
PLUME DESCRIPTION Color				
Distance Visible				
OTHER INFORMATION				

SUMMARY OF AVERAGE OPACITY

Set Number	Time	Opacity	
	Start--End	Sum	Average

Readings ranged from ____ to ____ % opacity

The source was/was not in compliance with ____ at the time evaluation was made.

Method 9, Continued

3.3.1 Calibration. The smoke meter is calibrated after allowing a minimum of 30 minutes warmup by alternately producing simulated opacity of 0 percent and 100 percent. When stable response at 0 percent or 100 percent is noted, the smoke meter is adjusted to produce an output of 0 percent or 100 percent, as appropriate. This calibration shall be repeated until stable 0 percent and

3.3.2 Smoke meter evaluation. The smoke meter design and performance are to be evaluated as follows:

3.3.2.1 Light source. Verify from manufacturer's data and from voltage measurements made at the lamp, as installed, that the lamp is operated within ±5 percent of the nominal rated voltage.

100 percent readings are produced without adjustment. Simulated 0 percent and 100 percent opacity values may be produced by alternately switching the power to the light source on and off while the smoke generator is not producing smoke.

3.3.2.2 Spectral response of photocell. Verify from manufacturer's data that the photocell has a photopic response; i.e., the spectral sensitivity of the cell shall closely approximate the standard spectral-luminosity curve for photopic vision which is referenced in (b) of Table 9-1.

3.3.2.3 Angle of view. Check construction geometry to ensure that the total angle of view of the smoke plume, as seen by the photocell, does not exceed 15°. The total angle of view may be calculated from: $\theta=2\tan^{-1} d/2L$, where θ=total angle of view; d=the sum of the photocell diameter+the diameter of the limiting aperture; and L=the distance from the photocell to the limiting aperture. The limiting aperture is the point in the path between the photocell and the smoke plume where the angle of view is most restricted. In smoke generator smoke meters this is normally an orifice plate.

3.3.2.4 Angle of projection. Check construction geometry to ensure that the total angle of projection of the lamp on the

FIGURE 9-2 OBSERVATION RECORD PAGE ___ OF ___

COMPANY ________________

LOCATION ________________

TEST NUMBER ________________

DATE ________________

OBSERVER ________________

TYPE FACILITY ________________

POINT OF EMISSIONS ________________

Hr.	Min.	Seconds				STEAM PLUME (check if applicable)		COMMENTS
		0	15	30	45	Attached	Detached	
	0							
	1							
	2							
	3							
	4							
	5							
	6							
	7							
	8							
	9							
	10							
	11							
	12							
	13							
	14							
	15							
	16							
	17							
	18							
	19							
	20							
	21							
	22							
	23							
	24							
	25							
	26							
	27							
	28							
	29							

Method 9, Continued

smoke plume does not exceed 15°. The total angle of projection may be calculated from: $\theta=2\tan^{-1} d/2L$, where θ= total angle of projection; d= the sum of the length of the lamp filament + the diameter of the limiting aperture; and L= the distance from the lamp to the limiting aperture.

3.3.2.5 Calibration error. Using neutral-density filters of known opacity, check the error between the actual response and the theoretical linear response of the smoke meter. This check is accomplished by first calibrating the smoke meter according to 3.3.1 and then inserting a series of three neutral-density filters of nominal opacity of 20, 50, and 75 percent in the smoke meter pathlength. Filters calibarted within ±2 percent shall be used. Care should be taken when inserting the filters to prevent stray light from affecting the meter. Make a total of five nonconsecutive readings for each filter. The maximum error on any one reading shall be 3 percent opacity.

3.3.2.6 Zero and span drift. Determine the zero and span drift by calibrating and operating the smoke generator in a normal manner over a 1-hour period. The drift is measured by checking the zero and span at the end of this period.

3.3.2.7 Response time. Determine the response time by producng the series of five simulated 0 percent and 100 percent opacity values and observing the time required to reach stable response. Opacity values of 0 percent and 100 percent may be simulated by alternately switching the power to the light source off and on while the smoke generator is not operating.

4. *References.*

4.1 Air Pollution Control District Rules and Regulations, Los Angeles County Air Pollution Control District, Regulation IV, Prohibitions, Rule 50.

4.2 Weisburd, Melvin I., Field Operations and Enforcement Manual for Air, U.S. Environmental Protection Agency, Research Triangle Park, N.C., APTD-1100, August 1972, pp. 4.1-4.36.

4.3 Condon, E. U., and Odishaw, H., Handbook of Physics, McGraw-Hill Co., N.Y., N.Y., 1958, Table 3.1, p. 6-52.

FIGURE 9-2 OBSERVATION RECORD PAGE ___ OF ___
(Continued)

COMPANY ____________________

LOCATION ____________________

TEST NUMBER ____________________

DATE ____________________

OBSERVER ____________________

TYPE FACILITY ____________________

POINT OF EMISSIONS ____________________

Hr.	Min.	Seconds				STEAM PLUME (check if applicable)		COMMENTS
		0	15	30	45	Attached	Detached	
	30							
	31							
	32							
	33							
	34							
	35							
	36							
	37							
	38							
	39							
	40							
	41							
	42							
	43							
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	45							
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Method 10

DETERMINATION OF CARBON MONOXIDE EMISSIONS FROM STATIONARY SOURCES

(40 CFR 60, Appendix A, July 1, 1976)

1. *Principle and Applicability*

1.1 *Principle.* An integrated or continuous gas sample is extracted from a sampling point and analyzed for carbon monoxide (CO) content using a Luft-type nondispersive infrared analyzer (NDIR) or equivalent.

1.2 *Applicability.* This method is applicable for the determination of carbon monoxide emissions from stationary sources only when specified by the test procedures for determining compliance with new source performance standards. The test procedure will indicate whether a continuous or an integrated sample is to be used.

2. *Range and sensitivity.*

2.1 *Range.* 0 to 1,000 ppm.

2.2 *Sensitivity.* Minimum detectable concentration is 20 ppm for a 0 to 1,000 ppm span.

3. *Interferences.* Any substance having a strong absorption of infrared energy will interfere to some extent. For example, discrimination ratios for water (H_2O) and carbon dioxide (CO_2) are 3.5 percent H_2O per 7 ppm CO and 10 percent CO_2 per 10 ppm CO, respectively, for devices measuring in the 1,500 to 3,000 ppm range. For devices measuring in the 0 to 100 ppm range, interference ratios can be as high as 3.5 percent H_2O per 25 ppm CO and 10 percent CO_2 per 50 ppm CO. The use of silica gel and ascarite traps will alleviate the major interference problems. The measured gas volume must be corrected if these traps are used.

4. *Precision and accuracy.*

4.1 *Precision.* The precision of most NDIR analyzers is approximately ±2 percent of span.

4.2 *Accuracy.* The accuracy of most NDIR analyzers is approximately ±5 percent of span after calibration.

5. *Apparatus.*

5.1 *Continuous sample* (Figure 10-1).

5.1.1 *Probe.* Stainless steel or sheathed Pyrex[1] glass, equipped with a filter to remove particulate matter.

5.1.2 *Air-cooled condenser or equivalent.* To remove any excess moisture.

5.2 *Integrated sample* (Figure 10-2).

5.2.1 *Probe.* Stainless steel or sheathed Pyrex glass, equipped with a filter to remove particulate matter.

5.2.2 *Air-cooled condenser or equivalent.* To remove any excess moisture.

5.2.3 *Valve.* Needle valve, or equivalent, to adjust flow rate.

5.2.4 *Pump.* Leak-free diaphragm type, or equivalent, to transport gas.

5.2.5 *Rate meter.* Rotameter, or equivalent, to measure a flow range from 0 to 1.0 liter per min. (0.035 cfm).

5.2.6 *Flexible bag.* Tedlar, or equivalent, with a capacity of 60 to 90 liters (2 to 3 ft³). Leak-test the bag in the laboratory before using by evacuating bag with a pump followed by a dry gas meter. When evacuation is complete, there should be no flow through the meter.

5.2.7 *Pitot tube.* Type S, or equivalent, attached to the probe so that the sampling rate can be regulated proportional to the stack gas velocity when velocity is varying with the time or a sample traverse is conducted.

5.3 *Analysis* (Figure 10-3).

5.3.1 *Carbon monoxide analyzer.* Nondispersive infrared spectrometer, or equivalent. This instrument should be demonstrated, preferably by the manufacturer, to meet or exceed manufacturer's specifications and those described in this method.

5.3.2 *Drying tube.* To contain approximately 200 g of silica gel.

5.3.3 *Calibration gas.* Refer to paragraph 6.1.

5.3.4 *Filter.* As recommended by NDIR manufacturer.

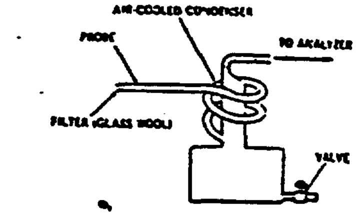

Figure 10-1. Continuous sampling train.

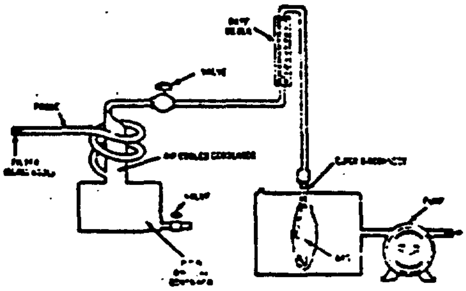

Figure 10-2. Integrated gas-sampling train.

5.3.5 *CO_2 removal tube.* To contain approximately 500 g of ascarite.

5.3.6 *Ice water bath.* For ascarite and silica gel tubes.

5.3.7 *Valve.* Needle valve, or equivalent, to adjust flow rate

5.3.8 *Rate meter.* Rotameter or equivalent to measure gas flow rate of 0 to 1.0 liter per min. (0.035 cfm) through NDIR.

5.3.9 *Recorder (optional).* To provide permanent record of NDIR readings.

6. *Reagents.*

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[1] Mention of trade names or specific products does not constitute endorsement by the Environmental Protection Agency.

Method 10, Continued

6.1 *Calibration gases.* Known concentration of CO in nitrogen (N_2) for instrument span, prepurified grade of N_2 for zero, and two additional concentrations corresponding approximately to 60 percent and 30 percent span. The span concentration shall not exceed 1.5 times the applicable source performance standard. The calibration gases shall be certified by the manufacturer to be within ±2 percent of the specified concentration.

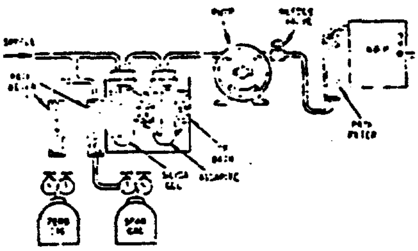

Figure 10-3. Analytical equipment.

6.2 *Silica gel.* Indicating type, 6 to 16 mesh, dried at 175° C (347° F) for 2 hours.

6.3 *Ascarite.* Commercially available.

7. *Procedure.*

7.1 *Sampling.*

7.1.1 *Continuous sampling.* Set up the equipment as shown in Figure 10-1 making sure all connections are leak free. Place the probe in the stack at a sampling point and purge the sampling line. Connect the analyzer and begin drawing sample into the analyzer. Allow 5 minutes for the system to stabilize, then record the analyzer reading as required by the test procedure. (See § 7.2 and 8). CO_2 content of the gas may be determined by using the Method 3 integrated sample procedure (36 FR 24886), or by weighing the ascarite CO_2 removal tube and computing CO_2 concentration from the gas volume sampled and the weight gain of the tube.

7.1.2 *Integrated sampling.* Evacuate the flexible bag. Set up the equipment as shown in Figure 10-2 with the bag disconnected. Place the probe in the stack and purge the sampling line. Connect the bag, making sure that all connections are leak free. Sample at a rate proportional to the stack velocity. CO_2 content of the gas may be determined by using the Method 3 integrated sample procedures (36 FR 24886), or by weighing the ascarite CO_2 removal tube and computing CO_2 concentration from the gas volume sampled and the weight gain of the tube.

7.2 *CO Analysis.* Assemble the apparatus as shown in Figure 10-3, calibrate the instrument, and perform other required operations as described in paragraph 8. Purge analyzer with N_2 prior to introduction of each sample. Direct the sample stream through the instrument for the test period, recording the readings. Check the zero and span again after the test to assure that any drift or malfunction is detected. Record the sample data on Table 10-1.

8. *Calibration.* Assemble the apparatus according to Figure 10-3. Generally an instrument requires a warm-up period before stability is obtained. Follow the manufacturer's instructions for specific procedure. Allow a minimum time of one hour for warm-up. During this time check the sample conditioning apparatus, i.e., filter, condenser, drying tube, and CO_2 removal tube, to ensure that each component is in good operating condition. Zero and calibrate the instrument according to the manufacturer's procedures using, respectively, nitrogen and the calibration gases.

TABLE 10-1.—*Field data*

Location .... Comments:
Test ....
Date ....
Operator ....

Clock time	*Rotameter setting, liters per minute (cubic feet per minute)*

9. *Calculation—Concentration of carbon monoxide.* Calculate the concentration of carbon monoxide in the stack using equation 10-1.

$$C_{CO_{stack}} = C_{CO_{NDIR}}(1 - F_{CO_2}) \qquad \text{equation 10-1}$$

where:

$C_{CO_{stack}}$ = concentration of CO in stack, ppm by volume (dry basis).

$C_{CO_{NDIR}}$ = concentration of CO measured by NDIR analyzer, ppm by volume (dry basis).

F_{CO_2} = volume fraction of CO_2 in sample, i.e., percent CO_2 from Orsat analysis divided by 100.

10. *Bibliography.*

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10.2 Jacobs, M. B., et al., Continuous Determination of Carbon Monoxide and Hydrocarbons in Air by a Modified Infrared Analyzer, J. Air Pollution Control Association, 9(2):110–114, August 1959.

10.3 MSA LIRA Infrared Gas and Liquid Analyzer Instruction Book, Mine Safety Appliances Co., Technical Products Division, Pittsburgh, Pa.

10.4 Models 215A, 315A, and 415A Infrared Analyzers, Beckman Instruments, Inc., Beckman Instructions 1635-B, Fullerton, Calif., October 1967.

10.5 Continuous CO Monitoring System, Model A5611, Intertech Corp., Princeton, N.J.

10.6 UNOR Infrared Gas Analyzers, Bendix Corp., Ronceverte, West Virginia.

ADDENDA

A. Performance Specifications for NDIR Carbon Monoxide Analyzers.

Range (minimum)	0–1000ppm.
Output (minimum)	0–10mV.
Minimum detectable sensitivity	20 ppm.
Rise time, 90 percent (maximum)	30 seconds.
Fall time, 90 percent (maximum)	30 seconds.
Zero drift (maximum)	10% in 8 hours.
Span drift (maximum)	10% in 8 hours.
Precision (minimum)	± 2% of full scale.
Noise (maximum)	± 1% of full scale.
Linearity (maximum deviation)	2% of full scale.
Interference rejection ratio	CO_2—1000 to 1, H_2O—500 to 1.

B. *Definitions of Performance Specifications.*

Range—The minimum and maximum measurement limits.

Output—Electrical signal which is proportional to the measurement; intended for connection to readout or data processing devices. Usually expressed as millivolts or milliamps full scale at a given impedance.

Full scale—The maximum measuring limit for a given range.

Minimum detectable sensitivity—The smallest amount of input concentration that can be detected as the concentration approaches zero.

Accuracy—The degree of agreement between a measured value and the true value; usually expressed as ± percent of full scale.

Time to 90 percent response—The time interval from a step change in the input concentration at the instrument inlet to a reading of 90 percent of the ultimate recorded concentration.

Rise Time (90 percent)—The interval between initial response time and time to 90 percent response after a step increase in the inlet concentration.

Fall Time (90 percent)—The interval between initial response time and time to 90 percent response after a step decrease in the inlet concentration.

Zero Drift—The change in instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation when the input concentration is zero; usually expressed as percent full scale.

Span Drift—The change in instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation when the input concentration is a stated upscale value; usually expressed as percent full scale.

Precision—The degree of agreement between repeated measurements of the same concentration, expressed as the average deviation of the single results from the mean.

Noise—Spontaneous deviations from a mean output not caused by input concentration changes.

Linearity—The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between upper and lower calibration points.

Method 11

DETERMINATION OF HYDROGEN SULFIDE EMISSIONS FROM STATIONARY SOURCES

(43 FR, 1495, January 10, 1978)

1. *Principle and applicability.* 1.1 *Principle.* Hydrogen sulfide (H_2S) is collected from a source in a series of midget impingers and absorbed in pH 3.0 cadmium sulfate ($CdSO_4$) solution to form cadmium sulfide (CdS). The latter compound is then measured iodometrically. An impinger containing hydrogen peroxide is included to remove SO_2 as an interfering species. This method is a revision of the H_2S method originally published in the FEDERAL REGISTER, Volume 39, No. 47, dated Friday, March 8, 1974.

1.2 *Applicability.* This method is applicable for the determination of the hydrogen sulfide content of fuel gas streams at petroleum refineries.

2. *Range and sensitivity.* The lower limit of detection is approximately 8 mg/m^3 (6 ppm). The maximum of the range is 740 mg/m^3 (520 ppm).

3. *Interferences.* Any compound that reduces iodine or oxidizes iodide ion will interfere in this procedure, provide it is collected in the cadmium sulfate impingers. Sulfur dioxide in concentrations of up to 2,600 mg/m^3 is eliminated by the hydrogen peroxide solution. Thiols precipitate with hydrogen sulfide. In the absence of H_2S, only co-traces of thiols are collected. When methane- and ethane-thiols at a total level of 300 mg/m^3 are present in addition to H_2S, the results vary from 2 percent low at an H_2S concentration of 400 mg/m^3 to 14 percent high at an H_2S concentration of 100 mg/m^3. Carbon oxysulfide at a concentration of 20 percent does not interfere. Certain carbonyl-containing compounds react with iodine and produce recurring end points. However, acetaldehyde and acetone at concentrations of 1 and 3 percent, respectively, do not interfere.

Entrained hydrogen peroxide produces a negative interference equivalent to 100 percent of that of an equimolar quantity of hydrogen sulfide. Avoid the ejection of hydrogen peroxide into the cadmium sulfate impingers.

4. *Precision and accuracy.* Collaborative testing has shown the within-laboratory coefficient of variation to be 2.2 percent and the overall coefficient of variation to be 5 percent. The method bias was shown to be −4.8 percent when only H_2S was present. In the presence of the interferences cited in section 3, the bias was positive at low H_2S concentrations and negative at higher concentrations. At 230 mg H_2S/m^3, the level of the compliance standard, the bias was +2.7 percent. Thiols had no effect on the precision.

5. *Apparatus.*

5.1 Sampling apparatus.

5.1.1 Sampling line. Six to 7 mm (¼ in.) Teflon[1] tubing to connect the sampling train to the sampling valve.

5.1.2 Impingers. Five midget impingers, each with 30 ml capacity. The internal diameter of the impinger tip must be 1 mm ±0.05 mm. The impinger tip must be positioned 4 to 6 mm from the bottom of the impinger.

5.1.3 Glass or Teflon connecting tubing for the impingers.

5.1.4 Ice bath container. To maintain absorbing solution at a low temperature.

5.1.5 Drying tube. Tube packed with 6- to 16-mesh indicating-type silica gel, or equivalent, to dry the gas sample and protect the meter and pump. If the silica gel has been used previously, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to approval of the Administrator.

NOTE.—Do not use more than 30 g of silica gel. Silica gel absorbs gases such as propane from the fuel gas stream, and use of excessive amounts of silica gel could result in errors in the determination of sample volume.

5.1.6 Sampling valve. Needle valve or equivalent to adjust gas flow rate. Stainless steel or other corrosion-resistant material.

5.1.7 Volume meter. Dry gas meter, sufficiently accurate to measure the sample volume within 2 percent, calibrated at the selected flow rate ($\sim$1.0 liter/min) and conditions actually encountered during sampling. The meter shall be equipped with a temperature gauge (dial thermometer or equivalent) capable of measuring temperature to within 3° C (5.4° F). The gas meter should have a petcock, or equivalent, on the outlet connector which can be closed during the leak check. Gas volume for one revolution of the meter must not be more than 10 liters.

5.1.8 Flow meter. Rotameter or equivalent, to measure flow rates in the range from 0.5 to 2 liters/min (1 to 4 cfh).

5.1.9 Graduated cylinder, 25 ml size.

5.1.10 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby National Weather Service station, in which case, the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice-versa for elevation decrease.

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[1] Mention of trade names of specific products does not constitute endorsement by the Environmental Protection Agency.

Method 11, Continued

5.1.11 U-tube manometer. 0-30 cm water column. For leak check procedure.

5.1.12 Rubber squeeze bulb. To pressurize train for leak check.

5.1.13 Tee, pinchclamp, and connecting tubing. For leak check.

5.1.14 Pump. Diaphragm pump, or equivalent. Insert a small surge tank between the pump and rate meter to eliminate the pulsation effect of the diaphragm pump on the rotameter. The pump is used for the air purge at the end of the sample run; the pump is not ordinarily used during sampling, because fuel gas streams are usually sufficiently pressurized to force sample gas through the train at the required flow rate. The pump need not be leak-free unless it is used for sampling.

5.1.15 Needle valve or critical orifice. To set air purge flow to 1 liter/min.

5.1.16 Tube packed with active carbon. To filter air during purge.

5.1.17 Volumetric flask. One 1,000 ml.

5.1.18 Volumetric pipette. One 15 ml.

5.1.19 Pressure-reduction regulator. Depending on the sampling stream pressure, a pressure-reduction regulator may be needed to reduce the pressure of the gas stream entering the Teflon sample line to a safe level.

5.1.20 Cold trap. If condensed water or amine is present in the sample stream, a corrosion-resistant cold trap shall be used immediately after the sample tap. The trap shall not be operated below 0° C (32° F) to avoid condensation of C_3 or C_4 hydrocarbons.

5.2 Sample recovery.

5.2.1 Sample container. Iodine flask, glass-stoppered: 500 ml size.

5.2.2 Pipette. 50 ml volumetric type.

5.2.3 Graduated cylinders. One each 25 and 250 ml.

5.2.4 Flasks. 125 ml. Erlenmeyer.

5.2.5 Wash bottle.

5.2.6 Volumetric flasks. Three 1,000 ml.

5.3 Analysis.

5.3.1 Flask. 500 ml glass-stoppered iodine flask.

5.3.2 Burette. 50 ml.

5.3.3 Flask. 125 ml. Erlenmeyer.

5.3.4 Pipettes, volumetric. One 25 ml; two each 50 and 100 ml.

5.3.5 Volumetric flasks. One 1,000 ml; two 500 ml.

5.3.6 Graduated cylinders. One each 10 and 100 ml.

6. *Reagents.* Unless otherwise indicated, it is intended that all reagents conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Otherwise, use best available grade.

6.1 Sampling.

6.1.1 Cadmium sulfate absorbing solution. Dissolve 41 g of $3CdSO_4 \cdot 8H_2O$ and 15 ml of 0.1 M sulfuric acid in a 1-liter volumetric flask that contains approximately ¾ liter of deionized distilled water. Dilute to volume with deionized water. Mix thoroughly. pH should be 3±0.1. Add 10 drops of Dow-Corning Antifoam B. Shake well before use. If Antifoam B is not used, the alternate acidified iodine extraction procedure (section 7.2.2) must be used.

6.1.2 Hydrogen peroxide, 3 percent. Dilute 30 percent hydrogen peroxide to 3 percent as needed. Prepare fresh daily.

6.1.3 Water. Deionized, distilled to conform to ASTM specifications D1193 72, Type 3. At the option of the analyst, the $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

6.2 Sample recovery.

6.2.1 Hydrochloric acid solution (HCl), 3M. Add 240 ml of concentrated HCl (specific gravity 1.19) to 500 ml of deionized, distilled water in a 1-liter volumetric flask. Dilute to 1 liter with deionized water. Mix thoroughly.

6.2.2 Iodine solution 0.1 N. Dissolve 24 g of potassium iodide (KI) in 30 ml of deionized, distilled water. Add 12.7 g of resublimed iodine (I_2) to the potassium iodide solution. Shake the mixture until the iodine is completely dissolved. If possible, let the solution stand overnight in the dark. Slowly dilute the solution to 1 liter with deionized, distilled water, with swirling. Filter the solution if it is cloudy. Store solution in a brown-glass reagent bottle.

6.2.3 Standard iodine solution, 0.01 N. Pipette 100.0 ml of the 0.1 N iodine solution into a 1-liter volumetric flask and dilute to volume with deionized, distilled water. Standardize daily as in section 8.1.1. This solution must be protected from light. Reagent bottles and flasks must be kept tightly stoppered.

6.3 Analysis.

6.3.1 Sodium thiosulfate solution, standard 0.1 N. Dissolve 24.8 g of sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$) or 15.8 g of anhydrous sodium thiosulfate ($Na_2S_2O_3$) in 1 liter of deionized, distilled water and add 0.01 g of anhydrous sodium carbonate (Na_2CO_3) and 0.4 ml of chloroform ($CHCl_3$) to stabilize. Mix thoroughly by shaking or by aerating with nitrogen for approximately 15 minutes and store in a glass-stoppered, reagent bottle. Standardize as in section 8.1.2.

6.3.2 Sodium thiosulfate solution, standard 0.01 N. Pipette 50.0 ml of the standard 0.1 N thiosulfate solution into a volumetric flask and dilute to 500 ml with distilled water.

NOTE.—A 0.01 N phenylarsine oxide solution may be prepared instead of 0.01 N thiosulfate (see section 6.3.3).

6.3.3 Phenylarsine oxide solution, standard 0.01 N. Dissolve 1.80 g of phenylarsine oxide (C_6H_5AsD) in 150 ml of 0.3 N sodium hydroxide. After settling, decant 140 ml of this solution into 800 ml of distilled water. Bring the solution to pH 6-7 with 6N hydrochloric acid and dilute to 1 liter. Standardize as in section 6.1.3.

• • •

6.3.4 Starch indicator solution. Suspend 10 g of soluble starch in 100 ml of deionized, distilled water and add 15 g of potassium hydroxide (KOH) pellets. Stir until dissolved, dilute with 900 ml of deionized distilled water and let stand for 1 hour. Neutralize the alkali with concentrated hydrochloric acid, using an indicator paper similar to Alkacid test ribbon, then add 2 ml of glacial acetic acid as a preservative.

NOTE.—Test starch indicator solution for decomposition by titrating, with 0.01 N iodine solution, 4 ml of starch solution in 200 ml of distilled water that contains 1 g potassium iodide. If more than 4 drops of the 0.01 N iodine solution are required to obtain the blue color, a fresh solution must be prepared.

7. *Procedure.*

7.1 Sampling.

7.1.1 Assemble the sampling train as shown in figure 11-1, connecting the five midget impingers in series. Place 15 ml of 3 percent hydrogen peroxide solution in the first impinger. Leave the second impinger empty. Place 15 ml of the cadmium sulfate absorbing solution in the third, fourth, and fifth impingers. Place the impinger assembly in an ice bath container and place crushed ice around the impingers. Add more ice during the run, if needed.

7.1.2 Connect the rubber bulb and manometer to first impinger, as shown in figure 11-1. Close the petcock on the dry gas meter outlet. Pressurize the train to 25-cm water pressure with the bulb and close off tubing connected to rubber bulb. The train must

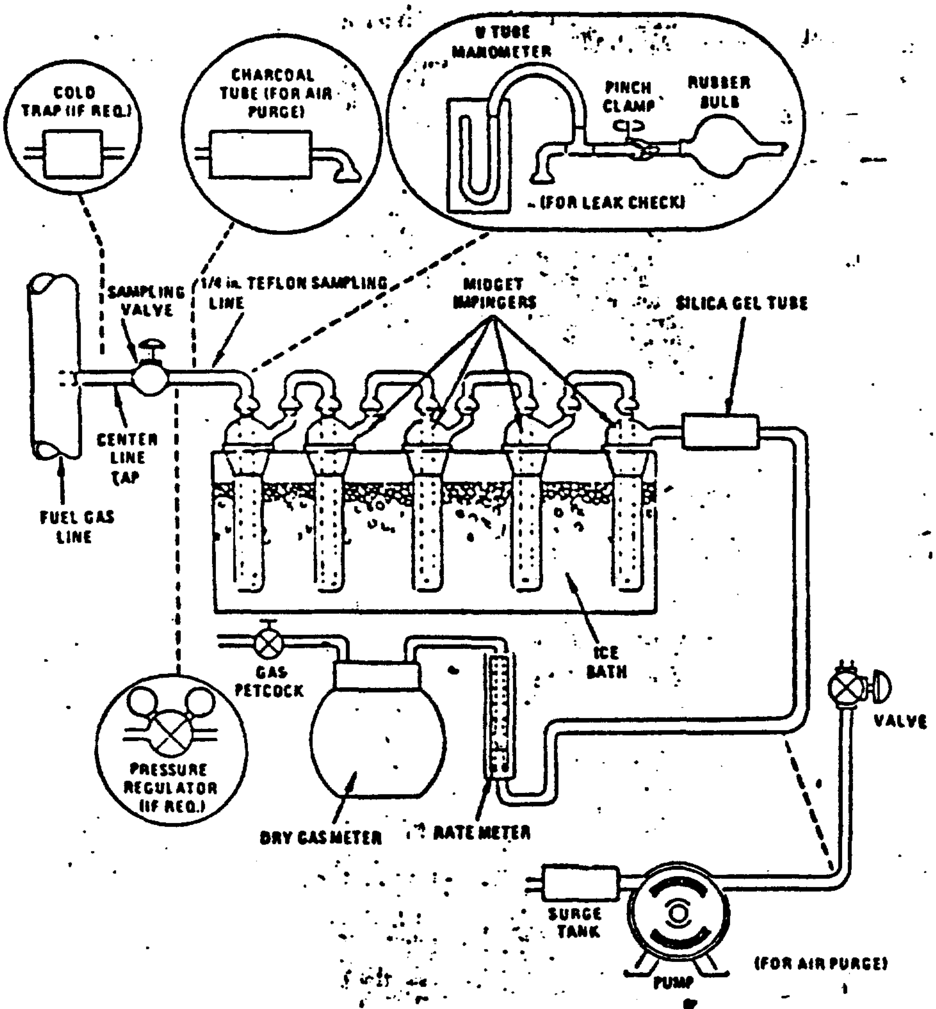

Figure 11-1. H_2S sampling train.

hold a 25-cm water pressure with not more than a 1-cm drop in pressure in a 1-minute interval. Stopcock grease is acceptable for sealing ground glass joints.

NOTE.—This leak check procedure is optional at the beginning of the sample run, but is mandatory at the conclusion. Note also that if the pump is used for sampling, it is recommended (but not required) that the pump be leak-checked separately, using a method consistent with the leak-check procedure for diaphragm pumps outlined in section 4.1.2 of reference method 6, 40 CFR Part 60, Appendix A.

7.1.3 Purge the connecting line between the sampling valve and first impinger, by disconnecting the line from the first impinger, opening the sampling valve, and allowing process gas to flow through the line for a minute or two. Then, close the sampling valve and reconnect the line to the impinger train. Open the petcock on the dry gas meter outlet. Record the initial dry gas meter reading.

7.1.4 Open the sampling valve and then adjust the valve to obtain a rate of approximately 1 liter/min. Maintain a constant (±10 percent) flow rate during the test. Record the meter temperature.

7.1.5 Sample for at least 10 min. At the end of the sampling time, close the sampling valve and record the final volume and temperature readings. Conduct a leak check as described in Section 7.1.2 above.

7.1.6 Disconnect the impinger train from the sampling line. Connect the charcoal tube and the pump, as shown in figure 11-1. Purge the train (at a rate of 1 liter/min) with clean ambient air for 15 minutes to ensure that all H_2S is removed from the hydrogen peroxide. For sample recovery, cap the open ends and remove the impinger train to a clean area that is away from sources of heat. The area should be well lighted, but not exposed to direct sunlight.

7.2 Sample recovery.

7.2.1 Discard the contents of the hydrogen peroxide impinger. Carefully rinse the contents of the third, fourth, and fifth impingers into a 500 ml iodine flask.

NOTE.—The impingers normally have only a thin film of cadmium sulfide remaining after a water rinse. If Antifoam B was not used or if significant quantities of yellow cadmium sulfide remain in the impingers, the alternate recovery procedure described below must be used.

7.2.2 Pipette exactly 50 ml of 0.01 N iodine solution into a 125 ml Erlenmeyer flask. Add 10 ml of 3 M HCl to the solution. Quantitatively rinse the acidified iodine into the iodine flask. Stopper the flask immediately and shake briefly.

7.2.2 (Alternate). Extract the remaining cadmium sulfide from the third, fourth, and fifth impingers using the acidified iodine solution. Immediately after pouring the acidified iodine into an impinger, stopper it and shake for a few moments, then transfer the liquid to the iodine flask. Do not transfer any rinse portion from one impinger to another; transfer it directly to the iodine flask. Once the acidified iodine solution has been poured into any glassware containing cadmium sulfide, the container must be tightly stoppered at all times except when adding more solution, and this must be done as quickly and carefully as possible. After adding any acidified iodine solution to the iodine flask, allow a few minutes for absorption of the H_2S before adding any further rinses. Repeat the iodine extraction until all cadmium sulfide is removed from the impingers. Extract that part of the connecting glassware that contains visible cadmium sulfide.

: : :

Quantitatively rinse all of the iodine from the impingers, connectors, and the beaker into the iodine flask using deionized, distilled water. Stopper the flask and shake briefly.

7.2.3 Allow the iodine flask to stand about 30 minutes in the dark for absorption of the H_2S into the iodine, then complete the titration analysis as in section 7.3.

NOTE.—Caution! Iodine evaporates from acidified iodine solutions. Samples to which acidified iodine have been added may not be stored, but must be analyzed in the time schedule stated in section 7.2.3.

7.2.4 Prepare a blank by adding 45 ml of cadmium sulfate absorbing solution to an iodine flask. Pipette exactly 50 ml of 0.01 N iodine solution into a 125-ml Erlenmeyer flask. Add 10 ml of 3 M HCl. Follow the same impinger extracting and quantitative rinsing procedure carried out in sample analysis. Stopper the flask, shake briefly, let stand 30 minutes in the dark, and titrate with the samples.

NOTE.—The blank must be handled by exactly the same procedure as that used for the samples.

7.3 Analysis.

NOTE.—Titration analyses should be conducted at the sample-cleanup area in order to prevent loss of iodine from the sample. Titration should never be made in direct sunlight.

7.3.1 Using 0.01 N sodium thiosulfate solution (or 0.01 N phenylarsine oxide, if applicable), rapidly titrate each sample in an iodine flask using gentle mixing, until solution is light yellow. Add 4 ml of starch indicator solution and continue titrating slowly until the blue color just disappears. Record V_{TT}, the volume of sodium thiosulfate solution used, or V_{AT}, the volume of phenylarsine oxide solution used (ml).

7.3.2 Titrate the blanks in the same manner as the samples. Run blanks each

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day until replicate values agree within 0.05 ml. Average the replicate titration values which agree within 0.05 ml.

8. *Calibration and standards.*

8.1 Standardizations.

8.1.1 Standardize the 0.01 N iodine solution daily as follows: Pipette 25 ml of the iodine solution into a 125 ml Erlenmeyer flask. Add 2 ml of 3 M HCl. Titrate rapidly with standard 0.01 N thiosulfate solution or with 0.01 N phenylarsine oxide until the solution is light yellow, using gentle mixing. Add four drops of starch indicator solution and continue titrating slowly until the blue color just disappears. Record V_T, the volume of thiosulfate solution used, or V_{As}, the volume of phenylarsine oxide solution used (ml). Repeat until replicate values agree within 0.05 ml. Average the replicate titration values which agree within 0.05 ml and calculate the exact normality of the iodine solution using equation 9.3. Repeat the standardization daily.

8.1.2 Standardize the 0.1 N thiosulfate solution as follows: Oven-dry potassium dichromate ($K_2Cr_2O_7$) at 180 to 200° C (360 to 390° F). Weigh to the nearest milligram, 2 g of potassium dichromate. Transfer the dichromate to a 500 ml volumetric flask, dissolve in deionized, distilled water and dilute to exactly 500 ml. In a 500 ml iodine flask, dissolve approximately 3 g of potassium iodide (KI) in 45 ml of deionized, distilled water, then add 10 ml of 3 M hydrochloric acid solution. Pipette 50 ml of the dichromate solution into this mixture. Gently swirl the solution once and allow it to stand in the dark for 5 minutes. Dilute the solution with 100 to 200 ml of deionized distilled water, washing down the sides of the flask with part of the water. Titrate with 0.1 N thiosulfate until the solution is light yellow. Add 4 ml of starch indicator and continue titrating slowly to a green end point. Record V_s, the volume of thiosulfate solution used (ml). Repeat until replicate analyses agree within 0.05 ml. Calculate the normality using equation 9.1. Repeat the standardization each week, or after each test series, whichever time is shorter.

8.1.3 Standardize the 0.01 N Phenylarsine oxide (if applicable) as follows: oven dry potassium dichromate ($K_2Cr_2O_7$) at 180 to 200° C (360 to 390° F). Weigh to the nearest milligram, 2 g of the $K_2Cr_2O_7$; transfer the dichromate to a 500 ml volumetric flask, dissolve in deionized, distilled water, and dilute to exactly 500 ml. In a 500 ml iodine flask, dissolve approximately 0.3 g of potassium iodide (KI) in 45 ml of deionized, distilled water; add 10 ml of 3M hydrochloric acid. Pipette 5 ml of the $K_2Cr_2O_7$ solution into the iodine flask. Gently swirl the contents of the flask once and allow to stand in the dark for 5 minutes. Dilute the solution with 100 to 200 ml of deionized, distilled water, washing down the sides of the flask with part of the water. Titrate with 0.01 N phenylarsine oxide until the solution is light yellow. Add 4 ml of starch indicator and continue titrating slowly to a green end point. Record V_A, the volume of phenylarsine oxide used (ml). Repeat until replicate analyses agree within 0.05 ml. Calculate the normality using equation 9.2. Repeat the standardization each week or after each test series, whichever time is shorter.

8.2 Sampling train calibration. Calibrate the sampling train components as follows:

8.2.1 Dry gas meter.

8.2.1.1 Initial calibration. The dry gas meter shall be calibrated before its initial use in the field. Proceed as follows: First, assemble the following components in series: Drying tube, needle valve, pump, rotameter, and dry gas meter. Then, leak-check the system as follows: Place a vacuum gauge (at least 760 mm Hg) at the inlet to the drying tube and pull a vacuum of 250 mm (10 in.) Hg; plug or pinch off the outlet of the flow meter, and then turn off the pump. The vacuum shall remain stable for at least 30 seconds. Carefully release the vacuum gauge before releasing the flow meter end.

Next, calibrate the dry gas meter (at the sampling flow rate specified by the method) as follows: Connect an appropriately sized wet test meter (e.g., 1 liter per revolution) to the inlet of the drying tube. Make three independent calibration runs, using at least five revolutions of the dry gas meter per run. Calculate the calibration factor, *Y* (wet test meter calibration volume divided by the dry gas meter volume, both volumes adjusted to the same reference temperature and pressure), for each run, and average the results. If any *Y* value deviates by more than 2 percent from the average, the dry gas meter is unacceptable for use. Otherwise, use the average as the calibration factor for subsequent test runs.

8.2.1.2 Post-test calibration check. After each field test series, conduct a calibration check as in section 8.2.1.1. above, except for the following variations: (a) The leak check is not to be conducted, (b) three or more revolutions of the dry gas meter may be used, and (3) only two independent runs need be made. If the calibration factor does not deviate by more than 5 percent from the initial calibration factor (determined in section 8.2.1.1.), then the dry gas meter volumes obtained during the test series are acceptable. If the calibration factor deviates by more than 5 percent, recalibrate the dry gas meter as in section 8.2.1.1, and for the calculations, use the calibration factor (initial or recalibration) that yields the lower gas volume for each test run.

8.2.2 Thermometers. Calibrate against mercury-in-glass thermometers.

8.2.3 Rotameter. The rotameter need not be calibrated, but should be cleaned and maintained according to the manufacturer's instruction.

8.2.4 Barometer. Calibrate against a mercury barometer.

Method 11, Continued

9. *Calculations.* Carry out calculations retaining at least one extra decimal figure beyond that of the acquired data. Round off results only after the final calculation.

9.1 Normality of the Standard (~0.1 N) Thiosulfate Solution.

$$N_S = 2.039 W/V_S$$

where:

W = Weight of $K_2Cr_2O_7$ used, g.
V_S = Volume of $Na_2S_2O_3$ solution used, ml.
N_S = Normality of standard thiosulfate solution, g-eq/liter.
2.039 = Conversion factor

(6 eq. I_2/mole $K_2Cr_2O_7$) (1,000 ml/liter)/=(294.2 g $K_2Cr_2O_7$/mole) (10 aliquot factor)

9.2 Normality of Standard Phenylarsine Oxide Solution (if applicable).

$$N_A = 0.2039 W/V_A$$

where:

W = Weight of $K_2Cr_2O_7$ used, g.
V_A = Volume of C_6H_5AsO used, ml.
N_A = Normality of standard phenylarsine oxide solution, g=eq/liter.
0.2039 = Conversion factor
(6 eq. I_2/mole $K_2Cr_2O_7$) (1,000 ml/liter)/(249.2 g $K_2Cr_2O_7$/mole) (100 aliquot factor)

9.3 Normality of Standard Iodine Solution.

$$N_I = N_T V_T / V_I$$

where:

N_I = Normality of standard iodine solution, g-eq/liter.
V_I = Volume of standard iodine solution used, ml.
N_T = Normality of standard (~0.01 N) thiosulfate solution; assumed to be 0.1 N_S, g-eq/liter.
V_T = Volume of thiosulfate solution used, ml.

NOTE.—If phenylarsine oxide is used intead of thiosulfate, replace N_T and V_T in Equation 9.3 with N_A and V_{AS}, respectively (see sections 8.1.1 and 8.1.3).

9.4 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C) and 760 mm Hg.

$$V_{m(std)} = V_m Y [(T_{std}/T_m)(P_{bar}/P_{std})]$$

where:

$V_{m(std)}$ = Volume at standard conditions of gas sample through the dry gas meter, standard liters.
V_m = Volume of gas sample through the dry gas meter (meter conditions), liters.
T_{std} = Absolute temperature at standard conditions, 293 K.
T_m = Average dry gas meter temperature, °K.
P_{bar} = Barometric pressure at the sampling site, mm Hg.
P_{std} = Absolute pressure at standard conditions, 760 mm Hg.
Y = Dry gas meter calibration factor.

* * *

9.5 Concentration of H_2S. Calculate the concentration of H_2S in the gas stream at standard conditions using the following equation:

$$C_{H_2S} = K[(V_{IT}N_I - V_{TT}N_T)\text{ sample} - (V_{IT}N_I - V_{TT}N_T)\text{ blank}]/V_{m(std)}$$

where (metric units):

C_{H_2S} = Concentration of H_2S at standard conditions, mg/dscm.
K = Conversion factor = 17.04×10^3

(34.07 g/mole H_2S) (1,000 liters/m^3) (1,000 mg/g)/=(1,000 ml/liter) (2H_2S eq/mole)

V_{IT} = Volume of standard iodine solution = 50.0 ml.
N_I = Normality of standard iodine solution, g-eq/liter.
V_{TT} = Volume of standard (~0.01 N) sodium thiosulfate solution, ml.
N_T = Normality of standard sodium thiosulfate solution, g-eq/liter.
$V_{m(std)}$ = Dry gas volume at standard conditions, liters.

NOTE.—If phenylarsine oxide is used instead of thiosulfate, replace N_T and V_{TT} in Equation 9.5 with N_A and V_{AT}, respectively (see Sections 7.3.1 and 8.1.3).

10. *Stability.* The absorbing solution is stable for at least 1 month. Sample recovery and analysis should begin within 1 hour of sampling to minimize oxidation of the acidified cadmium sulfide. Once iodine has been added to the sample, the remainder of the analysis procedure must be completed according to sections 7.2.2 through 7.3.2.

11. *Bibliography.*

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11.2 Tentative Method of Determination of Hydrogen Sulfide and Mercaptan Sulfur in Natural Gas, Natural Gas Processors Association, Tulsa, Okla., NGPA Publication No. 2265-65, 1965.

11.3 Knoll, J. E., and M. R. Midgett. Determination of Hydrogen Sulfide in Refinery Fuel Gases, Environmental Monitoring Series, Office of Research and Development, USEPA, Research Triangle Park, N.C. 27711, EPA 600/4-77-007.

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(Secs. 111, 114, 301(a), Clean Air Act as amended (42 U.S.C. 7411, 7414, 7601).)

[FR Doc. 78-482 Filed 1-9-78; 8:45 am]

Method 16

SEMI-CONTINUOUS DETERMINATION OF SULFUR EMISSIONS FROM STATIONARY SOURCES

(40 CFR 60, Appendix A, February 23, 1978)

Introduction

The method described below uses the principle of gas chromatographic separation and flame photometric detection. Since there are many systems or sets of operating conditions that represent usable methods of determining sulfur emissions, all systems which employ this principle, but differ only in details of equipment and operation, may be used as alternative methods, provided that the criteria set below are met.

1. *Principle and Applicability.*

1.1 Principle. A gas sample is extracted from the emission source and diluted with clean dry air. An aliquot of the diluted sample is then analyzed for hydrogen sulfide (H_2S), methyl mercaptan (MeSH), dimethyl sulfide (DMS) and dimethyl disulfide (DMDS) by gas chromatographic (GC) separation and flame photometric detection (FPD). These four compounds are known collectively as total reduced sulfur (TRS).

1.2 Applicability. This method is applicable for determination of TRS compounds from recovery furnaces, lime kilns, and smelt dissolving tanks at kraft pulp mills.

2. *Range and Sensitivity.*

2.1 Range. Coupled with a gas chromatographic system utilizing a ten milliliter sample size, the maximum limit of the FPD for each sulfur compound is approximately 1 ppm. This limit is expanded by dilution of the sample gas before analysis. Kraft mill gas samples are normally diluted tenfold (9:1), resulting in an upper limit of about 10 ppm for each compound.

For sources with emission levels between 10 and 100 ppm, the measuring range can be best extended by reducing the sample size to 1 milliliter.

2.2 Using the sample size, the minimum detectable concentration is approximately 50 ppb.

3. *Interferences.*

3.1 Moisture Condensation. Moisture condensation in the sample delivery system, the analytical column, or the FPD burner block can cause losses or interferences. This potential is eliminated by heating the sample line, and by conditioning the sample with dry dilution air to lower its dew point below the operating temperature of the GC/FPD analytical system prior to analysis.

3.2 Carbon Monoxide and Carbon Dioxide. CO and CO_2 have substantial desensitizing effect on the flame photometric detector even after 9:1 dilution. Acceptable systems must demonstrate that they have eliminated this interference by some procedure such as eluting these compounds before any of the compounds to be measured. Compliance with this requirement can be demonstrated by submitting chromatograms of calibration gases with and without CO_2 in the diluent gas. The CO_2 level should be approximately 10 percent for the case with CO_2 present. The two chromatographs should show agreement within the precision limits of Section 4.1.

3.3 Particulate Matter. Particulate matter in gas samples can cause interference by eventual clogging of the analytical system. This interference must be eliminated by use of a probe filter.

3.4 Sulfur Dioxide. SO_2 is not a specific interferent but may be present in such large amounts that it cannot be effectively separated from other compounds of interest. The procedure must be designed to eliminate this problem either by the choice of separation columns or by removal of SO_2 from the sample.

Compliance with this section can be demonstrated by submitting chromatographs of calibration gases with SO_2 present in the same quantities expected from the emission source to be tested. Acceptable systems shall show baseline separation with the amplifier attenuation set so that the reduced sulfur compound of concern is at least 50 percent of full scale. Base line separation is defined as a return to zero ± percent in the interval between peaks.

4. *Precision and Accuracy.*

4.1 GC/FPD and Dilution System Calibration Precision. A series of three consecutive injections of the same calibration gas, at any dilution, shall produce results which do not vary by more than ±3 percent from the mean of the three injections.

4.2 GC/FPD and Dilution System Calibration Drift. The calibration drift determined from the mean of three injections made at the beginning and end of any 8-hour period shall not exceed ± percent.

4.3 System Calibration Accuracy. The complete system must quantitatively transport and analyze with an accuracy of 20 percent. A correction factor is developed to adjust calibration accuracy to 100 percent.

5. *Apparatus* (See Figure 16-1).

5.1.1 Probe. The probe must be made of inert material such as stainless steel or glass. It should be designed to incorporate a filter and to allow calibration gas to enter the probe at or near the sample entry point. Any portion of the probe not exposed to the stack gas must be heated to prevent moisture condensation.

5.1.2 Sample Line. The sample line must be made of Teflon,[1] no greater than 1.3 cm (½) inside diameter. All parts from the probe to the dilution system must be thermostatically heated to 120° C.

5.1.3 Sample Pump. The sample pump shall be a leakless Teflon-coated diaphragm type or equivalent. If the pump is upstream of the dilution system, the pump head must be heated to 120° C.

5.2 Dilution System. The dilution system must be constructed such that all sample contacts are made of inert materials (e.g., stainless steel or Teflon). It must be heated to 120° C. and be capable of approximately a 9:1 dilution of the sample.

5.3 Gas Chromatograph. The gas chromatograph must have at least the following components:

5.3.1 Oven. Capable of maintaining the separation column at the proper operating temperature ± 1° C.

5.3.2 Temperature Gauge. To monitor column oven, detector, and exhaust temperature ± 1° C.

5.3.3 Flow System. Gas metering system to measure sample, fuel, combustion gas, and carrier gas flows.

5.3.4 Flame Photometric Detector.

5.3.4.1 Electrometer. Capable of full scale amplification of linear ranges of 10^{-9} to 10^{-4} amperes full scale.

5.3.4.2 Power Supply. Capable of delivering up to 750 volts.

5.3.4.3 Recorder. Compatible with the output voltage range of the electrometer.

5.4 Gas Chromatograph Columns. The column system must be demonstrated to be capable of resolving the four major reduced sulfur compounds: H_2S, MeSH, DMS, and DMDS. It must also demonstrate freedom from known interferences.

To demonstrate that adequate resolution has been achieved, the tester must submit a chromatograph of a calibration gas containing all four of the TRS compounds in the concentration range of the applicable standard. Adequate resolution will be defined as base line separation of adjacent peaks when the amplifier attenuation is set so that the smaller peak is at least 50 percent of full scale. Base line separation is defined in Section 3.4. Systems not meeting this criteria may be considered alternate methods subject to the approval of the Administrator.

5.5. Calibration System. The calibration system must contain the following components.

5.5.1 Tube Chamber. Chamber of glass or Teflon of sufficient dimensions to house permeation tubes.

5.5.2 Flow System. To measure air flow over permeation tubes at ±2 percent. Each flowmeter shall be calibrated after a complete test series with a wet test meter. If the flow measuring device differs from the wet test meter by 5 percent, the completed test shall be discarded. Alternatively, the tester may elect to use the flow data that would yield the lowest flow measurement. Calibration with a wet test meter before a test is optional.

5.5.3 Constant Temperature Bath. Device capable of maintaining the permeation tubes at the calibration temperature within ±0.1° C.

5.5.4 Temperature Gauge. Thermometer or equivalent to monitor bath temperature within ± 1° C.

6. *Reagents.*

6.1 Fuel. Hydrogen (H_2) prepurified grade or better.

6.2 Combustion Gas. Oxygen (O_2) or air, research purity or better.

6.3 Carrier Gas. Prepurified grade or better.

6.4 Diluent. Air containing less than 50 ppb total sulfur compounds and less than 10 ppm each of moisture and total hydrocarbons. This gas must be heated prior to mixing with the sample to avoid water condensation at the point of contact.

6.5 Calibration Gases. Permeation tubes, one each of H_2S, MeSH, DMS, and DMDS, agravimetrically calibrated and certified at some convenient operating temperature. These tubes consist of hermetically sealed FEP Teflon tubing in which a liquified gaseous substance is enclosed. The enclosed gas permeates through the tubing wall at a constant rate. When the temperature is constant, calibration gases covering a wide range of known concentrations can be generated by varying and accurately measuring the flow rate of diluent gas passing over the tubes. These calibration gases are used to calibrate the GC/FPD system and the dilution system.

7. *Pretest Procedures.* The following procedures are optional but would be helpful in preventing any problem which might occur later and invalidate the entire test.

7.1 After the complete measurement system has been set up at the site and deemed to be operational, the following procedures should be completed before sampling is initiated.

7.1.1 Leak Test. Appropriate leak test procedures should be employed to verify the integrity of all components, sample lines, and connections. The following leak test procedure is suggested: For components upstream of the sample pump, attach the probe end of the sample line to a manometer or vacuum gauge, start the pump and pull greater than 50 mm (2 in.) Hg vacuum, close off the pump outlet, and then stop the pump and ascertain that there is no leak for 1 minute. For components after the pump, apply a slight positive pressure and check for leaks by applying a liquid (detergent in water, for example) at each joint. Bubbling indicates the presence of a leak.

7.1.2 System Performance. Since the complete system is calibrated following each test, the precise calibration of each component is not critical. However, these components should be verified to be operating properly. This verification can be performed by observing the response of flowmeters or of the GC output to changes in flow rates or calibration gas concentrations and ascertaining the response to be within predicted limits. In any component, or if the complete system fails to respond in a normal and predictable manner, the source of the discrepancy should be identified and corrected before proceeding.

8. *Calibration.* Prior to any sampling run, calibrate the system using the following procedures. (If more than one run is performed during any 24-hour period, a calibra-

tion need not be performed prior to the second and any subsequent runs. The calibration must, however, be verified as prescribed in Section 10, after the last run made within the 24-hour period.)

8.1 General Considerations. This section outlines steps to be followed for use of the GC/FPD and the dilution system. The procedure does not include detailed instructions because the operation of these systems is complex, and it requires a understanding of the individual system being used. Each system should include a written operating manual describing in detail the operating procedures associated with each component in the measurement system. In addition, the operator should be familiar with the operating principles of the components; particularly the GC/FPD. The citations in the Bibliography at the end of this method are recommended for review for this purpose.

8.2 Calibration Procedure. Insert the permeation tubes into the tube chamber. Check the bath temperature to assure agreement with the calibration temperature of the tubes within ±0.1° C. Allow 24 hours for the tubes to equilibrate. Alternatively equilibration may be verified by injecting samples of calibration gas at 1-hour intervals. The permeation tubes can be assumed to have reached equilibrium when consecutive hourly samples agree within the precision limits of Section 4.1.

Vary the amount of air flowing over the tubes to produce the desired concentrations for calibrating the analytical and dilution systems. The air flow across the tubes must at all times exceed the flow requirement of the analytical systems. The concentration in parts per million generated by a tube containing a specific permeant can be calculated as follows:

$$C = K\frac{P_r}{ML}$$

Equation 16-1

where:

C = Concentration of permeant produced in ppm.

P_r = Permeation rate of the tube in μg/min.

M = Molecular weight of the permeant (g/g-mole).

L = Flow rate, l/min, of air over permeant @ 20° C, 760 mm Hg.

K = Gas constant at 20° C and 760 mm Hg = 24.04 l/g mole.

8.3 Calibration of analysis system. Generate a series of three or more known concentrations spanning the linear range of the FPD (approximately 0.05 to 1.0 ppm) for each of the four major sulfur compounds. Bypassing the dilution system, inject these standards into the GC/FPD analyzers and monitor the responses. Three injects for each concentration must yield the precision described in Section 4.1. Failure to attain this precision is an indication of a problem in the calibration or analytical system. Any such problem must be identified and corrected before proceeding.

8.4 Calibration Curves. Plot the GC/FPD response in current (amperes) versus their causative concentrations in ppm on log-log coordinate graph paper for each sulfur compound. Alternatively, a least squares equation may be generated from the calibration data.

8.5 Calibration of Dilution System. Generate a known concentration of hydrogen sulfide using the permeation tube system. Adjust the flow rate of diluent air for the first dilution stage so that the desired level of dilution is approximated. Inject the diluted calibration gas into the GC/FPD system and monitor its response. Three injections for each dilution must yield the precision described in Section 4.1. Failure to attain this precision in this step is an indication of a problem in the dilution system. Any such problem must be identified and corrected before proceeding. Using the calibration data for H_2S (developed under 8.3) determine the diluted calibration gas concentration in ppm. Then calculate the dilution factor as the ratio of the calibration gas concentration before dilution to the diluted calibration gas concentration determined under this paragraph. Repeat this procedure for each stage of dilution required. Alternatively, the GC/FPD system may be calibrated by generating a series of three or more concentrations of each sulfur compound and diluting these samples before injecting them into the GC/FPD system. This data will then serve as the calibration data for the unknown samples and a separate determination of the dilution factor will not be necessary. However, the precision requirements of Section 4.1 are still applicable.

9. *Sampling and Analysis Procedure.*

9.1 Sampling. Insert the sampling probe into the test port making certain that no dilution air enters the stack through the port. Begin sampling and dilute the sample approximately 9:1 using the dilution system. Note that the precise dilution factor is that which is determined in paragraph 8.5. Condition the entire system with sample for a minimum of 15 minutes prior to commencing analysis.

9.2 Analysis. Aliquots of diluted sample are injected into the GC/FPD analyzer for analysis.

9.2.1 Sample Run. A sample run is composed of 16 individual analyses (injects) performed over a period of not less than 3 hours or more than 6 hours.

9.2.2 Observation for Clogging of Probe. If reductions in sample concentrations are observed during a sample run that cannot be explained by process conditions, the sampling must be interrupted to determine if the sample probe is clogged with particulate matter. If the probe is found to be clogged, the test must be stopped and the results up to that point discarded. Testing may resume after cleaning the probe or replacing it with a clean one. After each run, the sample probe must be inspected and, if necessary, dismantled and cleaned.

10. *Post-Test Procedures.*

10.1 Sample Line Loss. A known concentration of hydrogen sulfide at the level of the applicable standard, ±20 percent, must be introduced into the sampling system at the opening of the probe in sufficient quantities to insure that there is an excess of sample which must be vented to the atmosphere. The sample must be transported through the entire sampling system to the measurement system in the normal manner. The resulting measured concentration should be compared to the known value to determine the sampling system loss. A sampling system loss of more than 20 percent is unacceptable. Sampling losses of 0-20 percent must be corrected for by dividing the resulting sample concentration by the fraction of recovery. The known gas sample may be generated using permeation tubes. Alternatively, cylinders of hydrogen sulfide mixed in air may be used provided they are traceable to permeation tubes. The optional pretest procedures provide a good guideline for determining if there are leaks in the sampling system.

10.2 Recalibration. After each run, or after a series of runs made within a 24-hour period, perform a partial recalibration using the procedures in Section 8. Only H_2S (or other permeant) need be used to recalibrate the GC/FPD analysis system (8.3) and the dilution system (8.5).

10.3 Determination of Calibration Drift. Compare the calibration curves obtained prior to the runs, to the calibration curves obtained under paragraph 10.1. The calibration drift should not exceed the limits set forth in paragraph 4.2. If the drift exceeds this limit, the intervening run or runs should be considered not valid. The tester, however, may instead have the option of choosing the calibration data set which would give the highest sample values.

11. *Calculations.*

11.1 Determine the concentrations of each reduced sulfur compound detected directly from the calibration curves. Alternatively, the concentrations may be calculated using the equation for the least square line.

11.2 Calculation of TRS. Total reduced sulfur will be determined for each analysis made by summing the concentrations of each reduced sulfur compound resolved during a given analysis.

$$TRS = \Sigma\,(H_2S,\ MeSH,\ DMS,\ 2DMDS)d$$

Equation 16-2

where:

TRS = Total reduced sulfur in ppm, wet basis.

H_2S = Hydrogen sulfide, ppm.

MeSH = Methyl mercaptan, ppm.

DMS = Dimethyl sulfide, ppm.

DMDS = Dimethyl disulfide, ppm.

d = Dilution factor, dimensionless.

11.3 Average TRS. The average TRS will be determined as follows:

$$\text{Average TRS} = \frac{\sum_{i=1}^{N} TRS_i}{N(1-B_{wo})}$$

Average TRS = Average total reduced sulfur in ppm, dry basis.

TRS_i = Total reduced sulfur in ppm as determined by Equation 16-2.

N = Number of samples.

B_{wo} = Fraction of volume of water vapor in the gas stream as determined by method 4—Determination of Moisture in Stack Gases (36 FR 24887).

11.4 Average concentration of individual reduced sulfur compounds.

$$C = \frac{\sum_{i=1}^{N} S_i}{N}$$

Equation 16-3

where:

S_i = Concentration of any reduced sulfur compound from the ith sample injection, ppm.

C = Average concentration of any one of the reduced sulfur compounds for the entire run, ppm.

N = Number of injections in any run period.

12. *Example System.* Described below is a system utilized by EPA in gathering NSPS data. This system does not now reflect all the latest developments in equipment and column technology, but it does represent one system that has been demonstrated to work.

12.1 Apparatus.

12.1.1 Sampling System.

12.1.1.1 Probe. Figure 16-1 illustrates the probe used in lime kilns and other sources where significant amounts of particulate matter are present. the probe is designed with the deflector shield placed between the sample and the gas inlet holes and the glass wool plugs to reduce clogging of the filter and possible adsorption of sample gas. The exposed portion of the probe between the sampling port and the sample line is heated with heating tape.

12.1.1.2 Sample Line 3/16 inch inside diameter Teflon tubing, heated to 120° C. This temperature is controlled by a thermostatic heater.

12.1.1.3 Sample Pump. Leakless Teflon coated diaphragm type or equivalent. The pump head is heated to 120° C by enclosing it in the sample dilution box (12.2.4 below).

12.1.2 Dilution System. A schematic diagram of the dynamic dilution system is given in Figure 16-2. The dilution system is constructed such that all sample contacts are made of inert materials. The dilution system which is heated to 120° C must be capable of a minimum of 9:1 dilution of sample. Equipment used in the dilution system is listed below:

12.1.2.1 Dilution Pump. Model A-150 Kohmyhr Teflon positive displacement type, nonadjustable 150 cc/min. ±2.0 percent, or equivalent, per dilution stage. A 9:1 dilution of sample is accomplished by combining 150 cc of sample with 1,350 cc of clean dry air as shown in Figure 16-2.

12.1.2.2 Valves. Three-way Teflon solenoid or manual type.

12.1.2.3 Tubing. Teflon tubing and fittings are used throughout from the sample probe to the GC/FPD to present an inert surface for sample gas.

12.1.2.4 Box. Insulated box, heated and maintained at 120° C, of sufficient dimensions to house dilution apparatus.

12.1.2.5 Flowmeters. Rotameters or equivalent to measure flow from 0 to 1500 ml/min ±1 percent per dilution stage.

12.1.3 Gas Chromatograph Columns. Two types of columns are used for separation of low and high molecular weight sulfur compounds:

12.1.3.1 Low Molecular Weight Sulfur Compounds Column (GC/FPD-1).

12.1.3.1 Separation Column. 11 m by 2.16 mm (36 ft by 0.085 in) inside diameter Teflon tubing packed with 30/60 mesh Teflon coated with 5 percent polyphenyl ether and 0.05 percent orthophosphoric acid, or equivalent (see Figure 16-3).

12.1.3.1.2 Stripper or Precolumn. 0.6 m by 2.16 mm (2 ft by 0.085 in) inside diameter Teflon tubing packed as in 5.3.1.

12.1.3.1.3 Sample Valve. Teflon 10-port gas sampling valve, equipped with a 10 ml sample loop, actuated by compressed air (Figure 16-3).

12.1.3.1.4 Oven. For containing sample valve, stripper column and separation column. The oven should be capable of maintaining an elevated temperature ranging from ambient to 100° C, constant within ±1° C.

12.1.3.1.5 Temperature Monitor. Thermocouple pyrometer to measure column oven, detector, and exhaust temperature ±1° C.

12.1.3.1.6 Flow System. Gas metering system to measure sample flow, hydrogen flow, and oxygen flow (and nitrogen carrier gas flow).

12.1.3.1.7 Detector. Flame photometric detector.

12.1.3.1.8 Electrometer. Capable of full scale amplification of linear ranges of 10^{-9} to 10^{-4} amperes full scale.

12.1.3.1.9 Power Supply. Capable of delivering up to 750 volts.

12.1.3.1.10 Recorder. Compatible with the output voltage range of the electrometer.

12.1.3.2 High Molecular Weight Compounds Column (GC/FPD-11).

12.1.3.2.1. Separation Column. 3.05 m by 2.16 mm (10 ft by 0.0885 in) inside diameter Teflon tubing packed with 30/60 mesh Teflon coated with 10 percent Triton X-305, or equivalent.

12.1.3.2.2 Sample Valve. Teflon 6-port gas sampling valve equipped with a 10 ml sample loop, actuated by compressed air (Figure 16-3).

12.1.3.2.3 Other Components. All components same as in 12.1.3.1.4 to 12.1.3.1.10.

12.1.4 Calibration. Permeation tube system (figure 16-4).

12.1.4.1 Tube Chamber. Glass chamber of sufficient dimensions to house permeation tubes.

12.1.4.2 Mass Flowmeters. Two mass flowmeters in the range 0-3 l/min. and 0-10 l/min. to measure air flow over permeation tubes at ±2 percent. These flowmeters shall be cross-calibrated at the beginning of each test. Using a convenient flow rate in the measuring range of both flowmeters, set and monitor the flow rate of gas over the permeation tubes. Injection of calibration gas generated at this flow rate as measured by one flowmeter followed by injection of calibration gas at the same flow rate as measured by the other flowmeter should agree within the specified precision limits. If they do not, then there is a problem with the mass flow measurement. Each mass flowmeter shall be calibrated prior to the first test with a wet test meter and thereafter, at least once each year.

12.1.4.3 Constant Temperature Bath. Capable of maintaining permeation tubes at certification temperature of 30° C. within ±0.1° C.

12.2 Reagents

12.2.1 Fuel. Hydrogen (H_2) prepurified grade or better.

12.2.2. Combustion Gas. Oxygen (O_2) research purity or better.

12.2.3 Carrier Gas. Nitrogen (N_2) prepurified grade or better.

12.2.4 Diluent. Air containing less than 50 ppb total sulfur compounds and less than 10 ppm each of moisture and total hydrocarbons, and filtered using MSA filters 46727 and 79030, or equivalent. Removal of sulfur compounds can be verified by injecting dilution air only, described in Section 8.3.

12.2.5 Compressed Air. 60 psig for GC valve actuation.

12.2.6 Calibrated Gases. Permeation tubes gravimetrically calibrated and certified at 30.0° C.

12.3 Operating Parameters.

12.3.1 Low-Molecular Weight Sulfur Compounds. The operating parameters for the GC/FPD system used for low molecular weight compounds are as follows: nitrogen carrier gas flow rate of 50 cc/min, exhaust temperature of 110° C, detector temperature of 105° C, oven temperature of 40° C, hydrogen flow rate of 80 cc/min, oxygen flow rate of 20 cc/min, and sample flow rate between 20 and 80 cc/min.

12.3.2 High-Molecular Weight Sulfur Compounds. The operating parameters for the GC/FPD system for high molecular weight compounds are the same as in 12.3.1 except: oven temperature of 70° C, and nitrogen carrier gas flow of 100 cc/min.

12.4 Analysis Procedure.

12.4.1 Analysis. Aliquots of diluted sample are injected simultaneously into both GC/FPD analyzers for analysis. GC/FPD-I is used to measure the low-molecular weight reduced sulfur compounds. The low molecular weight compounds include hydrogen sulfide, methyl mercaptan, and dimethyl sulfide. GC/FPD-II is used to resolve the high-molecular weight compound. The high-molecular weight compound is dimethyl disulfide.

12.4.1.1 Analysis of Low-Molecular Weight Sulfur Compounds. The sample valve is actuated for 3 minutes in which time an aliquot of diluted sample is injected into the stripper column and analytical column. The valve is then deactivated for approximately 12 minutes in which time, the analytical column continues to be foreflushed, the stripper column is backflushed, and the sample loop is refilled. Monitor the responses. The elution time for each compound will be determined during calibration.

12.4.1.2 Analysis of High-Molecular Weight Sulfur Compounds. The procedure is essentially the same as above except that no stripper column is needed.

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Amendment dtd. Aug. 7, 1978

2. In appendix A, paragraph 10.1 of method 16 is amended to read as follows:

* * * * *

10. POST-TEST PROCEDURES

10.1 Sample line loss. A known concentration of hydrogen sulfide at the level of the applicable standard, ± 20 percent, must be introduced into the sampling system in sufficient quantities to insure that there is an excess of sample which must be vented to the atmosphere. The sample must be introduced immediately after the probe and filter and transported through the remainder of the sampling system to the measurement system in the normal manner. The resulting measured concentration should be compared to the known value to determine the sampling system loss.

For sampling losses greater than 20 percent in a sample run, the sample run is not to be used when determining the arithmetic mean of the performance test. For sampling losses of 0-20 percent, the sample concentration must be corrected by dividing the sample concentration by the fraction of recovery. The fraction of recovery is equal to one minus the ratio of the measured concentration to the known concentration of hydrogen sulfide in the sample line loss procedure. The known gas sample may be generated using permeation tubes. Alternatively, cylinders of hydrogen sulfide mixed in air may be used provided they are traceable to permeation tubes. The optional pretest procedures provide a good guideline for determining if there are leaks in the sampling system.

* * *

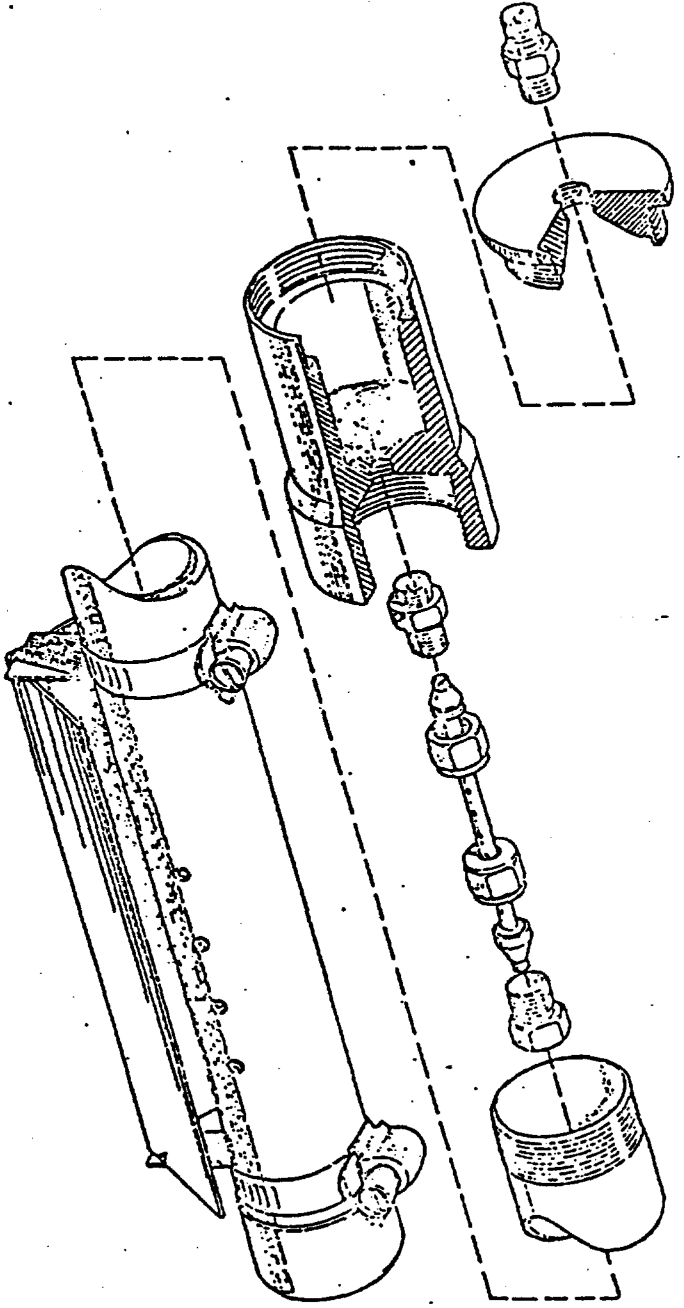

Figure 16-1. Probe used for sample gas containing high particulate loadings.

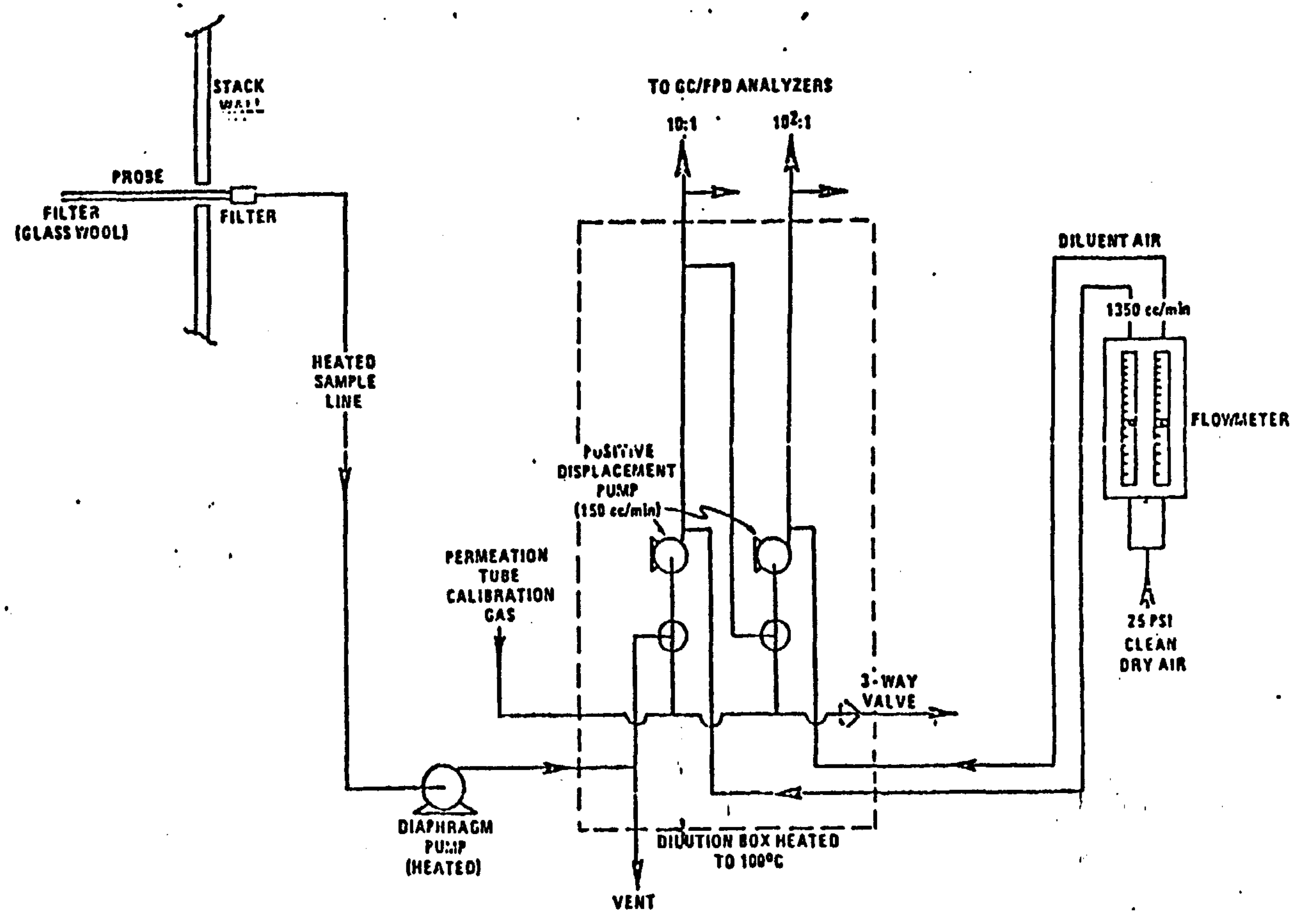

Figure 16-2. Sampling and dilution apparatus.

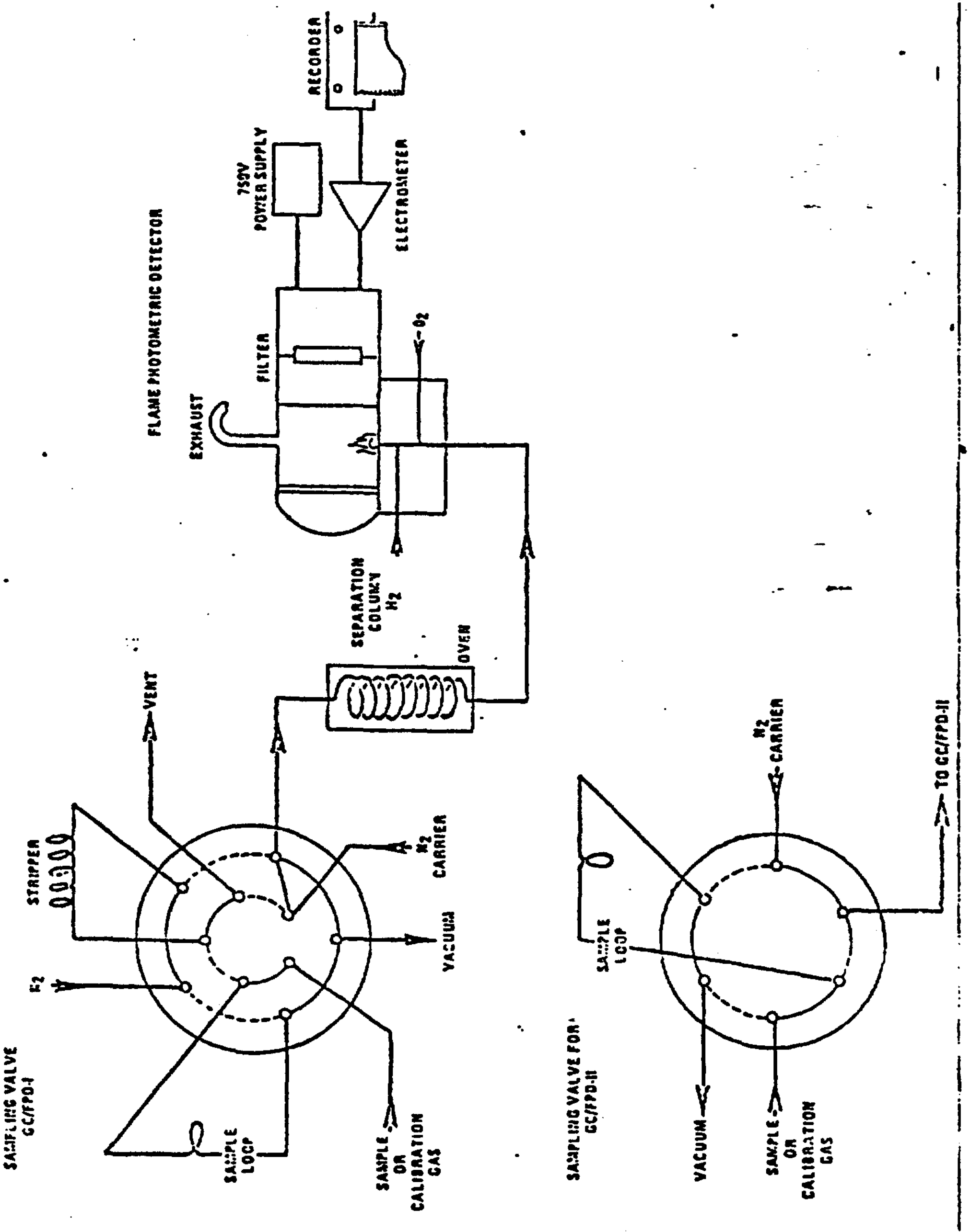

Figure 16-3. Gas chromatographic-flame photometric analyzers.

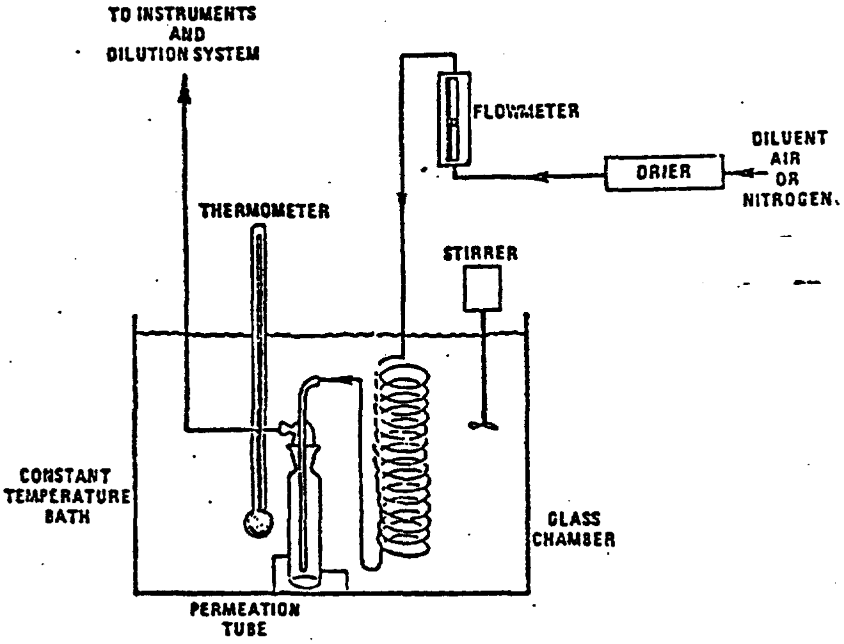

Figure 16-4. Apparatus for field calibration.

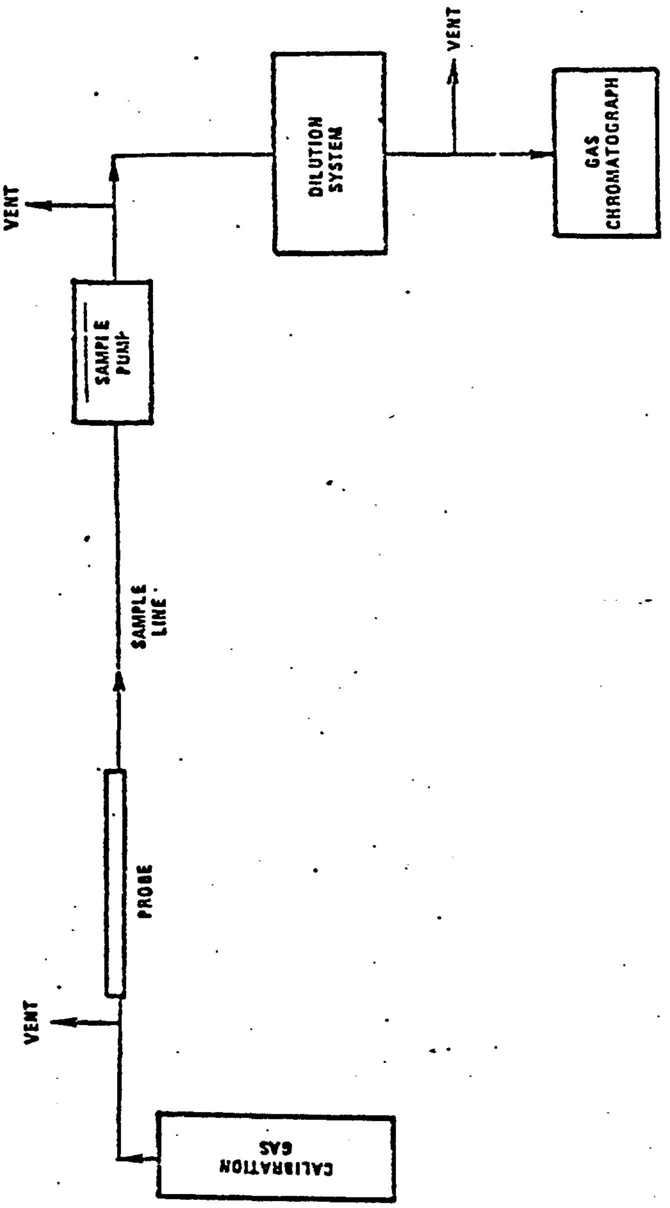

Figure 16- 5. Determination of sample line loss.

Method 17

DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES (IN-STACK FILTRATION METHOD)
(40 CFR 60, Appendix A, February 23, 1978)

Introduction

Particulate matter is not an absolute quantity; rather, it is a function of temperature and pressure. Therefore, to prevent variability in particulate matter emission regulations and/or associated test methods, the temperature and pressure at which particulate matter is to be measured must be carefully defined. Of the two variables (i.e., temperature and pressure), temperature has the greater effect upon the amount of particulate matter in an effluent gas stream; in most stationary source categories, the effect of pressure appears to be negligible.

In method 5, 250° F is established as a nominal reference temperature. Thus, where Method 5 is specified in an applicable subpart of the standards, particulate matter is defined with respect to temperature. In order to maintain a collection temperature of 250° F, Method 5 employs a heated glass sample probe and a heated filter holder. This equipment is somewhat cumbersome and requires care in its operation. Therefore, where particulate matter concentrations (over the normal range of temperature associated with a specified source category) are known to be independent of temperature, it is desirable to eliminate the glass probe and heating systems, and sample at stack temperature.

This method describes an in-stack sampling system and sampling procedures for use in such cases. It is intended to be used only when specified by an applicable subpart of the standards, and only within the applicable temperature limits (if specified), or when otherwise approved by the Administrator.

1. *Principle and Applicability.*

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and collected on a glass fiber filter maintained at stack temperature. The particulate mass is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method applies to the determination of particulate emissions from stationary sources for determining compliance with new source performance standards, only when specifically provided for in an applicable subpart of the standards. This method is not applicable to stacks that contain liquid droplets or are saturated with water vapor. In addition, this method shall not be used as written if the projected cross-sectional area of the probe-extension-filter holder assembly covers more than 5 percent of the stack cross-sectional area (see Section 4.1.2).

2. *Apparatus.*

2.1 Sampling Train. A schematic of the sampling train used in this method is shown in Figure 17-1. Construction details for many, but not all, of the train components are given in APTD-0581 (Citation 2 in Section 7); for changes from the APTD-0581 document and for allowable modifications to Figure 17-1, consult with the Administrator.

The operating and maintenance procedures for many of the sampling train components are described in APTD-0576 (Citation 3 in Section 7). Since correct usage is important in obtaining valid results, all users should read the APTD-0576 document and adopt the operating and maintenance procedures outlined in it, unless otherwise specified herein. The sampling train consists of the following components:

2.1.1 Probe Nozzle. Stainless steel (316) or glass, with sharp, tapered leading edge. The angle of taper shall be 030° and the taper shall be on the outside to preserve a constant internal diameter. The probe nozzle shall be of the button-hook or elbow design, unless otherwise specified by the Administrator. If made of stainless steel, the nozzle shall be constructed from seamless tubing. Other materials of construction may be used subject to the approval of the Administrator.

A range of sizes suitable for isokinetic sampling should be available, e.g., 0.32 to 1.27 cm (⅛ to ½ in)—or larger if higher volume sampling trains are used—inside diameter (ID) nozzles in increments of 0.16 cm (1/16 in). Each nozzle shall be calibrated according to the procedures outlined in Section 5.1.

2.1.2 Filter Holder. The in-stack filter holder shall be constructed of borosilicate or quartz glass, or stainless steel; if a gasket is used, it shall be made of silicone rubber, Teflon, or stainless steel. Other holder and gasket materials may be used subject to the approval of the Administrator. The filter holder shall be designed to provide a positive seal against leakage from the outside or around the filter.

2.1.3 Probe Extension. Any suitable rigid probe extension may be used after the filter holder.

2.1.4 Pitot Tube. Type S, as described in Section 2.1 of Method 2, or other device approved by the Administrator; the pitot tube shall be attached to the probe extension to allow constant monitoring of the stack gas velocity (see Figure 17-1). The impact (high pressure) opening plane of the pitot tube shall be even with or above the nozzle entry plane during sampling (see Method 2,

Figure 2-6b). It is recommended: (1) that the pitot tube have a known baseline coefficient, determined as outlined in Section 4 of Method 2; and (2) that this known coefficient be preserved by placing the pitot tube in an interference-free arrangement with respect to the sampling nozzle, filter holder, and temperature sensor (see Figure 17-1). Note that the 1.9 cm (0.75 in) free-space between the nozzle and pitot tube shown in Figure 17-1, is based on a 1.3 cm (0.5 in) ID nozzle. If the sampling train is designed for sampling at higher flow rates than that described in APTD-0581, thus necessitating the use of larger sized nozzles, the free-space shall be 1.9 cm (0.75 in) with the largest sized nozzle in place.

Source-sampling assemblies that do not meet the minimum spacing requirements of Figure 17-1 (or the equivalent of these requirements, e.g., Figure 2-7 of Method 2) may be used; however, the pitot tube coefficients of such assemblies shall be determined by calibration, using methods subject to the approval of the Administrator.

2.1.5 Differential Pressure Gauge. Inclined manometer or equivalent device (two), as described in Section 2.2 of Method 2. One manometer shall be used for velocity head (Δp) readings, and the other, for orifice differential pressure readings.

2.1.6 Condenser. It is recommended that the impinger system described in Method 5 be used to determine the moisture content of the stack gas. Alternatively, any system that allows measurement of both the water condensed and the moisture leaving the condenser, each to within 1 ml or 1 g, may be used. The moisture leaving the condenser can be measured either by: (1) monitoring the temperature and pressure at the exit of the condenser and using Dalton's law of partial pressures; or (2) passing the sample gas stream through a silica gel trap with exit gases kept below 20° C (68° F) and determining the weight gain.

Flexible tubing may be used between the probe extension and condenser. If means other than silica gel are used to determine the amount of moisture leaving the condenser, it is recommended that silica gel still be used between the condenser system and pump to prevent moisture condensation in the pump and metering devices and to avoid the need to make corrections for moisture in the metered volume.

2.1.7 Metering System. Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 3° C (5.4° F), dry gas meter capable of measuring volume to within 2 percent, and related equipment, as shown in Figure 17-1. Other metering systems capable of maintaining sampling rates within 10 percent of isokinetic and of determining sample volumes to within 2 percent may be used, subject to the approval of the Administrator. When the metering system is used in conjunction with a pitot tube, the system shall enable checks of isokinetic rates.

Sampling trains utilizing metering systems designed for higher flow rates than that described in APTD-0581 or APTD-0576 may be used provided that the specifications of this method are met.

2.1.8 Barometer. Mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 in. Hg). In many cases, the barometric reading may be obtained from a nearby national weather service station, in which case the station value (which is the absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and sampling point shall be applied at a rate of minus 2.5 mm Hg (0.1 in. Hg) per 30 m (100 ft) elevation increase or vice versa for elevation decrease.

2.1.9 Gas Density Determination Equipment. Temperature sensor and pressure gauge, as described in Sections 2.3 and 2.4 of Method 2, and gas analyzer, if necessary, as described in Method 3.

The temperature sensor shall be attached to either the pitot tube or to the probe extension, in a fixed configuration. If the temperature sensor is attached in the field; the sensor shall be placed in an interference-free arrangement with respect to the Type S pitot tube openings (as shown in Figure 17-1 or in Figure 2-7 of Method 2). Alternatively, the temperature sensor need not be attached to either the probe extension or pitot tube during sampling, provided that a difference of not more than 1 percent in the average velocity measurement is introduced. This alternative is subject to the approval of the Administrator.

2.2 Sample Recovery.

2.2.1 Probe Nozzle Brush. Nylon bristle brush with stainless steel wire handle. The brush shall be properly sized and shaped to brush out the probe nozzle.

2.2.2 Wash Bottles—Two. Glass wash bottles are recommended; polyethylene wash bottles may be used at the option of the tester. It is recommended that acetone not be stored in polyethylene bottles for longer than a month.

2.2.3 Glass Sample Storage Containers. Chemically resistant, borosilicate glass bottles, for acetone washes, 500 ml or 1000 ml. Screw cap liners shall either be rubber-backed Teflon or shall be constructed so as to be leak-free and resistant to chemical attack by acetone. (Narrow mouth glass bottles have been found to be less prone to leakage.) Alternatively, polyethylene bottles may be used.

2.2.4 Petri Dishes. For filter samples; glass or polyethylene, unless otherwise specified by the Administrator.

2.2.5 Graduated Cylinder and/or Balance. To measure condensed water to within 1 ml or 1 g. Graduated cylinders shall have subdivisions no greater than 2 ml. Most laboratory balances are capable of weighing to the nearest 0.5 g or less. Any of these balances is suitable for use here and in Section 2.3.4.

2.2.6 Plastic Storage Containers. Air tight containers to store silica gel.

2.2.7 Funnel and Rubber Policeman. To aid in transfer of silica gel to container; not necessary if silica gel is weighed in the field.

2.2.8 Funnel. Glass or polyethylene, to aid in sample recovery.

2.3 Analysis.

2.3.1 Glass Weighing Dishes.

2.3.2 Desiccator.

2.3.3 Analytical Balance. To measure to within 0.1 mg.

2.3.4 Balance. To measure to within 0.5 mg.

2.3.5 Beakers. 250 ml.

2.3.6 Hygrometer. To measure the relative humidity of the laboratory environment.

2.3.7 Temperature Gauge. To measure the temperature of the laboratory environment.

3. *Reagents.*

3.1 Sampling.

3.1.1 Filters. The in-stack filters shall be glass mats or thimble fiber filters, without organic binders, and shall exhibit at least 99.95 percent efficiency (00.05 percent penetration) on 0.3 micron dioctyl phthalate smoke particles. The filter efficiency tests shall be conducted in accordance with ASTM standard method D 2986-71. Test data from the supplier's quality control program are sufficient for this purpose.

3.1.2 Silica Gel. Indicating type, 6- to 16-mesh. If previously used, dry at 175° C (350° F) for 2 hours. New silica gel may be used as received. Alternatively, other types of desiccants (equivalent or better) may be used, subject to the approval of the Administrator.

3.1.3 Crushed Ice.

3.1.4 Stopcock Grease. Acetone-insoluble, heat-stable silicone grease. This is not necessary if screw-on connectors with Teflon sleeves, or similar, are used. Alternatively, other types of stopcock grease may be used, subject to the approval of the Administrator.

3.2 Sample Recovery. Acetone, reagent grade, 00.001 percent residue, in glass bottles. Acetone from metal containers generally has a high residue blank and should not be used. Sometimes, suppliers transfer acetone to glass bottles from metal containers. Thus, acetone blanks shall be run prior to field use and only acetone with low blank values (00.001 percent) shall be used. In no case shall a blank value of greater than 0.001 percent of the weight of acetone used be subtracted from the sample weight.

3.3 Analysis.

3.3.1 Acetone. Same as 3.2.

3.3.2 Desiccant. Anhydrous calcium sulfate, indicating type. Alternatively, other types of desiccants may be used, subject to the approval of the Administrator.

4. *Procedure.*

4.1 Sampling. The complexity of this method is such that, in order to obtain reliable results, testers should be trained and experienced with the test procedures.

4.1.1 Pretest Preparation. All components shall be maintained and calibrated according to the procedure described in APTD-0576, unless otherwise specified herein.

Weigh several 200 to 300 g portions of silica gel in air-tight containers to the nearest 0.5 g. Record the total weight of the silica gel plus container, on each container. As an alternative, the silica gel need not be preweighed, but may be weighed directly in its impinger or sampling holder just prior to train assembly.

Check filters visually against light for irregularities and flaws or pinhole leaks. Label filters of the proper size on the back side near the edge using numbering machine ink. As an alternative, label the shipping containers (glass or plastic petri dishes) and keep the filters in these containers at all times except during sampling and weighing.

Desiccate the filters at 20±5.6° C (68±10° F) and ambient pressure for at least 24 hours and weigh at intervals of at least 6 hours to a constant weight, i.e., 00.5 mg change from previous weighing; record results to the nearest 0.1 mg. During each weighing the filter must not be exposed to the laboratory atmosphere for a period greater than 2 minutes and a relative humidity above 50 percent. Alternatively (unless otherwise specified by the Administrator), the filters may be oven dried at 105° C (220° F) for 2 to 3 hours, desiccated for 2 hours, and weighed. Procedures other than those described, which account for relative humidity effects, may be used, subject to the approval of the Administrator.

4.1.2 Preliminary Determinations. Select the sampling site and the minimum number of sampling points according to Method 1 or as specified by the Administrator. Make a projected-area model of the probe extension-filter holder assembly, with the pitot tube face openings positioned along the centerline of the stack, as shown in Figure 17-2. Calculate the estimated cross-section blockage, as shown in Figure 17-2. If the blockage exceeds 5 percent of the duct cross sectional area, the tester has the following options: (1) a suitable out-of-stack filtration method may be used instead of in-stack filtration; or (2) a special in-stack arrangement, in which the sampling and velocity measurement sites are separate, may be used; for details concerning this approach, consult with the Administrator (see also Citation 10 in Section 7). Determine the stack pressure, temperature, and the range of velocity heads using Method 2; it is recommended that a leak-check of the pitot lines (see Method 2, Section 3.1) be performed. Determine the moisture content using Approximation Method 4 or its alternatives for the purpose of making isokinetic sampling rate settings. Determine the stack gas dry molecular weight, as described in Method 2, Section 3.6; if integrated Method 3 sampling is used for molecular weight determination, the integrated bag sample shall be taken simultaneously with, and for the same total length of time as, the particular sample run.

Select a nozzle size based on the range of velocity heads, such that it is not necessary to change the nozzle size in order to maintain isokinetic sampling rates. During the run, do not change the nozzle size. Ensure that the proper differential pressure gauge is chosen for the range of velocity heads encountered (see Section 2.2 of Method 2).

Select a probe extension length such that all traverse points can be sampled. For large stacks, consider sampling from opposite sides of the stack to reduce the length of probes.

Select a total sampling time greater than or equal to the minimum total sampling time specified in the test procedures for the specific industry such that (1) the sampling time per point is not less than 2 minutes (or some greater time interval if specified by the Administrator), and (2) the sample volume taken (corrected to standard conditions) will exceed the required minimum total gas sample volume. The latter is based on an approximate average sampling rate.

It is recommended that the number of minutes sampled at each point be an integer or an integer plus one-half minute, in order to avoid timekeeping errors.

In some circumstances, e.g., batch cycles, it may be necessary to sample for shorter times at the traverse points and to obtain smaller gas sample volumes. In these cases, the Administrator's approval must first be obtained.

4.1.3 Preparation of Collection Train. During preparation and assembly of the sampling train, keep all openings where contamination can occur covered until just prior to assembly or until sampling is about to begin.

If impingers are used to condense stack gas moisture, prepare them as follows: place 100 ml of water in each of the first two impingers, leave the third impinger empty, and transfer approximately 200 to 300 g of preweighed silica gel from its container to the fourth impinger. More silica gel may be used, but care should be taken to ensure that it is not entrained and carried out from the impinger during sampling. Place the container in a clean place for later use in the sample recovery. Alternatively, the weight of the silica gel plus impinger may be determined to the nearest 0.5 g and recorded.

If some means other than impingers is used to condense moisture, prepare the condenser (and, if appropriate, silica gel for condenser outlet) for use.

Using a tweezer or clean disposable surgical gloves, place a labeled (identified) and weighed filter in the filter holder. Be sure that the filter is properly centered and the gasket properly placed so as not to allow the sample gas stream to circumvent the filter. Check filter for tears after assembly is completed. Mark the probe extension with heat resistant tape or by some other method to denote the proper distance into the stack or duct for each sampling point.

Assemble the train as in Figure 17-1, using a very light coat of silicone grease on all ground glass joints and greasing only the outer portion (see APTD-0576) to avoid possibility of contamination by the silicone grease. Place crushed ice around the impingers.

4.1.4 Leak Check Procedures. —

4.1.4.1 Pretest Leak-Check. A pretest leak-check is recommended, but not required. If the tester opts to conduct the pretest leak-check, the following procedure shall be used.

After the sampling train has been assembled, plug the inlet to the probe nozzle with a material that will be able to withstand the stack temperature. Insert the filter holder into the stack and wait approximately 5 minutes (or longer, if necessary) to allow the system to come to equilibrium with the temperature of the stack gas stream. Turn on the pump and draw a vacuum of at least 380 mm Hg (15 in. Hg); note that a lower vacuum may be used, provided that it is not exceeded during the test. Determine the leakage rate. A leakage rate in excess of 4 percent of the average sampling rate or 0.00057 m^3/min. (0.02 cfm), whichever is less, is unacceptable.

The following leak-check instructions for the sampling train described in APTD-0576 and APTD-0581 may be helpful. Start the pump with by-pass valve fully open and coarse adjust valve completely closed. Partially open the coarse adjust valve and slowly close the by-pass valve until the desired vacuum is reached. Do not reverse direction of by-pass valve. If the desired vacuum is exceeded, either leak-check at this higher vacuum or end the leak-check as shown below and start over.

When the leak-check is completed, first slowly remove the plug from the inlet to the probe nozzle and immediately turn off the vacuum pump. This prevents water from being forced backward and keeps silica gel from being entrained backward.

4.1.4.2 Leak-Checks During Sample Run. If, during the sampling run, a component (e.g., filter assembly or impinger) change becomes necessary, a leak-check shall be conducted immediately before the change is made. The leak-check shall be done according to the procedure outlined in Section 4.1.4.1 above, except that it shall be done at a vacuum equal to or greater than the maximum value recorded up to that point in the test. If the leakage rate is found to be no greater than 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction will need to be applied to the total volume of dry gas metered; if, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and plan to correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

Immediately after component changes, leak-checks are optional; if such leak-checks are done, the procedure outlined in Section 4.1.4.1 above shall be used.

4.1.4.3 Post-Test Leak-Check. A leak-check is mandatory at the conclusion of each sampling run. The leak-check shall be done in accordance with the procedures outlined in Section 4.1.4.1, except that it shall be conducted at a vacuum equal to or greater than the maximum value reached during the sampling run. If the leakage rate is found to be no greater than 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate (whichever is less), the results are acceptable, and no correction need be applied to the total volume of dry gas metered. If, however, a higher leakage rate is obtained, the tester shall either record the leakage rate and correct the sample volume as shown in Section 6.3 of this method, or shall void the sampling run.

4.1.5 Particulate Train Operation. During the sampling run, maintain a sampling rate such that sampling is within 10 percent of true isokinetic, unless otherwise specified by the Administrator.

For each run, record the data required on the example data sheet shown in Figure 17-3. Be sure to record the initial dry gas meter reading. Record the dry gas meter readings at the beginning and end of each sampling time increment, when changes in flow rates are made, before and after each leak check, and when sampling is halted. Take other readings required by Figure 17-3 at least once at each sample point during each time increment and additional readings when significant changes (20 percent variation in velocity head readings) necessitate additional adjustments in flow rate. Level and zero the manometer. Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Clean the portholes prior to the test run to minimize the chance of sampling the deposited material. To begin sampling, remove the nozzle cap and verify that the pitot tube and probe extension are properly positioned. Position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Nomographs are available, which aid in the rapid adjustment to the isokinetic sampling rate without excessive computations. These nomographs are designed for use when the Type S pitot tube coefficient is 0.85±0.02, and the stack gas equivalent density (dry molecular weight) is equal to 29±4. APTD-0576 details the procedure for using the nomographs. If C_p and M_d are outside the above stated ranges, do not use the nomographs unless appropriate steps (see Citation 7 in Section 7) are taken to compensate for the deviations.

When the stack is under significant negative pressure (height of impinger stem), take care to close the coarse adjust valve before inserting the probe extension assembly into the stack to prevent water from being forced backward. If necessary, the pump may be turned on with the coarse adjust valve closed.

When the probe is in position, block off the openings around the probe and porthole to prevent unrepresentative dilution of the gas stream.

Traverse the stack cross section, as required by Method 1 or as specified by the Administrator, being careful not to bump the probe nozzle into the stack walls when sampling near the walls or when removing or inserting the probe extension through the portholes, to minimize chance of extracting deposited material.

During the test run, take appropriate steps (e.g., adding crushed ice to the impinger ice bath) to maintain a temperature of less than 20° C (68° F) at the condenser outlet; this will prevent excessive moisture losses. Also, periodically check the level and zero of the manometer.

If the pressure drop across the filter becomes too high, making isokinetic sampling difficult to maintain, the filter may be replaced in the midst of a sample run. It is recommended that another complete filter holder assembly be used rather than attempting to change the filter itself. Before a new filter holder is installed, conduct a leak check, as outlined in Section 4.1.4.2. The total particulate weight shall include the summation of all filter assembly catches.

A single train shall be used for the entire sample run, except in cases where simultaneous sampling is required in two or more separate ducts or at two or more different locations within the same duct, or, in cases where equipment failure necessitates a change of trains. In all other situations, the use of two or more trains will be subject to the approval of the Administrator. Note that when two or more trains are used, a separate analysis of the collected particulate from each train shall be performed, unless identical nozzle sizes were used on all trains, in which case the particulate catches from the individual trains may be combined and a single analysis performed.

At the end of the sample run, turn off the pump, remove the probe extension assembly from the stack, and record the final dry gas meter reading. Perform a leak-check, as outlined in Section 4.1.4.3. Also, leak-check the pitot lines as described in Section 3.1 of Method 2; the lines must pass this leak-check, in order to validate the velocity head data.

4.1.6 Calculation of Percent Isokinetic. Calculate percent isokinetic (see Section 6.11) to determine whether another test run should be made. If there is difficulty in maintaining isokinetic rates due to source conditions, consult with the Administrator for possible variance on the isokinetic rates.

4.2 Sample Recovery. Proper cleanup procedure begins as soon as the probe extension assembly is removed from the stack at the end of the sampling period. Allow the assembly to cool.

When the assembly can be safely handled, wipe off all external particulate matter near the tip of the probe nozzle and place a cap over it to prevent losing or gaining particulate matter. Do not cap off the probe tip tightly while the sampling train is cooling down as this would create a vacuum in the filter holder, forcing condenser water backward.

Before moving the sample train to the cleanup site, disconnect the filter holder-probe nozzle assembly from the probe extension; cap the open inlet of the probe extension. Be careful not to lose any condensate, if present. Remove the umbilical cord from the condenser outlet and cap the outlet. If a flexible line is used between the first impinger (or condenser) and the probe extension, disconnect the line at the probe extension and let any condensed water or liquid drain into the impingers or condenser. Disconnect the probe extension from the condenser; cap the probe extension outlet. After wiping off the silicone grease, cap off the condenser inlet. Ground glass stoppers, plastic caps, or serum caps (whichever are appropriate) may be used to close these openings.

Transfer both the filter holder-probe nozzle assembly and the condenser to the cleanup area. This area should be clean and protected from the wind so that the chances of contaminating or losing the sample will be minimized.

Save a portion of the acetone used for cleanup as a blank. Take 200 ml of this acetone directly from the wash bottle being used and place it in a glass sample container labeled "acetone blank."

Inspect the train prior to and during disassembly and note any abnormal conditions. Treat the samples as follows:

Container No. 1. Carefully remove the filter from the filter holder and place it in its identified petri dish container. Use a pair of tweezers and/or clean disposable surgical gloves to handle the filter. If it is necessary to fold the filter, do so such that the particulate cake is inside the fold. Carefully transfer to the petri dish any particulate matter and/or filter fibers which adhere to the filter holder gasket, by using a dry Nylon bristle brush and/or a sharp-edged blade. Seal the container.

Container No. 2. Taking care to see that dust on the outside of the probe nozzle or other exterior surfaces does not get into the sample, quantitatively recover particulate matter or any condensate from the probe nozzle, fitting, and front half of the filter holder by washing these components with acetone and placing the wash in a glass container. Distilled water may be used instead of acetone when approved by the Administrator and shall be used when specified by the Administrator; in these cases, save a water blank and follow Administrator's directions on analysis. Perform the acetone rinses as follows:

Carefully remove the probe nozzle and clean the inside surface by rinsing with acetone from a wash bottle and brushing with a Nylon bristle brush. Brush until acetone rinse shows no visible particles, after which make a final rinse of the inside surface with acetone.

Brush and rinse with acetone the inside parts of the fitting in a similar way until no visible particles remain. A funnel (glass or polyethylene) may be used to aid in transferring liquid washes to the container. Rinse the brush with acetone and quantitatively collect these washings in the sample container. Between sampling runs, keep brushes clean and protected from contamination.

After ensuring that all joints are wiped clean of silicone grease (if applicable), clean the inside of the front half of the filter holder by rubbing the surfaces with a Nylon bristle brush and rinsing with acetone. Rinse each surface three times or more if needed to remove visible particulate. Make final rinse of the brush and filter holder. After all acetone washings and particulate matter are collected in the sample container, tighten the lid on the sample container so that acetone will not leak out when it is shipped to the laboratory. Mark the height of the fluid level to determine whether or not leakage occurred during transport. Label the container to clearly identify its contents.

Container No. 3. If silica gel is used in the condenser system for mositure content determination, note the color of the gel to determine if it has been completely spent; make a notation of its condition. Transfer the silica gel back to its original container and seal. A funnel may make it easier to pour the silica gel without spilling, and a rubber policeman may be used as an aid in removing the silica gel. It is not necessary to remove the small amount of dust particles that may adhere to the walls and are difficult to remove. Since the gain in weight is to be used for moisture calculations, do not use any water or other liquids to transfer the silica gel. If a balance is available in the field, follow the procedure for Container No. 3 under "Analysis."

Condenser Water. Treat the condenser or impinger water as follows: make a notation of any color or film in the liquid catch. Measure the liquid volume to within ±1 ml by using a graduated cylinder or, if a balance is available, determine the liquid weight to within ±0.5 g. Record the total volume or weight of liquid present. This information is required to calculate the moisture content of the effluent gas. Discard the liquid after measuring and recording the volume or weight.

4.3 Analysis. Record the data required on the example sheet shown in Figure 17-4. Handle each sample container as follows:

Container No. 1. Leave the contents in the shipping container or transfer the filter and any loose particulate from the sample container to a tared glass weighing dish. Desiccate for 24 hours in a desiccator containing anhydrous calcium sulfate. Weigh to a constant weight and report the results to the nearest 0.1 mg. For purposes of this Section, 4.3, the term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater, between two consecutive weighings, with no less than 6 hours of desiccation time between weighings.

Alternatively, the sample may be oven dried at the average stack temperature or 105° C (220° F), whichever is less, for 2 to 3 hours, cooled in the desiccator, and weighed to a constant weight, unless otherwise specified by the Administrator. The tester may also opt to oven dry the sample at the average stack temperature or 105° C (220° F), whichever is less, for 2 to 3 hours, weigh the sample, and use this weight as a final weight.

Container No. 2. Note the level of liquid in the container and confirm on the analysis sheet whether or not leakage occurred during transport. If a noticeable amount of leakage has occurred, either void the sample or use methods, subject to the approval of the Administrator, to correct the final results. Measure the liquid in this container either volumetrically to ±1 ml or gravimetrically to ±0.5 g. Transfer the contents to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

Container No. 3. This step may be conducted in the field. Weigh the spent silica gel (or silica gel plus impinger) to the nearest 0.5 g using a balance.

"Acetone Blank" Container. Measure acetone in this container either volumetrically or gravimetrically. Transfer the acetone to a tared 250-ml beaker and evaporate to dryness at ambient temperature and pressure. Desiccate for 24 hours and weigh to a constant weight. Report the results to the nearest 0.1 mg.

NOTE.—At the option of the tester, the contents of Container No. 2 as well as the acetone blank container may be evaporated at temperatures higher than ambient. If evaporation is done at an elevated temperature, the temperature must be below the boiling point of the solvent; also, to prevent "bumping," the evaporation process must be closely supervised, and the contents of the beaker must be swirled occasionally to maintain an even temperature. Use extreme care, as acetone is highly flammable and has a low flash point.

5. *Calibration.* Maintain a laboratory log of all calibrations.

5.1 Probe Nozzle. Probe nozzles shall be calibrated before their initial use in the field. Using a micrometer, measure the inside diameter of the nozzle to the nearest 0.025 mm (0.001 in.). Make three separate measurements using different diameters each time, and obtain the average of the measurements. The difference between the high and low numbers shall not exceed 0.1 mm (0.004 in.). When nozzles become nicked, dented, or corroded, they shall be reshaped, sharpened, and recalibrated before use. Each nozzle shall be permanently and uniquely identified.

5.2 Pitot Tube. If the pitot tube is placed in an interference-free arrangement with respect to the other probe assembly components, its baseline (isolated tube) coefficient shall be determined as outlined in Section 4 of Method 2. If the probe assembly is not interference-free, the pitot tube assembly coefficient shall be determined by calibration, using methods subject to the approval of the Administrator.

5.3 Metering System. Before its initial use in the field, the metering system shall be calibrated according to the procedure outlined in APTD-0576. Instead of physically adjusting the dry gas meter dial readings to correspond to the wet test meter readings, calibration factors may be used to mathematically correct the gas meter dial readings to the proper values.

Before calibrating the metering system, it is suggested that a leak-check be conducted. For metering systems having diaphragm pumps, the normal leak-check procedure will not detect leakages within the pump. For these cases the following leak-check procedure is suggested: make a 10-minute calibration run at 0.00057 m^3/min (0.02 cfm); at the end of the run, take the difference of the measured wet test meter and dry gas meter volumes; divide the difference by 10, to get the leak rate. The leak rate should not exceed 0.00057 m^3/min (0.02 cfm).

After each field use, the calibration of the metering system shall be checked by performing three calibration runs at a single, intermediate orifice setting (based on the previous field test), with the vacuum set at the maximum value reached during the test series. To adjust the vacuum, insert a valve between the wet test meter and the inlet of the metering system. Calculate the average value of the calibration factor. If the calibration has changed by more than 5 percent, recalibrate the meter over the full range of orifice settings, as outlined in APTD-0576.

Alternative procedures, e.g., using the orifice meter coefficients, may be used, subject to the approval of the Administrator.

NOTE.—If the dry gas meter coefficient values obtained before and after a test series differ by more than 5 percent, the test series shall either be voided, or calculations for the test series shall be performed using whichever meter coefficient value (i.e., before or after) gives the lower value of total sample volume.

5.4 Temperature Gauges. Use the procedure in Section 4.3 of Method 2 to calibrate in-stack temperature gauges. Dial thermometers, such as are used for the dry gas meter and condenser outlet, shall be calibrated against mercury-in-glass thermometers.

5.5 Leak Check of Metering System Shown in Figure 17-1. That portion of the sampling train from the pump to the orifice meter should be leak checked prior to initial use and after each shipment. Leakage after the pump will result in less volume being recorded than is actually sampled. The following procedure is suggested (see Figure 17-5). Close the main valve on the meter box. Insert a one-hole rubber stopper with rubber tubing attached into the orifice exhaust pipe. Disconnect and vent the low side of the orifice manometer. Close off the low side orifice tap. Pressurize the system to 13 to 18 cm (5 to 7 in.) water column by blowing into the rubber tubing. Pinch off the tubing and observe the manometer for one minute. A loss of pressure on the manometer indicates a leak in the meter box; leaks, if present, must be corrected.

5.6 Barometer. Calibrate against a mercury barometer.

6. *Calculations.* Carry out calculations, retaining at least one extra decimal figure beyond that of the acquired data. Round off figures after the final calculation. Other forms of the equations may be used as long as they give equivalent results.

6.1 Nomenclature.

A_n = Cross-sectional area of nozzle, m^2 (ft^2).

B_{ws} = Water vapor in the gas stream, proportion by volume.

C_a = Acetone blank residue concentration, mg/g.

c_s = Concentration of particulate matter in stack gas, dry basis, corrected to standard conditions, g/dscm (g/dscf).

I = Percent of isokinetic sampling.

L_a = Maximum acceptable leakage rate for either a pretest leak check or for a leak check following a component change; equal to 0.00057 m^3/min (0.02 cfm) or 4 percent of the average sampling rate, whichever is less.

L_i = Individual leakage rate observed during the leak check conducted prior to the "i^{th}" component change (i = 1, 2, 3 . . . n), m^3/min (cfm).

L_p = Leakage rate observed during the post-test leak check, m^3/min (cfm).

m_n = Total amount of particulate matter collected, mg.

M_w = Molecular weight of water, 18.0 g/g-mole (18.0 lb/lb-mole).

m_a = Mass of residue of acetone after evaporation, mg.

P_{bar} = Barometric pressure at the sampling site, mm Hg (in. Hg).

P_s = Absolute stack gas pressure, mm Hg (in. Hg).

P_{std} = Standard absolute pressure, 760 mm Hg (29.92 in. Hg).

R = Ideal gas constant, 0.06236 mm Hg-m^3/°K-g-mole (21.85 in. Hg-ft^3/°R-lb-mole).

T_m = Absolute average dry gas meter temperature (see Figure 17-3), °K (°R).

T_s = Absolute average stack gas temperature (see Figure 17-3), °K (°R).

T_{std} = Standard absolute temperature, 293°K (528°R).

V_a = Volume of acetone blank, ml.

V_{aw} = Volume of acetone used in wash, ml.

V_{lc} = Total volume of liquid collected in impingers and silica gel (see Figure 17-4), ml.

V_m = Volume of gas sample as measured by dry gas meter, dcm (dcf).

$V_{m(std)}$ = Volume of gas sample measured by the dry gas meter, corrected to standard conditions, dscm (dscf).

$V_{w(std)}$ = Volume of water vapor in the gas sample, corrected to standard conditions, scm (scf).

v_s = Stack gas velocity, calculated by Method 2, Equation 2-9, using data obtained from Method 17, m/sec (ft/sec).

W_a = Weight of residue in acetone wash, mg.

Y = Dry gas meter calibration coefficient.

ΔH = Average pressure differential across the orifice meter (see Figure 17-3), mm H_2O (in. H_2O).

ρ_a = Density of acetone, mg/ml (see label on bottle).

ρ_w = Density of water, 0.9982 g/ml (0.002201 lb/ml).

θ = Total sampling time, min.

θ_1 = Sampling time interval, from the beginning of a run until the first component change, min.

θ_i = Sampling time interval, between two successive component changes, beginning with the interval between the first and second changes, min.

θ_p = Sampling time interval, from the final (n^{th}) component change until the end of the sampling run, min.
13.6 = Specific gravity of mercury.
60 = Sec/min.
100 = Conversion to percent.

6.2 Average dry gas meter temperature and average orifice pressure drop. See data sheet (Figure 17-3).

6.3 Dry Gas Volume. Correct the sample volume measured by the dry gas meter to standard conditions (20° C, 760 mm Hg or 68° F, 29.92 in. Hg) by using Equation 17-1.

$$V_{m(std)} = V_m Y\left(\frac{T_{std}}{T_m}\right)\left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right]$$

$$= K_1 V_m Y \frac{P_{bar} + (\Delta H/13.6)}{T_m}$$

Equation 17-1

where:

K_1 = 0.3858° K/mm Hg for metric units; 17.64° R/in. Hg for English units.

NOTE.—Equation 17-1 can be used as written unless the leakage rate observed during any of the mandatory leak checks (i.e., the post-test leak check or leak checks conducted prior to component changes) exceeds L_a. If L_p or L_i exceeds L_a, Equation 17-1 must be modified as follows:

(a) Case I. No component changes made during sampling run. In this case, replace V_m in Equation 17-1 with the expression:

$$[V_m - (L_p - L_a)\theta]$$

(b) Case II. One or more component changes made during the sampling run. In this case, replace V_m in Equation 17-1 by the expression:

$$[V_m - (L_1 - L_a)\theta_1 - \sum_{i=2}^{n}(L_i - L_a)\theta_i - (L_p - L_a)\theta_p]$$

and substitute only for those leakage rates (L_i or L_p) which exceed L_a.

6.4 Volume of water vapor.

$$V_{w(std)} = V_{1c}\left(\frac{\rho_w}{M_w}\right)\left(\frac{RT_{std}}{P_{std}}\right) = K_2 V_{1c}$$

Equation 17-2

where:

K_2 = 0.001333 m^3/ml for metric units; 0.04707 ft^3/ml for English units.

6.5 Moisture Content.

$$B_{ws} = \frac{V_{w(std)}}{V_{m(std)} + V_{w(std)}}$$

Equation 17-3

6.6 Acetone Blank Concentration.

$$C_a = \frac{m_a}{V_a \rho_a}$$

Equation 17-4

6.7 Acetone Wash Blank.

$$W_a = C_a V_{aw} \rho_a$$

Equation 17-5

6.8 Total Particulate Weight. Determine the total particulate catch from the sum of the weights obtained from containers 1 and 2 less the acetone blank (see Figure 17-4).

NOTE.—Refer to Section 4.1.5 to assist in calculation of results involving two or more filter assemblies or two or more sampling trains.

6.9 Particulate Concentration.

$$c_s = (0.001 \text{ g/mg})(m_n/V_{m(std)})$$

Equation 17-6

6.10 Conversion Factors:

From	To	Multiply by
scf	m^3	0.02832
g/ft^3	gr/ft^3	15.43
g/ft^3	lb/ft^3	2.205×10^{-3}
g/ft^3	g/m^3	35.31

6.11 Isokinetic Variation.

6.11.1 Calculation from Raw Data.

$$I = \frac{100\, T_s\, [K_3 V_{1c} + (V_m Y/T_m)\,(P_{bar} + \Delta H/13.6)]}{60\, \theta v_s\, P_s\, A_n}$$

Equation 17-7

where:

K_3 = 0.003454 mm Hg-m^3/ml-°K for metric units; 0.002669 in. Hg-ft^3/ml-°R for English units.

Method 17, Continued

6.11.2 Calculation from Intermediate Values.

$$I = \frac{T_s V_{m(std)} P_{std} 100}{T_{std} v_s \theta A_n P_s 60 (1-B_{ws})}$$

$$= K_4 \frac{T_s V_{m(std)}}{P_s v_s A_n \theta (1-B_{ws})}$$

Equation 17-8

where:

K_4=4.320 for metric units; 0.09450 for English units.

6.12 Acceptable Results. If 90 percent 010110 percent, the results are acceptable. If the results are low in comparison to the standard and I is beyond the acceptable range, or, if I is less than 90 percent, the Administrator may opt to accept the results. Use Citation 4 in Section 7 to make judgments. Otherwise, reject the results and repeat the test.

7. *Bibliography.*

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Method 17, Continued

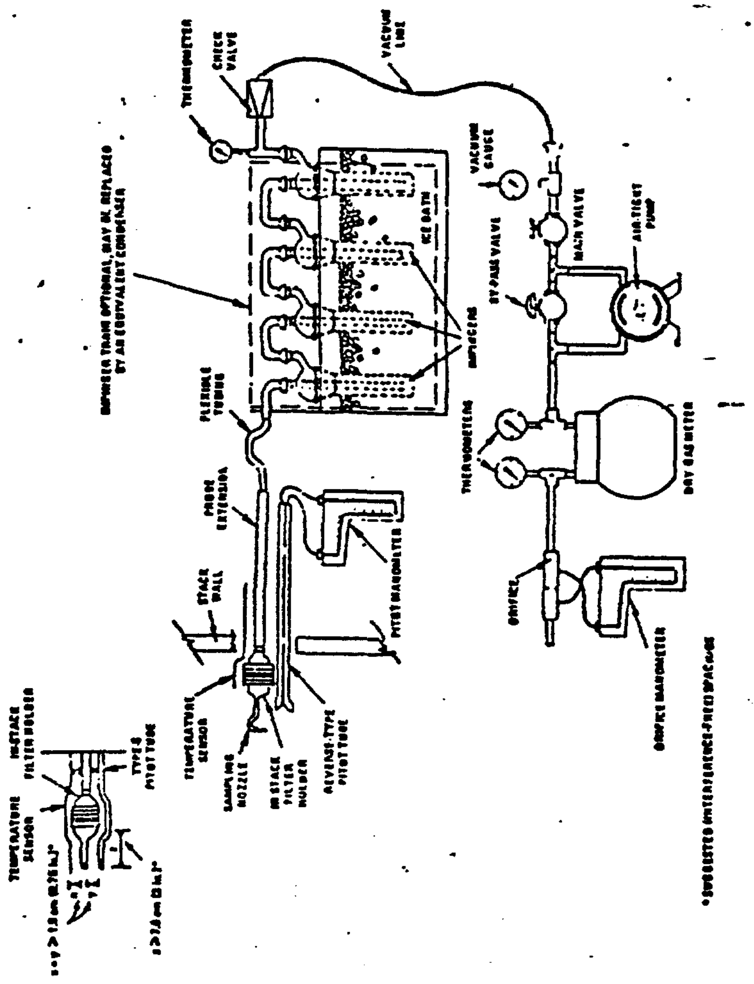

Figure 17-1. Particulate-Sampling Train, Equipped with In-Stack Filter.

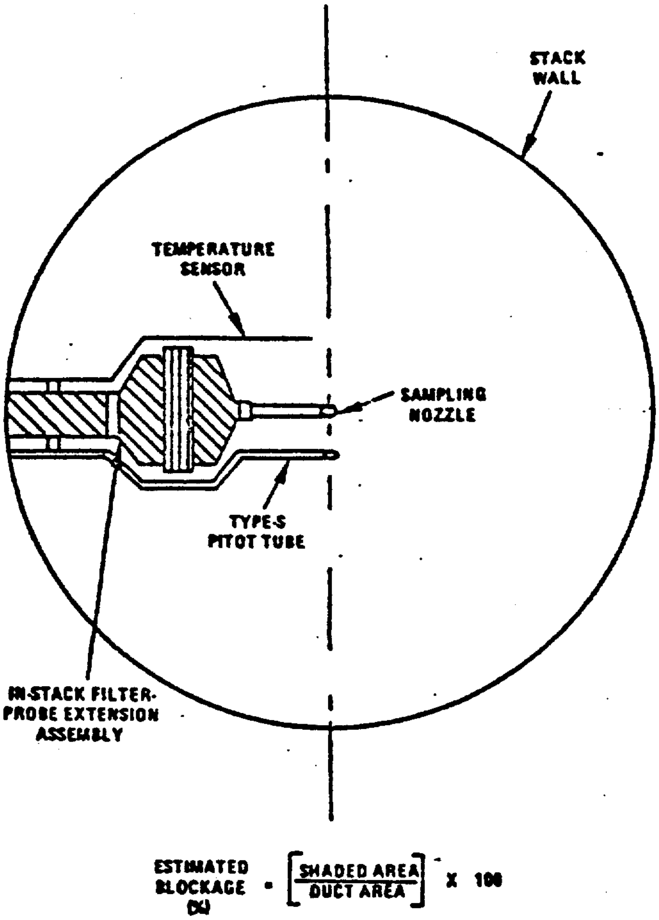

Figure 17-2. Projected-area model of cross-section blockage (approximate average for a sample traverse) caused by an in-stack filter holder-probe extension assembly.

PLANT ____________

LOCATION ____________

OPERATOR ____________

DATE ____________

RUN NO. ____________

SAMPLE BOX NO. ____________

METER BOX NO. ____________

METER ΔH@ ____________

C FACTOR ____________

PITOT TUBE COEFFICIENT, Cp ____________

SCHEMATIC OF STACK CROSS SECTION

BAROMETRIC PRESSURE ____________

ASSUMED MOISTURE, % ____________

PROBE EXTENSION LENGTH, m(ft.) ____________

NOZZLE IDENTIFICATION NO. ____________

AVERAGE CALIBRATED NOZZLE DIAMETER cm(in.) ____________

FILTER NO. ____________

LEAK RATE, m³/min,(cfm) ____________

STATIC PRESSURE, mm Hg (in. Hg) ____________

TRAVERSE POINT NUMBER	SAMPLING TIME (θ), min.	VACUUM mm Hg (in. Hg)	STACK TEMPERATURE (T_S), °C (°F)	VELOCITY HEAD (ΔP_S), mm H_2O (in. H_2O)	PRESSURE DIFFERENTIAL ACROSS ORIFICE METER, mm H_2O (in. H_2O)	GAS SAMPLE VOLUME, m^3 (ft^3)	GAS SAMPLE TEMPERATURE AT DRY GAS METER		TEMPERATURE OF GAS LEAVING CONDENSER OR LAST IMPINGER, °C (°F)
							INLET, °C (°F)	OUTLET, °C (°F)	
TOTAL							Avg	Avg	
AVERAGE							Avg		

Figure 17-3. Particulate field data.

Method 17, Continued

Plant ____________________

Date ____________________

Run No. ____________________

Filter No. ____________________

Amount liquid lost during transport ____________________

Acetone blank volume, ml ____________________

Acetone wash volume, ml ____________________

Acetone blank concentration, mg/mg (equation 17-4) ____________________

Acetone wash blank, mg (equation 17-5) ____________________

CONTAINER NUMBER	WEIGHT OF PARTICULATE COLLECTED, mg		
	FINAL WEIGHT	TARE WEIGHT	WEIGHT GAIN
1			
2			
TOTAL			
		Less acetone blank	
		Weight of particulate matter	

	VOLUME OF LIQUID WATER COLLECTED	
	IMPINGER VOLUME, ml	SILICA GEL WEIGHT, g
FINAL		
INITIAL		
LIQUID COLLECTED		
TOTAL VOLUME COLLECTED		g* ml

* CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER (1g/ml).

$$\frac{\text{INCREASE, g}}{1\ \text{g/ml}} = \text{VOLUME WATER, ml}$$

Figure 17-4. Analytical data.

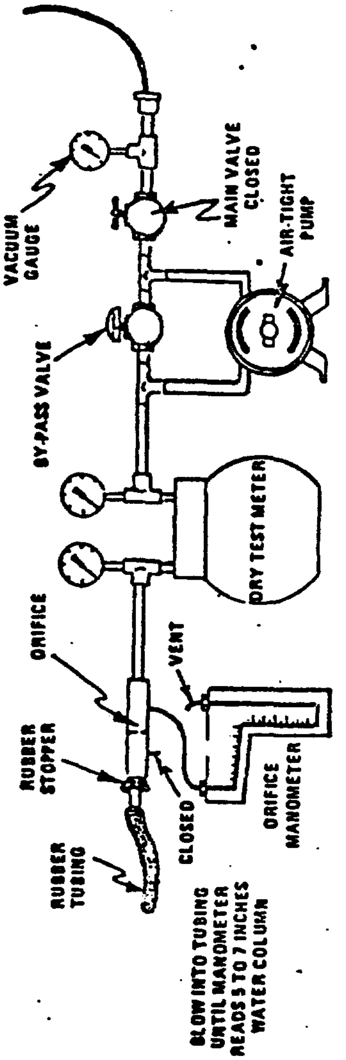

Figure 17-5. Leak check of meter box.

6 1.81

Method 19

DETERMINATION OF SULFUR DIOXIDE REMOVAL EFFICIENCY AND PARTICULATE, SULFUR DIOXIDE AND NITROGEN OXIDES EMISSION RATES FROM ELECTRIC UTILITY STEAM GENERATORS

(40 CFR 60, Appendix A, June 11, 1979)

1. *Principle and Applicability*

1.1 *Principle.*

1.1.1 Fuel samples from before and after fuel pretreatment systems are collected and analyzed for sulfur and heat content, and the percent sulfur dioxide (ng/Joule, lb/million Btu) reduction is calculated on a dry basis. (Optional Procedure.)

1.1.2 Sulfur dioxide and oxygen or carbon dioxide concentration data obtained from sampling emissions upstream and downstream of sulfur dioxide control devices are used to calculate sulfur dioxide removal efficiencies. (Minimum Requirement.) As an alternative to sulfur dioxide monitoring upstream of sulfur dioxide control devices, fuel samples may be collected in an as-fired condition and analyzed for sulfur and heat content. (Optional Procedure.)

1.1.3 An overall sulfur dioxide emission reduction efficiency is calculated from the efficiency of fuel pretreatment systems and the efficiency of sulfur dioxide control devices.

1.1.4 Particulate, sulfur dioxide, nitrogen oxides, and oxygen or carbon dioxide concentration data obtained from sampling emissions downstream from sulfur dioxide control devices are used along with F factors to calculate particulate, sulfur dioxide, and nitrogen oxides emission rates. F factors are values relating combustion gas volume to the heat content of fuels.

1.2 *Applicability.* This method is applicable for determining sulfur removal efficiencies of fuel pretreatment and sulfur dioxide control devices and the overall reduction of potential sulfur dioxide emissions from electric utility steam generators. This method is also applicable for the determination of particulate, sulfur dioxide, and nitrogen oxides emission rates.

2. *Determination of Sulfur Dioxide Removal Efficiency of Fuel Pretreatment Systems*

2.1 *Solid Fossil Fuel.*

2.1.1 *Sample Increment Collection.* Use ASTM D 2234 [1], Type I, conditions A, B, or C, and systematic spacing. Determine the number and weight of increments required per gross sample representing each coal lot according to Table 2 or Paragraph 7.1.5.2 of ASTM D 2234 [1]. Collect one gross sample for each raw coal lot and one gross sample for each product coal lot.

2.1.2 *ASTM Lot Size.* For the purpose of Section 2.1.1, the product coal lot size is defined as the weight of product coal produced from one type of raw coal. The raw coal lot size is the weight of raw coal used to produce one product coal lot. Typically, the lot size is the weight of coal processed in a 1-day (24 hours) period. If more than one type of coal is treated and produced in 1 day, then gross samples must be collected and analyzed for each type of coal. A coal lot size equaling the 90-day quarterly fuel quantity for a specific power plant may be used if representative sampling can be conducted for the raw coal and product coal.

Note.—Alternate definitions of fuel lot sizes may be specified subject to prior approval of the Administrator.

2.1.3 *Gross Sample Analysis.* Determine the percent sulfur content (%S) and gross calorific value (GCV) of the solid fuel on a dry basis for each gross sample. Use ASTM 2013 [1] for sample preparation, ASTM D 3177 [1] for sulfur analysis, and ASTM D 3173 [1] for moisture analysis. Use ASTM D 3176 [1] for gross calorific value determination.

2.2 *Liquid Fossil Fuel.*

2.2.1 *Sample Collection.* Use ASTM D 270 [1] following the practices outlined for continuous sampling for each gross sample representing each fuel lot.

2.2.2 *Lot Size.* For the purposes of Section 2.2.1, the weight of product fuel from one pretreatment facility and intended as one shipment (ship load, barge load, etc.) is defined as one product fuel lot. The weight of each crude liquid fuel type used to produce one product fuel lot is defined as one inlet fuel lot.

Note.—Alternate definitions of fuel lot sizes may be specified subject to prior approval of the Administrator.

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[1] Use the most recent revision or designation of the ASTM procedure specified.

Note.— For the purposes of this method, raw or inlet fuel (coal or oil) is defined as the fuel delivered to the desulfurization pretreatment facility or to the steam generating plant. For pretreated oil the input oil to the oil desulfurization process (e.g. hydrotreatment emitted) is sampled.

2.2.3 *Sample Analysis.* Determine the percent sulfur content (%S) and gross calorific value (GCV). Use ASTMD 240 [1] for the sample analysis. This value can be assumed to be on a dry basis.

2.3 *Calculation of Sulfur Dioxide Removal Efficiency Due to Fuel Pretreatment.* Calculate the percent sulfur dioxide reduction due to fuel pretreatment using the following equation:

$$\%R_f = 100 \left[1 - \frac{\%S_o/GCV_o}{\%S_i/GCV_i} \right]$$

Where:

$\%R_f$ = Sulfur dioxide removal efficiency due pretreatment; percent.

$\%S_o$ = Sulfur content of the product fuel lot on a dry basis; weight percent.

$\%S_i$ = Sulfur content of the inlet fuel lot on a dry basis; weight percent.

GCV_o = Gross calorific value for the outlet fuel lot on a dry basis; kJ/kg (Btu/lb).

GCV_i = Gross calorific value for the inlet fuel lot on a dry basis; kJ/kg (Btu/1b).

Note.—If more than one fuel type is used to produce the product fuel, use the following equation to calculate the sulfur contents per unit of heat content of the total fuel lot, %S/GCV:

$$\%S/GCV = \sum_{k=1}^{n} Y_k(\%S_k/GCV_k)$$

Where:

Y_k = The fraction of total mass input derived from each type, k, of fuel.

$\%S_k$ = Sulfur content of each fuel type, k, on a dry basis; weight percent.

GCV_k = Gross calorific value for each fuel type, k, on a dry basis; kJ/kg (Btu/lb).

n = The number of different types of fuels.

3. *Determination of Sulfur Removal Efficiency of the Sulfur Dioxide Control Device*

3.1 *Sampling.* Determine SO_2 emission rates at the inlet and outlet of the sulfur dioxide control system according to methods specified in the applicable subpart of the regulations and the procedures specified in Section 5. The inlet sulfur dioxide emission rate may be determined through fuel analysis (Optional, see Section 3.3.)

3.2 *Calculation.* Calculate the percent removal efficiency using the following equation:

$$\%R_{g(s)} = 100 \times \left(1.0 - \frac{E_{SO_2 o}}{E_{SO_2 i}}\right)$$

Where:

$\%R_g$ = Sulfur dioxide removal efficiency of the sulfur dioxide control system using inlet and outlet monitoring data; percent.

$E_{SO_2 o}$ = Sulfur dioxide emission rate from the outlet of the sulfur dioxide control system; ng/J (lb/million Btu).

$E_{SO_2 i}$ = Sulfur dioxide emission rate to the outlet of the sulfur dioxide control system; ng/J (lb/million Btu).

3.3 . *As-fired Fuel Analysis (Optional Procedure).* If the owner or operator of an electric utility steam generator chooses to determine the sulfur dioxide input rate at the inlet to the sulfur dioxide control device through an as-fired fuel analysis in lieu of data from a sulfur dioxide control system inlet gas monitor, fuel samples must be collected in accordance with applicable paragraph in Section 2. The sampling can be conducted upstream of any fuel processing, e.g., plant coal pulverization. For the purposes of this section, a fuel lot size is defined as the weight of fuel consumed in 1 day (24 hours) and is directly related to the exhaust gas monitoring data at the outlet of the sulfur dioxide control system.

3.3.1 *Fuel Analysis.* Fuel samples must be analyzed for sulfur content and gross calorific value. The ASTM procedures for determining sulfur content are defined in the applicable paragraphs of Section 2.

3.3.2 *Calculation of Sulfur Dioxide Input Rate.* The sulfur dioxide input rate determined from fuel analysis is calculated by:

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[1] Use the most recent revision or designation of the ASTM procedure specified.

$$I_s = \frac{2.0(\%S_f)}{GCV} \times 10^7 \text{ for S. I. units.}$$

$$I_s = \frac{2.0(\%S_f)}{GCV} \times 10^4 \text{ for English units.}$$

Where:

I_s = Sulfur dioxide input rate from as-fired fuel analysis, ng/J (lb/million Btu).

$\%S_f$ = Sulfur content of as-fired fuel, on a dry basis; weight percent.

GCV = Gross calorific value for as-fired fuel, on a dry basis; kJ/kg (Btu/lb).

5.3.3 *Calculation of Sulfur Dioxide Emission Reduction Using As-fired Fuel Analysis.* The sulfur dioxide emission reduction efficiency is calculated using the sulfur imput rate from paragraph 5.3.2 and the sulfur dioxide emission rate, E_{SO_2}, determined in the applicable paragraph of Section 5.3. The equation for sulfur dioxide emission reduction efficiency is:

$$\%R_{g(f)} = 100 \times (1.0 - \frac{E_{SO_2}}{I_s})$$

Where:

$\%R_{g(f)}$ = Sulfur dioxide removal efficiency of the sulfur dioxide control system using as-fired fuel analysis data; percent.

E_{SO_2} = Sulfur dioxide emission rate from sulfur dioxide control system; ng/J (lb/million Btu).

I_s = Sulfur dioxide input rate from as-fired fuel analysis; ng/J (lb/million Btu).

4. *Calculation of Overall Reduction in Potential Sulfur Dioxide Emission*

4.1 The overall percent sulfur dioxide reduction calculation uses the sulfur dioxide concentration at the inlet to the sulfur dioxide control device as the base value. Any sulfur reduction realized through fuel cleaning is introduced into the equation as an average percent reduction, $\%R_f$.

4.2 Calculate the overall percent sulfur reduction as:

$$\%R_o = 100[1.0 - (1.0 - \frac{\%R_f}{100})(1.0 - \frac{\%R_g}{100})]$$

Where:

$\%R_o$ = Overall sulfur dioxide reduction; percent.

$\%R_f$ = Sulfur dioxide removal efficiency of fuel pretreatment from Section 2; percent. Refer to applicable subpart for definition of applicable averaging period.

$\%R_g$ = Sulfur dioxide removal efficiency of sulfur dioxide control device either O_2 or CO_2 - based calculation or calculated from fuel analysis and emission data, from Section 3; percent. Refer to applicable subpart for definition of applicable averaging period.

5. *Calculation of Particulate, Sulfur Dioxide, and Nitrogen Oxides Emission Rates*

5.1 *Sampling.* Use the outlet SO_2 or O_2 or CO_2 concentrations data obtained in Section 3.1. Determine the particulate, NO_x, and O_2 or CO_2 concentrations according to methods specified in an applicable subpart of the regulations.

5.2 *Determination of an F Factor.* Select an average F factor (Section 5.2.1) or calculate an applicable F factor (Section 5.2.2.). If combined fuels are fired, the selected or calculated F factors are prorated using the procedures in Section 5.2.3. F factors are ratios of the gas volume released during combustion of a fuel divided by the heat content of the fuel. A dry F factor (F_d) is the ratio of the volume of dry flue gases generated to the calorific value of the fuel combusted; a wet F factor (F_w) is the ratio of the volume of wet flue gases generated to the calorific value of the fuel combusted; and the carbon F factor (F_c) is the ratio of the volume of carbon dioxide generated to the calorific value of the fuel combusted. When pollutant and oxygen concentrations have been determined in Section 5.1, wet or dry F factors are used. (F_w) factors and associated emission calculation procedures are not applicable and may not be used after wet scrubbers; (F_c) or (F_d) factors and associated emission calculation procedures are used after wet scrubbers.) When pollutant and carbon dioxide concentrations have been determined in Section 5.1, F_c factors are used.

5.2.1 *Average F Factors.* Table 1 shows average F_d, F_w, and F_c factors (scm/J, scf/million Btu) determined for commonly used fuels. For fuels not listed in Table 1, the F factors are calculated according to the procedures outlined in Section 5.2.2 of this section.

5.2.2 *Calculating an F Factor.* If the fuel burned is not listed in Table 1 or if the owner or operator chooses to determine an F factor rather than use the tabulated data, F factors are calculated using the equations below. The sampling and analysis procedures followed in obtaining data for these calculations are subject to the approval of the Administrator and the Administrator should be consulted prior to data collection.

For SI Units:

$$F_d = \frac{227.0(\%H) + 95.7(\%C) + 35.4(\%S) + 8.6(\%N) - 28.5(\%O)}{GCV}$$

$$F_w = \frac{347.4(\%H)+95.7(\%C)+35.4(\%S)+8.6(\%N)-28.5(\%O)+13.0(\%H_2O)^{**}}{GCV_w}$$

$$F_c = \frac{20.0(\%C)}{GCV}$$

For English Units:

$$F_d = \frac{10^6[5.57(\%H) + 1.53(\%C) + 0.57(\%S) + 0.14(\%N) - 0.46(\%O)]}{GCV}$$

$$F_w = \frac{10^6[5.57(\%H)+1.53(\%C)+0.57(\%S)+0.14(\%N)-0.46(\%O)+0.21(\%H_2O)^{**}]}{GCV_w}$$

$$F_c = \frac{10^6[0.321(\%C)]}{GCV}$$

** The $\%H_2O$ term may be omitted if %H and %O include the unavailable hydrogen and oxygen in the form of H_2O.

Where:

F_d, F_w, and F_c have the units of scm/J, or scf/million Btu; %H, %C, %S, %N, %O, and $\%H_2O$ are the concentrations by weight (expressed in percent) of hydrogen, carbon, sulfur, nitrogen, oxygen, and water from an ultimate analysis of the fuel; and GCV is the gross calorific value of the fuel in kJ/kg or Btu/lb and consistent with the ultimate analysis. Follow ASTM D 2015* for solid fuels, D 240* for liquid fuels, and D 1826* for gaseous fuels as applicable in determining GCV.

5.2.3 *Combined Fuel Firing F Factor.* For affected facilities firing combinations of fossil fuels or fossil fuels and wood residue, the F_d, F_w, or F_c factors determined by Sections 5.2.1 or 5.2.2 of this section shall be prorated in accordance with applicable formula as follows:

$$F_d = \sum_{k=1}^{n} x_k F_{dk} \quad \text{or}$$

$$F_w = \sum_{k=1}^{n} x_k F_{wk} \quad \text{or}$$

$$F_c = \sum_{k=1}^{n} x_k F_{ck}$$

Where:

x_k = The fraction of total heat input derived from each type of fuel, K.

n = The number of fuels being burned in combination.

5.3 *Calculation of Emission Rate.* Select from the following paragraphs the applicable calculation procedure and calculate the particulate, SO_2, and NO_x emission rate. The values in the equations are defined as:

E = Pollutant emission rate, ng/J (lb/million Btu).

C = Pollutant concentration, ng/scm (lb/scf).

Note.—It is necessary in some cases to convert measured concentration units to other units for these calculations.

Use the following table for such conversions:

Conversion Factors for Concentration

From—	To—	Multiply by—
g/scm	ng/scm	10^9
mg/scm	ng/scm	10^6
lb/scf	ng/scm	1.602×10^{13}
ppm(SO_2)	ng/scm	2.660×10^6
ppm(NO_2)	ng/scm	1.912×10^6
ppm/(SO_2)	lb/scf	1.660×10^{-7}
ppm/(NO_2)	lb/scf	1.194×10^{-7}

5.3.1. *Oxygen-Based F Factor Procedure.*

5.3.1.1 *Dry Basis.* When both percent oxygen ($\%O_{2d}$) and the pollutant concentration (C_d) are measured in the flue gas on a dry basis, the following equation is applicable:

$$E = C_d F_d \left[\frac{20.9}{20.9 - \%O_{2d}}\right]$$

5.3.1.2 *Wet Basis.* When both the percent oxygen ($\%O_{2w}$) and the pollutant concentration (C_w) are measured in the flue gas on a wet basis, the following equations are applicable: (Note: F_w factors are not applicable after wet scrubbers.)

$$\text{(a)} \quad E = C_w F_w \left[\frac{20.9}{20.9(1 - B_{wa}) - \%O_{2w}}\right]$$

Where:

B_{wa} = Proportion by volume of water vapor in the ambient air.

In lieu of actual measurement, B_{wa} may be estimated as follows:

Note.—The following estimating factors are selected to assure that any negative error introduced in the term:

$$\left(\frac{20.9}{20.9(1 - B_{wa}) - \%O_{2ws}}\right)$$

will not be larger than −1.5 percent. However, positive errors, or over-estimation of emissions, of as much as 5 percent may be introduced depending upon the geographic location of the facility and the associated range of ambient moisture.

(i) B_{wa} = 0.027. This factor may be used as a constant value at any location.

(ii) B_{wa} = Highest monthly average of B_{wa} which occurred within a calendar year at the nearest Weather Service Station.

(iii) B_{wa} = Highest daily average of B_{wa} which occurred within a calendar month at the nearest Weather Service Station, calculated from the data for the past 3 years. This factor shall be calculated for each month and may be used as an estimating factor for the respective calendar month.

$$\text{(b)} \quad E = C_w F_d \left[\frac{20.9}{20.9(1 - B_{ws}) - \%O_{2w}}\right]$$

Where:

B_{ws} = Proportion by volume of water vapor in the stack gas.

5.3.1.3 *Dry/Wet Basis.* When the pollutant concentration (C_w) is measured on a wet basis and the oxygen concentration ($\%O_{2d}$) or measured on a dry basis, the following equation is applicable:

$$E = \left[\frac{C_w F_d}{(1 - B_{ws})}\right] \left[\frac{20.9}{20.9 - \%O_{2d}}\right]$$

When the pollutant concentration (C_d) is measured on a dry basis and the oxygen concentration ($\%O_{2w}$) is measured on a wet basis, the following equation is applicable:

$$E = C_d F_d \frac{20.9}{20.9 - \dfrac{\%O_{2w}}{(1 - B_{ws})}}$$

5.3.2 *Carbon Dioxide-Based F Factor Procedure.*

5.3.2.1 *Dry Basis.* When both the percent carbon dioxide ($\%CO_{2d}$) and the pollutant concentration (C_d) are measured in the flue gas on a dry basis, the following equation is applicable:

$$E = C_d F_c \left(\frac{100}{\%CO_{2d}}\right)$$

5.3.2.2 *Wet Basis.* When both the percent carbon dioxide ($\%CO_{2w}$) and the pollutant concentration (C_w) are measured on a wet basis, the following equation is applicable:

$$E = C_w F_c \left(\frac{100}{\%CO_{2w}}\right)$$

5.3.2.3 *Dry/Wet Basis.* When the pollutant concentration (C_w) is measured on a wet basis and the percent carbon dioxide ($\%CO_{2d}$) is measured on a dry basis, the following equation is applicable:

$$E = \left[\frac{C_w F_c}{(1 - B_{ws})}\right] \left[\frac{100}{\%CO_{2d}}\right]$$

When the pollutant concentration (C_d) is measured on a dry basis and the precent carbon dioxide ($\%CO_{2w}$) is measured on a wet basis, the following equation is applicable:

$$E = C_d (1 - B_{ws}) F_c \left(\frac{100}{\%CO_{2w}}\right)$$

5.4 *Calculation of Emission Rate from Combined Cycle-Gas Turbine Systems.* For gas turbine-steam generator combined cycle systems, the emissions from supplemental fuel fired to the steam generator or the percentage reduction in potential (SO_2) emissions cannot be determined directly. Using measurements from the gas turbine exhaust (performance test, subpart GG) and the combined exhaust gases from the steam generator, calculate the emission rates for these two points following the appropriate paragraphs in Section 5.3.

Note.—F_w factors shall not be used to determine emission rates from gas turbines because of the injection of steam nor to calculate emission rates after wet scrubbers; F_d or F_c factor and associated calculation procedures are used to combine effluent emissions according to the procedure in Paragraph 5.2.3.

The emission rate from the steam generator is calculated as:

$$E_{sg} = \frac{E_c - X_{gt}\,E_{gt}}{X_{sg}}$$

Where:

E_{sg} = Pollutant emission rate from steam generator effluent, ng/J (lb/million Btu).

E_c = Pollutant emission rate in combined cycle effluent; ng/J (lb/million Btu).

E_{gt} = Pollutant emission rate from gas turbine effluent; ng/J (lb/million Btu).

X_{sg} = Fraction of total heat input from supplemental fuel fired to the steam generator.

X_{gt} = Fraction of total heat input from gas turbine exhaust gases.

Note.—The total heat input to the steam generator is the sum of the heat input from supplemental fuel fired to the steam generator and the heat input to the steam generator from the exhaust gases from the gas turbine.

5.5 *Effect of Wet Scrubber Exhaust, Direct-Fired Reheat Fuel Burning.* Some wet scrubber systems require that the temperature of the exhaust gas be raised above the moisture dew-point prior to the gas entering the stack. One method used to accomplish this is directfiring of an auxiliary burner into the exhaust gas. The heat required for such burners is from 1 to 2 percent of total heat input of the steam generating plant. The effect of this fuel burning on the exhaust gas components will be less than ±1.0 percent and will have a similar effect on emission rate calculations. Because of this small effect, a determination of effluent gas constituents from direct-fired reheat burners for correction of stack gas concentrations is not necessary.

Table 19-1.—*F Factors for Various fuels*[c]

Fuel type	F_d		F_w		F_c	
	dscm/J	dscf/10^6 Btu	wscm/J	wscf/10^6 Btu	scm/J	scf/10^6 Btu
Coal:						
Anthracite[a]	2.71×10^{-7}	(10100)	2.83×10^{-7}	(10540)	0.530×10^{-7}	(1970)
Bituminous[a]	2.63×10^{-7}	(9780)	2.86×10^{-7}	(10640)	0.484×10^{-7}	(1800)
Lignite	2.65×10^{-7}	(9860)	3.21×10^{-7}	(11950)	0.513×10^{-7}	(1910)
Oil[b]	2.47×10^{-7}	(9190)	2.77×10^{-7}	(10320)	0.383×10^{-7}	(1420)
Gas:						
Natural	2.43×10^{-7}	(8710)	2.85×10^{-7}	(10610)	0.287×10^{-7}	(1040)
Propane	2.34×10^{-7}	(8710)	2.74×10^{-7}	(10200)	0.321×10^{-7}	(1190)
Butane	2.34×10^{-7}	(8710)	2.79×10^{-7}	(10390)	0.337×10^{-7}	(1250)
Wood	2.48×10^{-7}	(9240)			0.492×10^{-7}	(1830)
Wood Bark	2.58×10^{-7}	(9600)			0.497×10^{-7}	(1860)

[a] As classified according to ASTM D 388-66.

[b] Crude, residual, or distillate.

[c] Determined at standard conditions: 20° C (68° F) and 760 mm Hg (29.92 in. Hg).

6. *Calculation of Confidence Limits for Inlet and Outlet Monitoring Data*

6.1 *Mean Emission Rates.* Calculate the mean emission rates using hourly averages in ng/J (lb/million Btu) for SO_2 and NO_x outlet data and, if applicable, SO_2 inlet data using the following equations:

$$E_o = \frac{\Sigma x_o}{n_o}$$

$$E_i = \frac{\Sigma x_i}{n_i}$$

Where:

E_o=Mean outlet emission rate: ng/J (lb/million Btu).

E_i=Mean inlet emission rate: ng/J (lb/million Btu).

x_o=Hourly average outlet emission rate: ng/J (lb/million Btu).

x_i=Hourly average in let emission rate: ng/J (lb/million Btu).

n_o=Number of outlet hourly averages available for the reporting period.

n_i=Number of inlet hourly averages available for reporting period.

6.2 *Standard Deviation of Hourly Emission Rates.* Calculate the standard deviation of the available outlet hourly average emission rates for SO_2 and NO_x and, if applicable, the available inlet hourly average emission rates for SO_2 using the following equations:

$$s_o = \left(\sqrt{\frac{1}{n_o} - \frac{1}{720}}\right)\left(\sqrt{\frac{\Sigma (E_o - x_o)^2}{n_o - 1}}\right)$$

$$s_i = \left(\sqrt{\frac{1}{n_i} - \frac{1}{720}}\right)\left(\sqrt{\frac{\Sigma (E_i - x_i)^2}{n_i - 1}}\right)$$

Where:

s_o=Standard deviation of the average outlet hourly average emission rates for the reporting period: ng/J (lb/million Btu).

s_i=Standard deviation of the average inlet hourly average emission rates for the reporting period: ng/J (lb/million Btu).

6.3 *Confidence Limits.* Calculate the lower confidence limit for the mean outlet emission rates for SO_2 and NO_x and, if applicable, the upper confidence limit for the mean inlet emission rate for SO_2 using the following equations:

$E_o^* = E_o - t_{0.95} s_o$

$E_i^* = E_i + t_{0.95} s_i$

Where:

E_o^*=The lower confidence limit for the mean outlet emission rates: ng/J (lb/million Btu).

E_i^*=The upper confidence limit for the mean inlet emission rate: ng/J (lb/million Btu).

$t_{0.95}$=Values shown below for the indicated number of available data points (n):

n	Values for $t_{0.95}$	$t_{0.95}$
2		6.31
3		2.42
4		2.35
5		2.13
6		2.02
7		1.94
8		1.90
9		1.86
10		1.83
11		1.81
12–16		1.77
17–21		1.73
22–26		1.71
27–31		1.70
32–51		1.68
52–91		1.67
92–151		1.66
152 or more		1.65

The values of this table are corrected for n-1 degrees of freedom. Use n equal to the number of hourly average data points.

7. *Calculation to Demonstrate Compliance When Available Monitoring Data Are Less Than the Required Minimum*

7.1 *Determine Potential Combustion Concentration (PCC) for SO_2.*

7.1.1 When the removal efficiency due to fuel pretreatment (% R_f) is included in the overall reduction in potential sulfur dioxide emissions (% R_o) and the "as-fired" fuel analysis is not used, the potential combustion concentration (PCC) is determined as follows:

$$PCC = E_i^* + 2\left(\frac{\% S_i}{GCV_i} - \frac{\% S_o}{GCV_o}\right) 10^7;\ ng/J$$

$$PCC = E_i^* + 2\left(\frac{\% S_i}{GCV_i} - \frac{\% S_o}{GCV_o}\right) 10^4;\ lb/million\ Btu.$$

Where:

$\left(\frac{\% S_i}{GCV_i} - \frac{\% S_o}{GCV_o}\right)$ = Potential emissions removed by the pretreatment process, using the fuel parameters defined in section 2.3; ng/J (lb/million Btu).

* * *

* * *

7.1.2 When the "as-fired" fuel analysis is used and the removal efficiency due to fuel pretreatment (% R_f) is not included in the overall reduction in potential sulfur dioxide emissions (% R_o), the potential combustion concentration (PCC) is determined as follows:

$PCC = I_s$

Where:

I_s = The sulfur dioxide input rate as defined in section 3.3

7.1.3 When the "as-fired" fuel analysis is used and the removal efficiency due to fuel pretreatment (% R_f) is included in the overall reduction (% R_o), the potential combustion concentration (PCC) is determined as follows:

$$PCC = I_s + 2\left(\frac{\%\ S_i}{GCV_i} - \frac{\%\ S_o}{GCV_o}\right)10^7;\ ng/J$$

$$PCC = I_s + 2\left(\frac{\%\ S_i}{GCV_i} - \frac{\%\ S_o}{GCV_o}\right)10^4;\ lb/million\ Btu.$$

7.1.4 When inlet monitoring data are used and the removal efficiency due to fuel pretreatment (% R_f) is not included in the overall reduction in potential sulfur dioxide emissions (% R_o), the potential combustion concentration (PCC) is determined as follows:

$PCC = E_i^*$

Where:

E_i^* = The upper confidence limit of the mean inlet emission rate, as determined in section 6.3.

7.2 *Determine Allowable Emission Rates* (*E_{std}*).

7.2.1 *NO_x*. Use the allowable emission rates for NO_x as directly defined by the applicable standard in terms of ng/J (lb/million Btu).

7.2.2 *SO_2*. Use the potential combustion concentration (PCC) for SO_2 as determined in section 7.1, to determine the applicable emission standard. If the applicable standard is an allowable emission rate in ng/J (lb/million Btu), the allowable emission rate is used as E_{std}. If the applicable standard is an allowable percent emission, calculate the allowable emission rate (E_{std}) using the following equation:

E_{std} = % PCC/100

Where:

% PCC = Allowable percent emission as defined by the applicable standard; percent.

7.3 *Calculate E_o^*/E_{std}*. To determine compliance for the reporting period calculate the ratio:

E_o^*/E_{std}

Where:

E_o^* = The lower confidence limit for the mean outlet emission rates, as defined in section 6.3; ng/J (lb/million Btu).

E_{std} = Allowable emission rate as defined in section 7.2; ng/J (lb/million Btu).

If E_o^*/E_{std} is equal to or less than 1.0, the facility is in compliance; if E_o^*/E_{std} is greater than 1.0, the facility is not in compliance for the reporting period.

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6.1.81.

Method 20

DETERMINATION OF NITROGEN OXIDES, SULFUR DIOXIDE, AND OXYGEN EMISSIONS FROM STATIONARY GAS TURBINES

(40 CFR 60, Appendix A, September 10, 1979)

1. Applicability and Principle

1.1 Applicability. This method is applicable for the determination of nitrogen oxides (NO_x), sulfur dioxide (SO_2), and oxygen (O_2) emissions from stationary gas turbines. For the NO_x and O_2 determinations, this method includes: (1) measurement system design criteria, (2) analyzer performance specifications and performance test procedures; and (3) procedures for emission testing.

1.2 Principle. A gas sample is continuously extracted from the exhaust stream of a stationary gas turbine; a portion of the sample stream is conveyed to instrumental analyzers for determination of NO_x and O_2 content. During each NO_x and OO_2 determination, a separate measurement of SO_2 emissions is made, using Method 6, or it equivalent. The O_2 determination is used to adjust the NO_x and SO_2 concentrations to a reference condition.

2. Definitions

2.1 Measurement System. The total equipment required for the determination of a gas concentration or a gas emission rate. The system consists of the following major subsystems:

2.1.1 Sample Interface. That portion of a system that is used for one or more of the following: sample acquisition, sample transportation, sample conditioning, or protection of the analyzers from the effects of the stack effluent.

2.1.2 NO_x Analyzer. That portion of the system that senses NO_x and generates an output proportional to the gas concentration.

2.1.3 O_2 Analyzer. That portion of the system that senses O_2 and generates an output proportional to the gas concentration.

2.2 Span Value. The upper limit of a gas concentration measurement range that is specified for affected source categories in the applicable part of the regulations.

2.3 Calibration Gas. A known concentration of a gas in an appropriate diluent gas.

2.4 Calibration Error. The difference between the gas concentration indicated by the measurement system and the known concentration of the calibration gas.

2.5 Zero Drift. The difference in the measurement system output readings before and after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place and the input concentration at the time of the measurements was zero.

2.6 Calibration Drift. The difference in the measurement system output readings before and after a stated period of operation during which no unscheduled maintenance, repair, or adjustment took place and the input at the time of the measurements was a high-level value.

2.7 Residence Time. The elapsed time from the moment the gas sample enters the probe tip to the moment the same gas sample reaches the analyzer inlet.

2.8 Response Time. The amount of time required for the continuous monitoring system to display on the data output 95 percent of a step change in pollutant concentration.

2.9 Interference Response. The output response of the measurement system to a component in the sample gas, other than the gas component being measured.

3. Measurement System Performance Specifications

3.1 NO_2 to NO Converter. Greater than 90 percent conversion efficiency of NO_2 to NO.

3.2 Interference Response. Less than ± 2 percent of the span value.

3.3 Residence Time. No greater than 30 seconds.

3.4 Response Time. No greater than 3 minutes.

3.5 Zero Drift. Less than ± 2 percent of the span value.

3.6 Calibration Drift. Less than ± 2 percent of the span value.

4. Apparatus and Reagents

4.1 Measurement System. Use any measurement system for NO_x and O_2 that is expected to meet the specifications in this method. A schematic of an acceptable measurement system is shown in Figure 20-1. The essential components of the measurement system are described below:

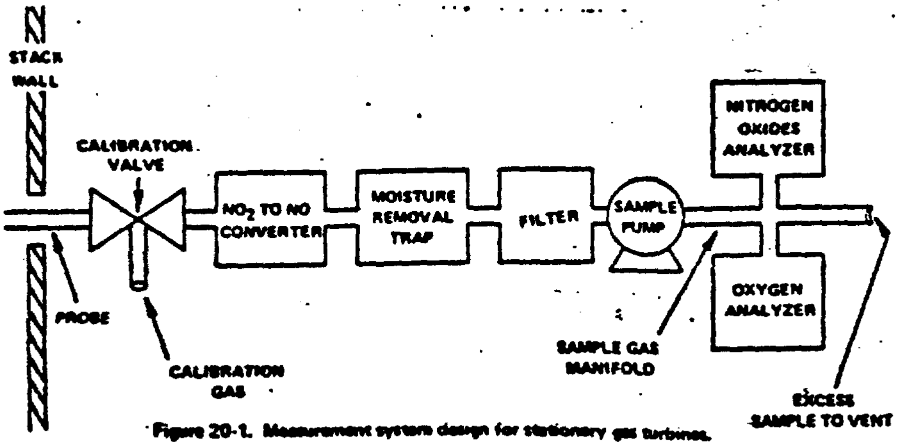


Figure 20-1. Measurement system design for stationary gas turbines.

4.1.1 Sample Probe. Heated stainless steel, or equivalent, open-ended, straight tube of sufficient length to traverse the sample points.

4.1.2 Sample Line. Heated (>95°C) stainless steel or Teflon tubing to transport the sample gas to the sample conditioners and analyzers.

4.1.3 Calibration Valve Assembly. A three-way valve assembly to direct the zero and calibration gases to the sample conditioners and to the analyzers. The calibration valve assembly shall be capable of blocking the sample gas flow and of introducing calibration gases to the measurement system when in the calibration mode.

4.1.4 NO_2 to NO Converter. That portion of the system that converts the nitrogen dioxide (NO_2) in the sample gas to nitrogen oxide (NO). Some analyzers are designed to measure NO_x as NO_2 on a wet basis and can be used without an NO_2 to NO converter or a moisture removal trap provided the sample line to the analyzer is heated (>95°C) to the inlet of the analyzer. In addition, an NO_2 to NO converter is not necessary if the NO_2 portion of the exhaust gas is less than 5 percent of the total NO_x concentration. As a guideline, an NO_2 to NO converter is not necessary if the gas turbine is operated at 90 percent or more of peak load capacity. A converter is necessary under lower load conditions.

4.1.5 Moisture Removal Trap. A refrigerator-type condenser designed to continuously remove condensate from the sample gas. The moisture removal trap is not necessary for analyzers that can measure NO_x concentrations on a wet basis; for these analyzers, (a) heat the sample line up to the inlet of the analyzers, (b) determine the moisture content using methods subject to the approval of the Administrator, and (c) correct the NO_x and O_2 concentrations to a dry basis

4.1.6 Particulate Filter. An in-stack or an out-of-stack glass fiber filter, of the type specified in EPA Reference Method 5; however, an out-of-stack filter is recommended when the stack gas temperature exceeds 250 to 300°C.

4.1.7 Sample Pump. A nonreactive leak-free sample pump to pull the sample gas through the system at a flow rate sufficient to minimize transport delay. The pump shall be made from stainless steel or coated with Teflon or equivalent.

4.1.8 Sample Gas Manifold. A sample gas manifold to divert portions of the sample gas stream to the analyzers. The manifold may be constructed of glass, Teflon, type 316 stainless steel, or equivalent.

4.1.9 Oxygen and Analyzer. An analyzer to determine the percent O_2 concentration of the sample gas stream.

4.1.10 Nitrogen Oxides Analyzer. An analyzer to determine the ppm NO_x concentration in the sample gas stream.

4.1.11 Data Output. A strip-chart recorder, analog computer, or digital recorder for recording measurement data.

4.2 Sulfur Dioxide Analysis. EPA Reference Method 6 apparatus and reagents.

4.3 NO_x Caliberation Gases. The calibration gases for the NO_x analyzer may be NO in N_2, NO_2 in air or N_2, or NO and NO_2 in N_2. For NO_x measurement analyzers that require oxidation of NO to NO_2, the calibration gases must be in the form of NO in N_2. Use four calibration gas mixtures as specified below:

4.3.1 High-level Gas. A gas concentration that is equivalent to 80 to 90 percent of the span value.

4.3.2 Mid-level Gas. A gas concentration that is equivalent to 45 to 55 percent of the span value.

4.3.3 Low-level Gas. A gas concentration that is equivalent to 20 to 30 percent of the span value.

4.3.4 Zero Gas. A gas concentration of less than 0.25 percent of the span value. Ambient air may be used for the NO_x zero gas.

4.4 O_2 Calibration Gases. Use ambient air at 20.9 percent as the high-level O_2 gas. Use a gas concentration that is equivalent to 11–14 percent O_2 for the mid-level gas. Use purified nitrogen for the zero gas.

4.5 NO_2/NO Gas Mixture. For determining the conversion efficiency of the NO_2 to NO converter, use a calibration gas mixture of NO_2 and NO in N_2. The mixture will be known concentrations of 40 to 60 ppm NO_2 and 90 to 110 ppm NO and certified by the gas manufacturer. This certification of gas concentration must include a brief description of the procedure followed in determining the concentrations.

5. *Measurement System Performance Test Procedures*

Perform the following procedures prior to measurement of emissions (Section 6) and only once for each test program, i.e., the series of all test runs for a given gas turbine engine.

5.1 Calibration Gas Checks. There are two alternatives for checking the concentrations of the calibration gases. (a) The first is to use calibration gases that are documented traceable to National Bureau of Standards Reference Materials. Use *Traceability Protocol for Establishing True Concentrations of Gases Used for Calibrations and Audits of Continuous Source Emission Monitors* (Protocol Number 1) that is available from the Environmental Monitoring and Support Laboratory, Quality Assurance Branch, Mail Drop 77, Environmental Protection Agency, Research Triangle Park, North Carolina 27711. Obtain a certification from the gas manufacturer that the protocol was followed. These calibration gases are not to be analyzed with the Reference Methods. (b) The second alternative is to use calibration gases not prepared according to the protocol. If this alternative is chosen, within 1 month prior to the emission test, analyze each of the calibration gas mixtures in triplicate using Reference Method 7 or the procedure outlined in Citation 8.1 for NO_x and use Reference Method 3 for O_2. Record the results on a data sheet (example is shown in Figure 20-2). For the low-level, mid-level, or high-level gas mixtures, each of the individual NO_x analytical results must be within 10 percent (or 10 ppm, whichever is greater) of the triplicate set average (O_2 test results must be within 0.5 percent O_2); otherwise, discard the entire set and repeat the triplicate analyses. If the average of the triplicate reference method test results is within 5 percent for NO_x gas or 0.5 percent O_2 for the O_2 gas of the calibration gas manufacturer's tag value, use the tag value; otherwise, conduct at least three additional reference method test analyses until the results of six individual NO_x runs (the three original plus three additional) agree within 10 percent (or 10 ppm, whichever is greater) of the average (O_2 test results must be within 0.5 percent O_2). Then use this average for the cylinder value.

Date __________ (Must be within 1 month prior to the test period)

Reference method used ____________________

Sample run	Gas concentration, ppm		
	Low level[a]	Mid level[b]	High level[c]
1			
2			
3			
Average			
Maximum % deviation[d]			

[a] Average must be 20 to 30% of span value.

[b] Average must be 45 to 55% of span value.

[c] Average must be 80 to 90% of span value.

[d] Must be ≤ ± 10% of applicable average or 10 ppm, whichever is greater.

Figure 20-2. Analysis of calibration gases.

Conduct an interference response test of each analyzer prior to its initial use in the field. Thereafter, recheck the measurement system if changes are made in the instrumentation that could alter the interference response, e.g., changes in the type of gas detector.

In lieu of conducting the interference response test, instrument vendor data, which demonstrate that for the test gases of Table 20-1 the interference performance specification is not exceeded, are acceptable.

5.5 Residence and Response Time.

5.5.1 Calculate the residence time of the sample interface portion of the measurement system using volume and pump flow rate information. Alternatively, if the response time determined as defined in Section 5.5.2 is less than 30 seconds, the calculations are not necessary.

5.5.2 To determine response time, first introduce zero gas into the system at the calibration valve until all readings are stable; then, switch to monitor the stack effluent until a stable reading can be obtained. Record the upscale response time. Next, introduce high-level calibration gas into the system. Once the system has stabilized at the high-level concentration, switch to monitor the stack effluent and wait until a stable value is reached. Record the downscale response time. Repeat the procedure three times. A stable value is equivalent to a change of less than 1 percent of span value for 30 seconds or less than 5 percent of the measured average concentration for 2 minutes. Record the response time data on a form similar to Figure 20-5, the readings of the upscale or downscale reponse time, and report the greater time as the "response time" for the analyzer. Conduct a response time test prior to the initial field use of the measurement system, and repeat if changes are made in the measurement system.

5.6 NO_2 NO Conversion Efficiency. Introduce to the system, at the calibration valve assembly, the NO_2/NO gas mixture (Section 4.5). Record the response of the NO_x analyzer. If the instrument response indicates less than 90 percent NO_2 to NO conversion, make corrections to the measurement system and repeat the check. Alternatively, the NO_x to NO converter check described in Title 40 Part 86: *Certification and Test Procedures for Heavy-Duty Engines for 1979 and Later Model Years* may be used. Other alternate procedures may be used with approval of the Administrator.

Date of test ____________________

Analyzer type ____________________ S/N ____________

Span gas concentration ____________ ppm

Analyzer span setting ____________ ppm

Upscale
1 ____________ seconds
2 ____________ seconds
3 ____________ seconds

Average upscale response ____________ seconds

Downscale
1 ____________ seconds
2 ____________ seconds
3 ____________ seconds

Average downscale response ____________ seconds

System response time = slower average time = ____________ seconds.

Figure 20-5. Response time

5.2 Measurement System Preparation. Prior to the emission test, assemble the measurement system following the manufacturer's written instructions in preparing and operating the NO_2 to NO converter, the NO_x analyzer, the O_2 analyzer, and other components.

5.3 Calibration Check. Conduct the calibration checks for both the NO_x and the O_2 analyzers as follows:

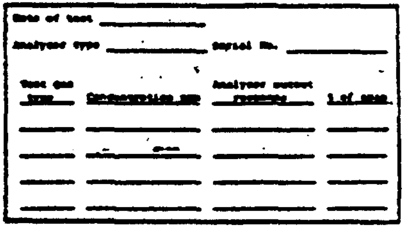
5.3.1 After the measurement system has been prepared for use (Section 5.2), introduce zero gases and the mid-level calibration gases; set the analyzer output responses to the appropriate levels. Then introduce each of the remainder of the calibration gases described in Sections 4.3 or 4.4, one at a time, to the measurement system. Record the responses on a form similar to Figure 20-3.

5.3.2 If the linear curve determined from the zero and mid-level calibration gas responses does not predict the actual response of the low-level (not applicable for the O_2 analyzer) and high-level gases within ±2 percent of the span value, the calibration shall be considered invalid. Take corrective measures on the measurement system before proceeding with the test.

5.4 Interference Response. Introduce the gaseous components listed in Table 20-1 into the measurement system separately, or as gas mixtures. Determine the total interference output response of the system to these components in concentration units; record the values on a form similar to Figure 20-4. If the sum of the interference responses of the test gases for either the NO_x or O_2 analyzers is greater than 2 percent of the applicable span value, take corrective measure on the measurement system.

Table 20-1.—*Interference Test Gas Concentration*

CO	500 ± 50 ppm
SO_2	200 ± 20 ppm
CO_2	10 ± 1 percent
O_2	20.9 ± 1 percent



Date of test ____________

Analyzer type ____________ Serial No. ____________

Test gas type	Concentration, ppm	Analyzer output response	% of span

$$\% \text{ of span} = \frac{\text{Analyzer output response}}{\text{Instrument span}} \times 100$$

Figure 20-4 Interference response

Turbine type: ____________ Identification number ____________

Date: ____________ Test number ____________

Analyzer type: ____________ Identification number ____________

	Cylinder value, ppm or %	Initial analyzer response, ppm or %	Final analyzer responses, ppm or %	Difference: initial-final, ppm or %
Zero gas				
Low - level gas				
Mid - level gas				
High - level gas				

$$\text{Percent drift} = \frac{\text{Absolute difference}}{\text{Span value}} \times 100.$$

Figure 20-3. Zero and calibration data.

6. Emission Measurement Test Procedure

6.1 Preliminaries.

6.1.1 Selection of a Sampling Site. Select a sampling site as close as practical to the exhaust of the turbine. Turbine geometry, stack configuration, internal baffling, and point of introduction of dilution air will vary for different turbine designs. Thus, each of these factors must be given special consideration in order to obtain a representative sample. Whenever possible, the sampling site shall be located upstream of the point of introduction of dilution air into the duct. Sample ports may be located before or after the upturn elbow, in order to accommodate the configuration of the turning vanes and baffles and to permit a complete, unobstructed traverse of the stack. The sample ports shall not be located within 5 feet or 2 diameters (whichever is less) of the gas discharge to atmosphere. For supplementary-fired, combined-cycle plants, the sampling site shall be located between the gas turbine and the boiler. The diameter of the sample ports shall be sufficient to allow entry of the sample probe.

6.1.2 A preliminary O_2 traverse is made for the purpose of selecting low O_2 values. Conduct this test at the turbine condition that is the lowest percentage of peak load operation included in the program. Follow the procedure below or alternative procedures subject to the approval of the Administrator may be used:

6.1.2.1 Minimum Number of Points. Select a minimum number of points as follows: (1) eight, for stacks having cross-sectional areas less than 1.5 m^2 (16.1 ft^2); (2) one sample point for each 0.2 m^2 (2.2 ft^2 of areas, for stacks of 1.5 m^2 to 10.0 m^2 (16.1–107.6 ft^2) in cross-sectional area; and (3) one sample point for each 0.4 m^2 (4.4 ft^2) of area, for stacks greater than 10.0 m^2 (107.6 ft^2) in cross-sectional area. Note that for circular ducts, the number of sample points must be a multiple of 4, and for rectangular ducts, the number of points must be one of those listed in Table 20-2; therefore, round off the number of points (upward), when appropriate.

6.1.2.2 Cross-sectional Layout and Location of Traverse Points. After the number of traverse points for the preliminary O^2 sampling has been determined, use Method 1 to located the traverse points.

6.1.2.3 Preliminary O^2 Measurement. While the gas turbine is operating at the lowest percent of peak load, conduct a preliminary O^2 measurement as follows: Position the probe at the first traverse point and begin sampling. The minimum sampling time at each point shall be 1 minute plus the average system response time. Determine the average steady-state concentration of O^2 at each point and record the data on Figure 20-6.

6.1.2.4 Selection of Emission Test Sampling Points. Select the eight sampling points at which the lowest O^2 concentration were obtained. Use these same points for all the test runs at the different turbine load conditions. More than eight points may be used, if desired.

Table 20-2.—*Cross-sectional Layout for Rectangular Stacks*

No. of traverse points	Matrix layout
9	3 x 3
12	4 x 3
16	4 x 4
20	5 x 4
25	5 x 5
30	6 x 5
36	6 x 6
42	7 x 6
49	7 x 7

6.2 NO_x and O_2 Measurement. This test is to be conducted at each of the specified load conditions. Three test runs at each load condition constitute a complete test.

6.2.1 At the beginning of each NO_x test run and, as applicable, during the run, record turbine data as indicated in Figure 20-7. Also, record the location and number of the traverse points on a diagram.

6.2.2 Position the probe at the first point determined in the preceding section and begin sampling. The minimum sampling time at each point shall be at least 1 minute plus the average system response time. Determine the average steady-state concentration of O_2 and NO_x at each point and record the data on Figure 20-6.

6.2.3 After sampling the last point, conclude the test run by recording the final turbine operating parameters and by determining the zero and calibration drift, as follows:

Immediately following the test run at each load condition, or if adjustments are necessary for the measurement system during the tests, reintroduce the zero and mid-level calibration gases as described in Sections 4.3, and 4.4, one at a time, to the measurement system at the calibration valve assembly. (Make no adjustments to the measurement system until after the drift checks are made). Record the analyzers' responses on a form similar to Figure 20-3. If the drift values exceed the specified limits, the test run preceding the check is considered invalid and will be repeated following corrections to the measurement system. Alternatively, the test results may be accepted provided the measurement system is recalibrated and the calibration data that result in the highest corrected emission rate are used.

Location: Date ______

Plant ______

City, State ______

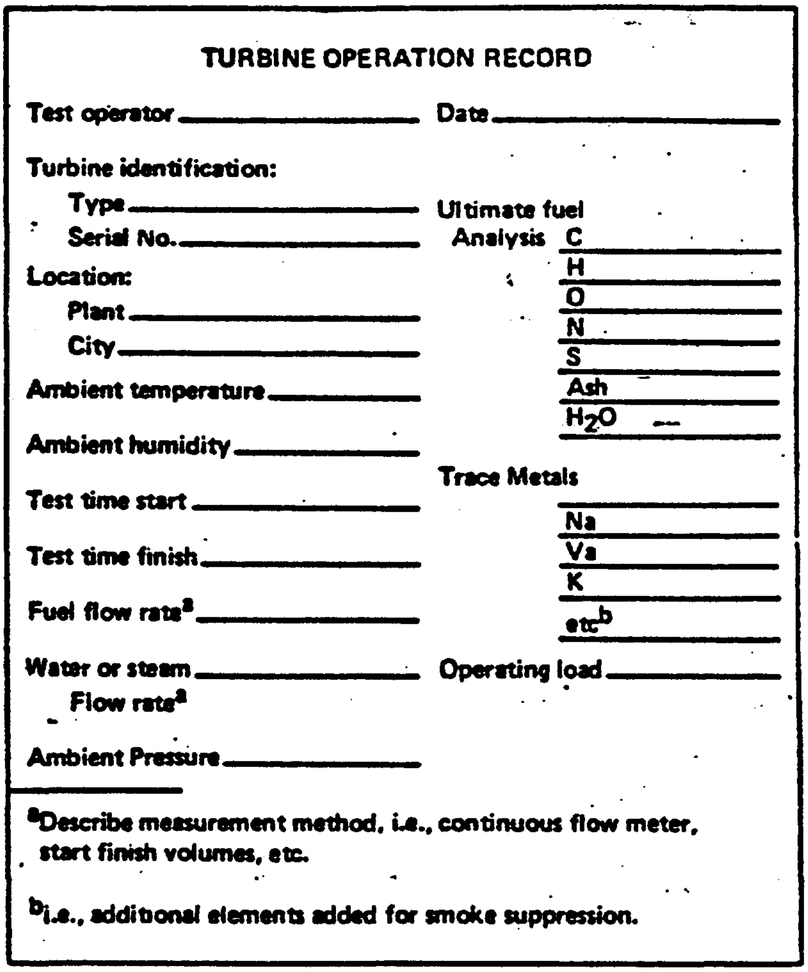
Turbine identification:

Manufacturer ______

Model, serial number ______

Sample point	Oxygen concentration, ppm

Figure 20-6. Preliminary oxygen traverse.



TURBINE OPERATION RECORD

Test operator ______________ Date ______________

Turbine identification:

Type ______________

Serial No. ______________

Location:

Plant ______________

City ______________

Ambient temperature ______________

Ambient humidity ______________

Test time start ______________

Test time finish ______________

Fuel flow rate[a] ______________

Water or steam Flow rate[a] ______________

Ambient Pressure ______________

Ultimate fuel Analysis

C ______________

H ______________

O ______________

N ______________

S ______________

Ash ______________

H_2O ______________

Trace Metals

____

Na ______________

Va ______________

K ______________

etc[b] ______________

Operating load ______________

---

[a] Describe measurement method, i.e., continuous flow meter, start finish volumes, etc.

[b] i.e., additional elements added for smoke suppression.

Figure 20-7. Stationary gas turbine data.

6.3 SO_2 Measurement. This test is conducted only at the 100 percent peak load condition. Determine SO_2 using Method 6, or equivalent, during the test. Select a minimum of six total points from those required for the NO_x measurements; use two points for each sample run. The sample time at each point shall be at least 10 minutes. Average the O_2 readings taken during the NO_x test runs at sample points corresponding to the SO_2 traverse points (see Section 6.2.2) and use this average O_2 concentration to correct the integrated SO_2 concentration obtained by Method 6 to 15 percent O_2 (see Equation 20-1).

If the applicable regulation allows fuel sampling and analysis for fuel sulfur content to demonstrate compliance with sulfur emission unit, emission sampling with Reference Method 6 is not required, provided the fuel sulfur content meets the limits of the regulation.

7. Emission Calculations

7.1 Correction to 15 Percent Oxygen. Using Equation 20-1, calculate the NO_x and SO_2 concentrations (adjusted to 15 percent O_2). The correction to 15 percent O_2 is sensitive to the accuracy of the O_2 measurement. At the level of analyzer drift specified in the method (±2 percent of full scale), the change in the O_2 concentration correction can exceed 10 percent when the O_2 content of the exhaust is above 16 percent O_2. Therefore O_2 analyzer stability and careful calibration are necessary.

$$C_{adj} = C_{meas} \times \frac{5.9}{20.9 - \%\, O_2} \qquad \text{(Equation 20-1)}$$

Where:

C_{adj} = Pollutant concentration adjusted to 15 percent O_2 (ppm)
C_{meas} = Pollutant concentration measured, dry basis (ppm)
5.9 = 20.9 percent O_2 − 15 percent O_2, the defined O_2 correction basis
Percent O_2 = Percent O_2 measured, dry basis (%)

7.2 Calculate the average adjusted NO_x concentration by summing the point values and dividing by the number of sample points.

8. Citations

8.1 Curtis, F. A Method for Analyzing NO_x Cylinder Gases-Specific Ion Electrode Procedure, Monograph available from Emission Measurement Laboratory, ESED, Research Triangle Park, N.C. 27711, October 1978.

[FR Doc. 79-27[illegible] Filed 9-7-79; 8:45 am]

Turbine identification:

Manufacturer __________

Model, serial No. __________

Location:

Plant __________

City, State __________

Ambient temperature __________

Ambient pressure __________

Date __________

Test time - start __________

Test time - finish __________

Test operator name __________

O_2 instrument type __________

Serial No. __________

NO_x instrument type __________

Serial No. __________

Sample point	Time, min.	O_2,[a] %	NO_x,[a] ppm

[a] Average steady-state value from recorder or instrument readout.

Figure 20-8. Stationary gas turbine sample point record.

10.9.79

Rule 913: Ambient-Air Testing for Common Air Pollutants

Method A

REFERENCE METHOD FOR THE DETERMINATION OF SULFUR DIOXIDE IN THE ATMOSPHERE (PARAROSANILINE METHOD)

(40 CFR 50, Appendix A, July 1, 1976)

1. *Principle and Applicability.* 1.1 Sulfur dioxide is absorbed from air in a solution of potassium tetrachloromercurate (TCM). A dichlorosulfitomercurate complex, which resists oxidation by the oxygen in the air, is formed (*1, 2*). Once formed, this complex is stable to strong oxidants (e.g., ozone, oxides of nitrogen). The complex is reacted with pararosaniline and formaldehyde to form intensely colored pararosaniline methyl sulfonic acid (*3*). The absorbance of the solution is measured spectrophotometrically.

1.2 The method is applicable to the measurement of sulfur dioxide in ambient air using sampling periods up to 24 hours.

2. *Range and Sensitivity.* 2.1 Concentrations of sulfur dioxide in the range of 25 to 1,050 µg/m.^{3} (0.01 to 0.40 p.p.m.) can be measured under the conditions given. One can measure concentrations below 25 µg./m.^{3} by sampling larger volumes of air, but only if the absorption efficiency of the particular system is first determined. Higher concentrations can be analyzed by using smaller gas samples, a larger collection volume, or a suitable aliquot of the collected sample. Beer's Law is followed through the working range from 0.03 to 1.0 absorbance units (0.8 to 27 µg. of sulfite ion in 25 ml. final solution computed as SO_2).

2.2 The lower limit of detection of sulfur dioxide in 10 ml. TCM is 0.75 µg. (based on twice the standard deviation) representing a concentration of 25 µg./m.^{3} SO_2 (0.01 p.p.m.) in an air sample of 30 liters.

3. *Interferences.* 3.1 The effects of the principal known interferences have been minimized or eliminated. Interferences by oxides of nitrogen are eliminated by sulfamic acid (*4, 5*), ozone by time-delay (*6*), and heavy metals by EDTA (ethylenediaminetetraacetic acid, disodium salt) and phosphoric acid (*4, 6*). At least 60 µg. Fe (III), 10 µg. Mn(II), and 10 µg. Cr(III) in 10 ml. absorbing reagent can be tolerated in the procedure. No significant interference was found with 10 µg. Cu (II) and 22 µg. V(V).

4. *Precision, Accuracy, and Stability.* 4.1 Relative standard deviation at the 95 percent confidence level is 4.6 percent for the analytical procedure using standard samples. (*5*)

4.2 After sample collection the solutions are relatively stable. At 22° C. losses of sulfur dioxide occur at the rate of 1 percent per day. When samples are stored at 5° C. for 30 days, no detectable losses of sulfur dioxide occur. The presence of EDTA enhances the stability of SO_2 in solution, and the rate of decay is independent of the concentration of SO_2. (*7*)

5. *Apparatus.*

5.1 *Sampling.*

5.1.1 *Absorber.* Absorbers normally used in air pollution sampling are acceptable for concentrations above 25 µg./m.^{3} (0.01 p.p.m.). An all-glass midget impinger, as shown in Figure A1, is recommended for 30-minute and 1-hour samples.

For 24-hour sampling, assemble an absorber from the following parts:

Polypropylene 2-port tube closures, special manufacture (available from Bel-Art Products, Pequannock, N.J.).

Glass impingers, 6 mm. tubing, 6 inches long, one end drawn to small diameter such that No. 79 jewelers drill will pass through, but No. 78 jewelers drill will not. (Other end fire polished.)

Polypropylene tubes, 164 by 32 mm. (Nalgene or equal).

5.1.2 *Pump.* Capable of maintaining an air pressure differential greater than 0.7 atmosphere at the desired flow rate.

5.1.3 *Air Flowmeter or Critical Orifice.* A calibrated rotameter or critical orifice capable of measuring air flow within ±2 percent. For 30-minute sampling, a 22-gauge hypodermic needle 1 inch long may be used as a critical orifice to give a flow of about 1 liter/minute. For 1-hour sampling, a 23-gauge hypodermic needle five-eighths of an inch long may be used as a critical orifice to give a flow of about 0.5 liter/minute. For 24-hour sampling, a 27-gauge hypodermic needle three-eighths of an inch long may be used to give a flow of about 0.2 liter/minute. Use a membrane filter to protect the needle (*Figure A1a*).

5.2 *Analysis.*

5.2.1. *Spectrophotometer.* Suitable for measurement of absorbance at 548 nm. with an effective spectral band width of less than 15 nm. Reagent blank problems may occur with spectrophotometers having greater spectral band width. The wavelength calibration of the instrument should be verified. If transmittance is measured, this can be converted to absorbance:

$$A=\log_{10}(1/T)$$

6. *Reagents.*

6.1 *Sampling*

6.1.1 *Distilled water.* Must be free from oxidants.

6.1.2 *Absorbing Reagent [0.04 M Potassium Tetrachloromercurate (TCM)].* Dissolve 10.86 g. mercuric chloride, 0.066 g. EDTA (ethylenediaminetetraacetic acid, disodium salt), and 6.0 g. potassium chloride in water and bring to mark in a 1,000-ml. volumetric flask. (Caution: highly poisonous. If spilled on skin, flush off with water immediately). The pH of this reagent should be approximately 4.0, but it has been shown that there is no appreciable difference in collection efficiency over the range of pH 3 to pH 5.(*7*) The absorbing reagent is normally stable for 6 months. If a precipitate forms, discard the reagent.

: : :

Method A, Continued

6.2 *Analysis.*

6.2.1 *Sulfamic Acid (0.6 percent).* Dissolve 0.6 g. sulfamic acid in 100 ml. distilled water. Prepare fresh daily.

6.2.2 *Formaldehyde (0.2 percent).* Dilute 5 ml. formaldehyde solution (36–38 percent) to 1,000 ml. with distilled water. Prepare daily.

6.2.3 *Stock Iodine Solution (0.1 N).* Place 12.7 g. iodine in a 250-ml. beaker; add 40 g. potassium iodide and 25 ml. water. Stir until all is dissolved, then dilute to 1,000 ml. with distilled water.

6.2.4 *Iodine Solution (0.01 N).* Prepare approximately 0.01 N iodine solution by diluting 50 ml. of stock solution to 500 ml. with distilled water.

6.2.5 *Starch Indicator Solution.* Triturate 0.4 g. soluble starch and 0.002 g. mercuric iodide (preservative) with a little water, and add the paste slowly to 200 ml. boiling water. Continue boiling until the solution is clear; cool, and transfer to a glass-stoppered bottle.

6.2.6 *Stock Sodium Thiosulfate Solution (0.1 N).* Prepare a stock solution by dissolving 25 g. sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$) in 1,000 ml. freshly boiled, cooled, distilled water and add 0.1 g. sodium carbonate to the solution. Allow the solution to stand 1 day before standardizing. To standardize, accurately weigh, to the nearest 0.1 mg., 1.5 g. primary standard potassium iodate dried at 180° C. and dilute to volume in a 500-ml. volumetric flask. To a 500-ml. iodine flask, pipet 50 ml. of iodate solution. Add 2 g. potassium iodide and 10 ml. of 1 N hydrochloric acid. Stopper the flask. After 5 minutes, titrate with stock thiosulfate solution to a pale yellow. Add 5 ml. starch indicator solution and continue the titration until the blue color disappears.

6.2.7 *Sodium Thiosulfate Titrant (0.01 N).* Dilute 100 ml. of the stock thiosulfate solution to 1,000 ml. with freshly boiled distilled water.

Normality = Normality of stock solution × 0.100.

6.2.8 *Standardized Sulfite Solution for Preparation of Working Sulfite-TCM Solution.* Dissolve 0.3 g. sodium metabisulfite ($Na_2S_2O_5$) or 0.40 g. sodium sulfite (Na_2SO_3) in 500 ml. of recently boiled, cooled, distilled water. (Sulfite solution is unstable; it is therefore important to use water of the highest purity to minimize this instability.) This solution contains the equivalent of 320 to 400 µg./ml. of SO_2. The actual concentration of the solution is determined by adding excess iodine and back-titrating with standard sodium thiosulfate solution. To back-titrate, pipet 50 ml. of the 0.01 N iodine into each of two 500-ml. iodine flasks (A and B). To flask A (blank) add 25 ml. distilled water, and to flask B (sample) pipet 25 ml. sulfite solution. Stopper the flasks and allow to react for 5 minutes. Prepare the working sulfite-TCM Solution (6.2.9) at the same time iodine solution is added to the flasks. By means of a buret containing standardized 0.01 N thiosulfate, titrate each flask in turn to a pale yellow. Then add 5 ml. starch solution and continue the titration until the blue color disappears.

6.2.9 *Working Sulfite-TCM Solution.* Pipet accurately 2 ml. of the standard solution into a 100 ml volumetric flask and bring to mark with 0.04 M TCM. Calculate the concentration of sulfur dioxide in the working solution:

$$\mu g\ SO_2/ml. = \frac{(A-B)\ (N)\ (32{,}000)}{25} \times 0.02$$

A = Volume thiosulfate for blank, ml.
B = Volume thiosulfate for sample, ml.
N = Normality of thiosulfate titrant.
32,000 = Milliequivalent wt. of SO_2, µg.
25 = Volume standard sulfite solution, ml.
0.02 = Dilution factor.

This solution is stable for 30 days if kept at 5° C. (refrigerator). If not kept at 5° C., prepare daily.

6.2.10 *Purified Pararosaniline Stock Solution (0.2 percent nominal).*

6.2.10.1 *Dye Specifications.* The pararosaniline dye must meet the following performance specifications: (1) the dye must have a wavelength of maximum absorbance at 540 nm. when assayed in a buffered solution of 0.1 M sodium acetate-acetic acid; (2) the absorbance of the reagent blank, which is temperature-sensitive (0.015 absorbance unit/°C), should not exceed 0.170 absorbance unit at 22° C. with a 1-cm. optical path length, when the blank is prepared according to the prescribed analytical procedure and to the specified concentration of the dye; (3) the calibration curve (Section 8.2.1) should have a slope of 0.030±0.002 absorbance units/µg. SO_2 at this path length when the dye is pure and the sulfite solution is properly standardized.

6.2.10.2 *Preparation of Stock Solution.* A specially purified (99–100 percent pure) solution of pararosaniline, which meets the above specifications, is commercially available in the required 0.20 percent concentration (Harleco*). Alternatively, the dye

Calculate the normality of the stock solution:

$$N = \frac{W}{M} \times 2.80$$

N = Normality of stock thiosulfate solution.
M = Volume of thiosulfate required, ml.
W = Weight of potassium iodate, grams.

$$2.80 = \frac{10^3\,(\text{conversion of g. to mg.}) \times 0.1\ (\text{fraction iodate used})}{35.67\ (\text{equivalent weight of potassium iodate})}$$

---

*Hartman-Leddon, 60th and Woodland Avenue, Philadelphia, PA 19143.

may be purified, a stock solution prepared and then assayed according to the procedure of Scaringelli, et al. (4)

6.2.11 *Pararosaniline Reagent*. To a 250-ml. volumetric flask, add 20 ml. stock pararosaniline solution. Add an additional 0.2 ml. stock solution for each percent the stock assays below 100 percent. Then add 25 ml. 3 M phosphoric acid and dilute to volume with distilled water. This reagent is stable for at least 9 months.

7. *Procedure.*

7.1 *Sampling*. Procedures are described for short-term (30 minutes and 1 hour) and for long-term (24 hours) sampling. One can select different combinations of sampling rate and time to meet special needs. Sample volumes should be adjusted, so that linearity is maintained between absorbance and concentration over the dynamic range.

7.1.1 *30-Minute and 1-Hour Samplings.* Insert a midget impinger into the sampling system, Figure A1. Add 10 ml. TCM solution to the impinger. Collect sample at 1 liter/minute for 30 minutes, or at 0.5 liter/minute for 1 hour, using either a rotameter, as shown in Figure A1, or a critical orifice, as shown in Figure A1a, to control flow. Shield the absorbing reagent from direct sunlight during and after sampling by covering the impinger with aluminum foil, to prevent deterioration. Determine the volume of air sampled by multiplying the flow rate by the time in minutes and record the atmospheric pressure and temperature. Remove and stopper the impinger. If the sample must be stored for more than a day before analysis, keep it at 5° C. in a refrigerator (see 4.2).

7.1.2 *24-Hour Sampling*. Place 50 ml. TCM solution in a large absorber and collect the sample at 0.2 liter/minute for 24 hours from midnight to midnight. Make sure no entrainment of solution results with the impinger. During collection and storage protect from direct sunlight. Determine the total air volume by multiplying the air flow rate by the time in minutes. The correction of 24-hour measurements for temperature and pressure is extremely difficult and is not ordinarily done. However, the accuracy of the measurement will be improved if meaningful corrections can be applied. If storage is necessary, refrigerate at 5° C. (see 4.2).

7.2 *Analysis.*

7.2.1 *Sample Preparation*. After collection, if a precipitate is observed in the sample, remove it by centrifugation.

7.2.1.1 *30-Minute and 1-Hour Samples.* Transfer the sample quantitatively to a 25-ml. volumetric flask; use about 5 ml. distilled water for rinsing. Delay analyses for 20 minutes to allow any ozone to decompose.

7.2.1.2 *24-Hour Sample*. Dilute the entire sample to 50 ml. with absorbing solution. Pipet 5 ml. of the sample into a 25-ml. volumetric flask for chemical analyses. Bring volume to 10 ml. with absorbing reagent. Delay analyses for 20 minutes to allow any ozone to decompose.

7.2.2 *Determination*. For each set of determinations prepare a reagent blank by adding 10 ml. unexposed TCM solution to a 25-ml. volumetric flask. Prepare a control solution by adding 2 ml. of working sulfite-TCM solution and 8 ml. TCM solution to a 25-ml. volumetric flask. To each flask containing either sample, control solution, or reagent blank, add 1 ml. 0.6 percent sulfamic acid and allow to react 10 minutes to destroy the nitrite from oxides of nitrogen. Accurately pipet in 2 ml. 0.2 percent formaldehyde solution, then 5 ml. pararosaniline solution. Start a laboratory timer that has been set for 30 minutes. Bring all flasks to volume with freshly boiled and cooled distilled water and mix thoroughly. After 30 minutes and before 60 minutes, determine the absorbances of the sample (denote as A), reagent blank (denote as A_0) and the control solution at 548 nm. using 1-cm. optical path length cells. Use distilled water, not the reagent blank, as the reference. (Note! This is important because of the color sensitivity of the reagent blank to temperature changes which can be induced in the cell compartment of a spectrophotometer.) Do not allow the colored solution to stand in the absorbance cells, because a film of dye may be deposited. Clean cells with alcohol after use. If the temperature of the determinations does not differ by more than 2° C. from the calibration temperature (8.2), the reagent blank should be within 0.03 absorbance unit of the y-intercept of the calibration curve (8.2). If the reagent blank differs by more than 0.03 absorbance unit from that found in the calibration curve, prepare a new curve.

7.2.3 *Absorbance Range*. If the absorbance of the sample solution ranges between 1.0 and 2.0, the sample can be diluted 1:1 with a portion of the reagent blank and read within a few minutes. Solutions with higher absorbance can be diluted up to sixfold with the reagent blank in order to obtain onscale readings within 10 percent of the true absorbance value.

8. *Calibration and Efficiencies.*

8.1 *Flowmeters and Hypodermic Needle.* Calibrate flowmeters and hypodermic needle (8) against a calibrated wet test meter.

8.2 *Calibration Curves.*

8.2.1 *Procedure with Sulfite Solution.* Accurately pipet graduated amounts of the working sulfite-TCM solution (6.2.9) (such as 0, 0.5, 1, 2, 3, and 4 ml.) into a series of 25-ml. volumetric flasks. Add sufficient TCM solution to each flask to bring the volume to approximately 10 ml. Then add the remaining reagents as described in 7.2.2. For maximum precision use a constant-temperature bath. The temperature of calibration must be maintained within ±1° C. and in the range of 20° to 30° C. The temperature of calibration and the temperature of analysis must be within 2 degrees. Plot the absorbance against the total concentration in μg. SO_2 for the corresponding solution. The total μg. SO_2 in solution equals the concentration of the standard (Section 6.2.9) in μg. SO_2/ml. times the ml. sulfite solution added (μg. SO_2= μg./ml. SO_2×ml. added). A linear relationship should be obtained, and the y-intercept should be within 0.03 absorbance unit of the zero standard absorbance. For maximum precision determine the line of best fit using regression analysis by the method of least squares. Determine the slope of the line of best fit, calculate its reciprocal and denote as B_s. B_s is the calibration factor. (See Section 6.2.10.1 for specifications on the slope of the calibration curve). This calibration factor can be used for calculating results provided there are no radical changes in temperature or pH. At least one control sample containing a known concentration of SO_2 for each series of determinations, is recommended to insure the reliability of this factor.

8.2.2 *Procedure with SO_2 Permeation Tubes.*

8.2.2.1 *General Considerations.* Atmospheres containing accurately known amounts of sulfur dioxide at levels of interest can be prepared using permeation tubes. In the systems for generating these atmospheres, the permeation tube emits SO_2 gas at a known, low, constant rate, provided the temperature of the tube is held constant (±0.1° C.) and provided the tube has been accurately calibrated at the temperature of use. The SO_2 gas permeating from the tube is carried by a low flow of inert gas to a mixing chamber where it is accurately diluted with SO_2-free air to the level of interest and the sample taken. These systems are shown schematically in Figures A2 and A3 and have been described in detail by O'Keeffe and Ortman (*9*), Scaringelli, Frey, and Saltzman (*10*), and Scaringelli, O'Keeffe, Rosenberg, and Bell (*11*).

8.2.2.2 *Preparation of Standard Atmospheres.* Permeation tubes may be prepared or purchased. Scaringelli, O'Keeffe, Rosenberg, and Bell (*11*) give detailed, explicit directions for permeation tube calibration. Tubes with a certified permeation rate are available from the National Bureau of Standards. Tube permeation rates from 0.2 to 0.4 μg./minute, inert gas flows of about 50 ml./minute, and dilution air flow rates from 1.1 to 15 liters/minute conveniently give standard atmospheres containing desired levels of SO_2 (25 to 390 μg./m.^{3}; 0.01 to 0.15 p.p.m. SO_2). The concentration of SO_2 in any standard atmosphere can be calculated as follows:

$$C=\frac{P\times 10^3}{R_d+R_i}$$

Where:

C =Concentration of SO_2, μg./m.^{3} at reference conditions.

P =Tube permeation rate, μg./minute.

R_d=Flow rate of dilution air, liter/minute at reference conditions.

R_i=Flow rate of inert gas, liter/minute at reference conditions.

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8.2.2.3 *Sampling and Preparation of Calibration Curve.* Prepare a series (usually six) of standard atmospheres containing SO_2 levels from 25 to 390 μg. SO_2/m.^{3}. Sample each atmosphere using similar apparatus and taking exactly the same air volume as will be done in atmospheric sampling. Determine absorbances as directed in 7.2. Plot the concentration of SO_2 in μg./m.^{3} (x-axis) against $A-A_o$ values (y-axis), draw the straight line of best fit and determine the slope. Alternatively, regression analysis by the method of least squares may be used to calculate the slope. Calculate the reciprocal of the slope and denote as B_g.

8.3 *Sampling Efficiency.* Collection efficiency is above 98 percent; efficiency may fall off, however, at concentrations below 25 μg./m.^{3}. (*12, 13*)

9. *Calculations.*

9.1 *Conversion of Volume.* Convert the volume of air sampled to the volume at reference conditions of 25° C. and 760 mm. Hg.

(On 24-hour samples, this may not be possible.)

$$V_R=V\times\frac{P}{760}\times\frac{298}{t+273}$$

V_R=Volume of air at 25° C. and 760 mm. Hg, liters.

V =Volume of air sampled, liters.

P =Barometric pressure, mm. Hg.

t =Temperature of air sample, °C.

9.2 *Sulfur Dioxide Concentration.*

9.2.1 When sulfite solutions are used to prepare calibration curves, compute the concentration of sulfur dioxide in the sample:

$$\mu g.\ SO_2/m.^3=\frac{(A-A_o)\ (10^3)\ (B_s)}{V_R}\times D$$

A =Sample absorbance.

A_o=Reagent blank absorbance.

10^3=Conversion of liters to cubic meters.

V_R =The sample corrected to 25° C. and 760 mm. Hg, liters.

B_s =Calibration factor, μg./absorbance unit.

D =Dilution factor.

For 30-minute and 1-hour samples, D=1.

For 24-hour samples, D=10.

9.2.2 When SO_2 gas standard atmospheres are used to prepare calibration curves, compute the sulfur dioxide in the sample by the following formula:

$$SO_2,\ \mu g./m.^3=(A-A_o)\times B_g$$

A =Sample absorbance.

A_o=Reagent blank absorbance.

B_g=(See 8.2.2.3).

9.2.3 *Conversion of μg./m.^{3} to p.p.m.*=If desired, the concentration of sulfur dioxide may be calculated as p.p.m. SO_2 at reference conditions as follows:

$$p.p.m.\ SO_2=\mu g.\ SO_2/m.^3\times 3.82\times 10^{-4}$$

Method A, Continued

10. *References.*

(1) West, P. W., and Gaeke, G. C., "Fixation of Sulfur Dioxide as Sulfitomercurate III and Subsequent Colorimetric Determination", *Anal. Chem. 28*, 1816 (1956).

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(13) Bostrom, C. E., "The Absorption of Sulfur Dioxide at Low Concentrations (p.p.m.) Studied by an Isotopic Tracer Method", *Intern. J. Air Water Poll. 9*, 33 (1965).

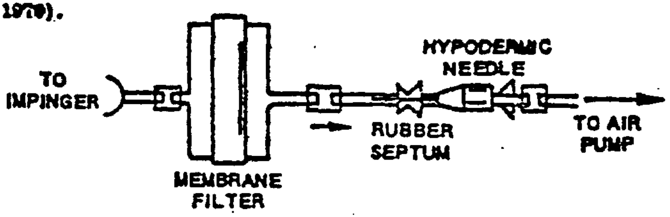

Figure A1a. Critical orifice flow control.

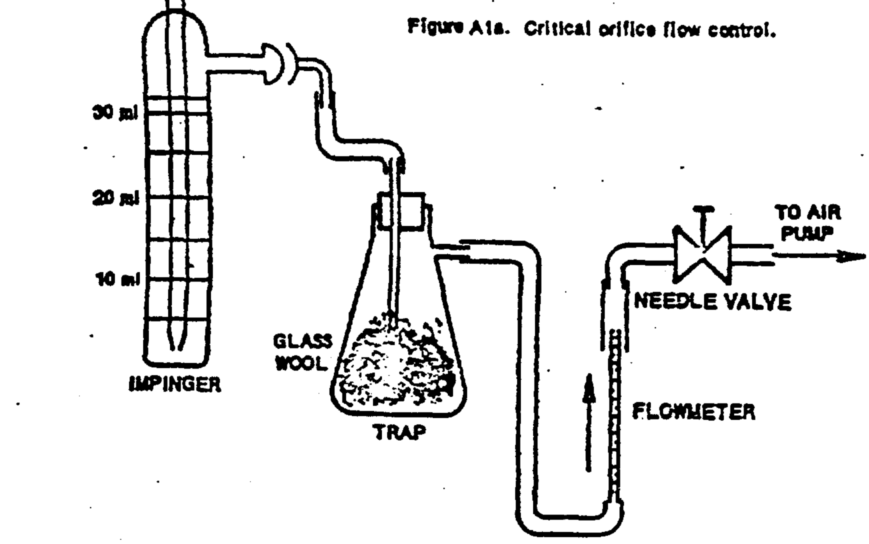

Figure A1. Sampling train.

Method A, Continued

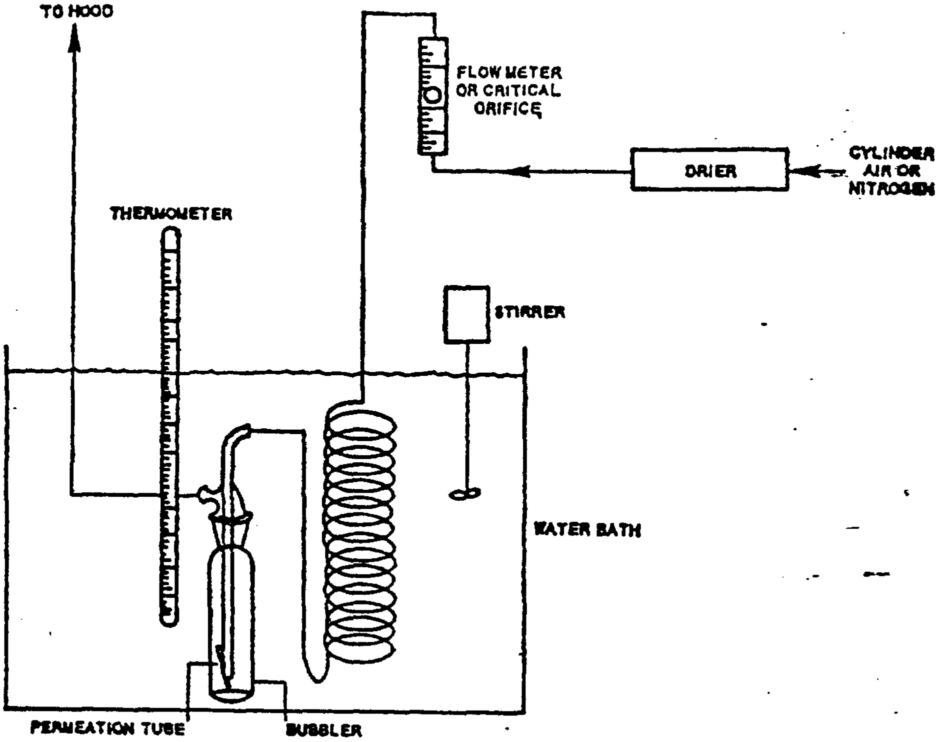

Figure A2. Apparatus for gravimetric calibration and field use.

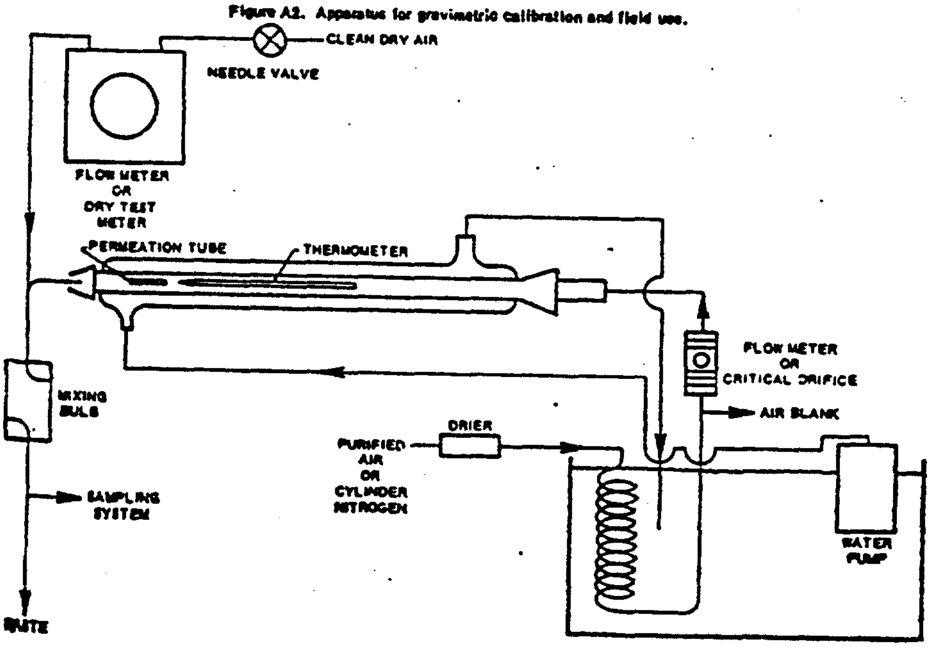

Figure A3. Permeation tube schematic for laboratory use.

10-9-79

Method B

REFERENCE METHOD FOR THE DETERMINATION OF SUSPENDED PARTICULATES IN THE ATMOSPHERE (HIGH VOLUME METHOD)

(40 CFR 50, Appendix B, July 1, 1976)

1. *Principle and Applicability.*

1.1 Air is drawn into a covered housing and through a filter by means of a high-flow-rate blower at a flow rate (1.13 to 1.70 m.^{3}/min.; 40 to 60 ft.^{3}/min.) that allows suspended particles having diameters of less than 100 μm. (Stokes equivalent diameter) to pass to the filter surface. (*1*) Particles within the size range of 100 to 0.1 μm. diameter are ordinarily collected on glass fiber filters. The mass concentration of suspended particulates in the ambient air (μg./m.^{3}) is computed by measuring the mass of collected particulates and the volume of air sampled.

1.2 This method is applicable to measurement of the mass concentration of suspended particulates in ambient air. The size of the sample collected is usually adequate for other analyses.

2. *Range and Sensitivity.*

2.1 When the sampler is operated at an average flow rate of 1.70 m.^{3}/min. (60 ft.^{3}/min.) for 24 hours, an adequate sample will be obtained even in an atmosphere having concentrations of suspended particulates as low as 1 μg./m.^{3}. If particulate levels are unusually high, a satisfactory sample may be obtained in 6 to 8 hours or less. For determination of average concentrations of suspended particulates in ambient air, a standard sampling period of 24 hours is recommended.

2.2 Weights are determined to the nearest milligram, airflow rates are determined to the nearest 0.03 m.^{3}/min. (1.0 ft.^{3}/min.), times are determined to the nearest 2 minutes, and mass concentrations are reported to the nearest microgram per cubic meter.

3. *Interferences.*

3.1 Particulate matter that is oily, such as photochemical smog or wood smoke, may block the filter and cause a rapid drop in airflow at a nonuniform rate. Dense fog or high humidity can cause the filter to become too wet and severely reduce the airflow through the filter.

3.2 Glass-fiber filters are comparatively insensitive to changes in relative humidity, but collected particulates can be hygroscopic. (*2*)

4. *Precision, Accuracy, and Stability.*

4.1 Based upon collaborative testing, the relative standard deviation (coefficient of variation) for single analyst variation (repeatability of the method) is 3.0 percent. The corresponding value for multilaboratory variation (reproducibility of the method) is 3.7 percent. (*3*)

4.2 The accuracy with which the sampler measures the true average concentration depends upon the constancy of the airflow rate through the sampler. The airflow rate is affected by the concentration and the nature of the dust in the atmosphere. Under these conditions the error in the measured average concentration may be in excess of ±50 percent of the true average concentration, depending on the amount of reduction of airflow rate and on the variation of the mass concentration of dust with time during the 24-hour sampling period. (*4*)

5. *Apparatus.*

5.1 *Sampling.*

5.1.1 *Sampler.* The sampler consists of three units: (1) the faceplate and gasket, (2) the filter adapter assembly, and (3) the motor unit. Figure B1 shows an exploded view of these parts, their relationship to each other, and how they are assembled. The sampler must be capable of passing environmental air through a 406.5 cm.^{2} (63 in.^{2}) portion of a clean 20.3 by 25.4 cm. (8- by 10-in.) glass-fiber filter at a rate of at least 1.70 m.^{3}/min. (60 ft.^{3}/min.). The motor must be capable of continuous operation for 24-hour periods with input voltages ranging from 110 to 120 volts, 50–60 cycles alternating current and must have third-wire safety ground. The housing for the motor unit may be of any convenient construction so long as the unit remains airtight and leak-free. The life of the sampler motor can be extended by lowering the voltage by about 10 percent with a small "buck or boost" transformer between the sampler and power outlet.

5.1.2 *Sampler Shelter.* It is important that the sampler be properly installed in a suitable shelter. The shelter is subjected to extremes of temperature, humidity, and all types of air pollutants. For these reasons the materials of the shelter must be chosen carefully. Properly painted exterior plywood or heavy gauge aluminum serve well. The sampler must be mounted vertically in the shelter so that the glass-fiber filter is parallel with the ground. The shelter must be provided with a roof so that the filter is protected from precipitation and debris. The internal arrangement and configuration of a suitable shelter with a gable roof are shown in Figure B2. The clearance area between the main housing and the roof at its closest point should be 580.6±193.5 cm.^{2} (90±30 in.^{2}). The main housing should be rectangular, with dimensions of about 29 by 36 cm. (11½ by 14 in.).

5.1.3 *Rotameter.* Marked in arbitrary units, frequently 0 to 70, and capable of being calibrated. Other devices of at least comparable accuracy may be used.

5.1.4 *Orifice Calibration Unit.* Consisting of a metal tube 7.6 cm. (3 in.) ID and 15.9 cm. (6¼ in.) long with a static pressure tap 5.1 cm. (2 in.) from one end. See Figure B3. The tube end nearest the pressure tap is flanged to about 10.8 cm. (4¼ in.) OD with a male thread of the same size as the inlet end of the high-volume air sampler. A single metal plate 9.2 cm. (3⅝ in.) in diameter and 0.24 cm. (3/32 in.) thick with a central orifice 2.9 cm. (1⅛ in.) in diameter is held in place at the air inlet end with a female threaded ring. The other end of the tube is flanged to hold a loose female threaded coupling, which screws onto the inlet of the sampler. An 18-hole metal plate, an integral part of the unit, is positioned between the orifice and sampler to simulate the resistance of a clean glass-fiber filter. An orifice calibration unit is shown in Figure B3.

5.1.5 *Differential Manometer.* Capable of measuring to at least 40 cm. (16 in.) of water.

5.1.6 *Positive Displacement Meter.* Calibrated in cubic meters or cubic feet, to be used as a primary standard.

5.1.7 *Barometer.* Capable of measuring atmospheric pressure to the nearest mm.

5.2 *Analysis.*

5.2.1 *Filter Conditioning Environment.* Balance room or desiccator maintained at 15° to 35°C. and less than 50 percent relative humidity.

5.2.2 *Analytical Balance.* Equipped with a weighing chamber designed to handle unfolded 20.3 by 25.4 cm. (8- by 10-in.) filters and having a sensitivity of 0.1 mg.

5.2.3 *Light Source.* Frequently a table of the type used to view X-ray films.

5.2.4 *Numbering Device.* Capable of printing identification numbers on the filters.

6. *Reagents.*

6.1 *Filter Media.* Glass-fiber filters having a collection efficiency of at least 99 percent for particles of 0.3 µm. diameter, as measured by the DOP test, are suitable for the quantitative measurement of concentrations of suspended particulates, (5) although some other medium, such as paper, may be desirable for some analyses. If a more detailed analysis is contemplated, care must be exercised to use filters that contain low background concentrations of the pollutant being investigated. Careful quality control is required to determine background values of these pollutants.

7. *Procedure.*

7.1 *Sampling.*

7.1.1 *Filter Preparation.* Expose each filter to the light source and inspect for pinholes, particles, or other imperfections. Filters with visible imperfections should not be used. A small brush is useful for removing particles. Equilibrate the filters in the filter conditioning environment for 24 hours. Weigh the filters to the nearest milligram; record tare weight and filter identification number. Do not bend or fold the filter before collection of the sample.

7.1.2 *Sample Collection.* Open the shelter, loosen the wing nuts, and remove the faceplate from the filter holder. Install a numbered, preweighed, glass-fiber filter in position (rough side up), replace the faceplate without disturbing the filter, and fasten securely. Undertightening will allow air leakage, overtightening will damage the sponge-rubber faceplate gasket. A very light application of talcum powder may be used on the sponge-rubber faceplate gasket to prevent the filter from sticking. During inclement weather the sampler may be removed to a protected area for filter change. Close the roof of the shelter, run the sampler for about 5 minutes, connect the rotameter to the nipple on the back of the sampler, and read the rotameter ball with rotameter in a vertical position. Estimate to the nearest whole number. If the ball is fluctuating rapidly, tip the rotameter and slowly straighten it until the ball gives a constant reading. Disconnect the rotameter from the nipple; record the initial rotameter reading and the starting time and date on the filter folder. (The rotameter should never be connected to the sampler except when the flow is being measured.) Sample for 24 hours from midnight to midnight and take a final rotameter reading. Record the final rotameter reading and ending time and date on the filter folder. Remove the faceplate as described above and carefully remove the filter from the holder, touching only the outer edges. Fold the filter lengthwise so that only surfaces with collected particulates are in contact, and place in a manila folder. Record on the folder the filter number, location, and any other factors, such as meteorological conditions or razing of nearby buildings, that might affect the results. If the sample is defective, void it at this time. In order to obtain a valid sample, the high-volume sampler must be operated with the same rotameter and tubing that were used during its calibration.

7.2 *Analysis.* Equilibrate the exposed filters for 24 hours in the filter conditioning environment, then reweigh. After they are weighed, the filters may be saved for detailed chemical analysis.

7.3 *Maintenance.*

7.3.1 *Sampler Motor.* Replace brushes before they are worn to the point where motor damage can occur.

7.3.2 *Faceplate Gasket.* Replace when the margins of samples are no longer sharp. The gasket may be sealed to the faceplate with rubber cement or double-sided adhesive tape.

7.3.3 *Rotameter.* Clean as required, using alcohol.

8. *Calibration.*

8.1 *Purpose.* Since only a small portion of the total air sampled passes through the rotameter during measurement, the rotameter must be calibrated against actual airflow with the orifice calibration unit. Before the orifice calibration unit can be used to calibrate the rotameter, the orifice calibration unit itself must be calibrated against the positive displacement primary standard.

8.1.1 *Orifice Calibration Unit.* Attach the orifice calibration unit to the intake end of the positive displacement primary standard and attach a high-volume motor blower unit to the exhaust end of the primary standard. Connect one end of a differential manometer to the differential pressure tap of the orifice calibration unit and leave the other end open to the atmosphere. Operate the high-volume motor blower unit so that a series of different, but constant, airflows (usually six) are obtained for definite time periods. Record the reading on the differential manometer at each airflow. The different constant airflows are obtained by placing a series of loadplates, one at a time, between the calibration unit and the primary standard. Placing the orifice before the inlet reduces the pressure at the inlet of the primary standard below atmospheric; therefore, a correction must be made for the increase in volume caused by this decreased inlet pressure. Attach one end of a second differential manometer to an inlet pressure tap of the primary standard and leave the other open to the atmosphere. During each of the constant airflow measurements made above, measure the true inlet pressure of the primary standard with this second differential manometer. Measure atmospheric pressure and temperature. Correct the measured air volume to true air volume as directed in 9.1.1, then obtain true airflow rate, Q, as directed in 9.1.3. Plot the differential manometer readings of the orifice unit versus Q.

8.1.2 *High-Volume Sampler.* Assemble a high-volume sampler with a clean filter in place and run for at least 5 minutes. Attach a rotameter, read the ball, adjust so that the ball reads 65, and seal the adjusting mechanism so that it cannot be changed easily. Shut off motor, remove the filter, and attach the orifice calibration unit in its place. Operate the high-volume sampler at a series of different, but constant, airflows (usually six). Record the reading of the differential manometer on the orifice calibration unit, and record the readings of the rotameter at each flow. Measure atmospheric pressure and temperature. Convert the differential manometer reading to m.³/min., Q, then plot rotameter reading versus Q.

8.1.3 *Correction for Differences in Pressure or Temperature.* See Addendum B.

9. *Calculations.*

9.1 *Calibration of Orifice.*

9.1.1 *True Air Volume.* Calculate the air volume measured by the positive displacement primary standard.

$$V_a = \frac{(P_a - P_m)}{P_a}(V_M)$$

V_a = True air volume at atmospheric pressure, m.³

P_a = Barometric pressure, mm. Hg.

P_m = Pressure drop at inlet of primary standard, mm. Hg.

V_M = Volume measured by primary standard, m.³

9.1.2 *Conversion Factors.*

Inches Hg. × 25.4 = mm. Hg.

Inches water × 73.48 × 10⁻³ = inches Hg.

Cubic feet air × 0.0284 = cubic meters air.

9.1.3 *True Airflow Rate.*

$$Q = \frac{V_a}{T}$$

Q = Flow rate, m.³/min.

T = Time of flow, min.

9.2 *Sample Volume.*

9.2.1 *Volume Conversion.* Convert the initial and final rotameter readings to true airflow rate, Q, using calibration curve of 8.1.2.

9.2.2 *Calculate volume of air sampled*

$$V = \frac{Q_i + Q_f}{2} \times T$$

V = Air volume sampled, m.³

Q_i = Initial airflow rate, m.³/min.

Q_f = Final airflow rate, m.³/min.

T = Sampling time, min.

9.3 *Calculate mass concentration of suspended particulates*

$$S.P. = \frac{(W_f - W_i) \times 10^6}{V}$$

S.P. = Mass concentration of suspended particulates, µg/m.³

W_i = Initial weight of filter, g.

W_f = Final weight of filter, g.

V = Air volume sampled, m.³

10^6 = Conversion of g. to µg.

10. *References.*

(1) Robson, C. D., and Foster, K. E., "Evaluation of Air Particulate Sampling Equipment", *Am. Ind. Hyg. Assoc. J.* 24, 404 (1962).

(2) Tierney, G. P., and Conner, W. D., "Hygroscopic Effects on Weight Determinations of Particulates Collected on Glass-Fiber Filters", *Am. Ind. Hyg. Assoc. J.* 28, 363 (1967).

(3) Unpublished data based on a collaborative test involving 12 participants, conducted under the direction of the Methods Standardization Services Section of the National Air Pollution Control Administration, October, 1972.

(4) Harrison, W. K., Nader, J. S., and Fugman, F. S., "Constant Flow Regulators for High-Volume Air Sampler", *Am. Ind. Hyg. Assoc. J.* 21, 114-120 (1960).

(5) Pate, J. B., and Tabor, E. C., "Analytical Aspects of the Use of Glass-Fiber Filters for the Collection and Analysis of Atmospheric Particulate Matter", *Am. Ind. Hyg. Assoc. J.* [illegible] ([illegible]).

ADDENDA

A. *Alternative Equipment.*

A modification of the high-volume sampler incorporating a method for recording the actual airflow over the entire sampling period has been described, and is acceptable for measuring the concentration of suspended particulates ([illegible], J. S., [illegible] Conference on Methods in Air Pollution and Industrial Hygiene Studies, 1967, Oakland, Calif.). This modification consists of an exhaust orifice meter assembly connected through a transducer to a system for continuously recording airflow on a circular chart. The volume of air sampled is calculated by the following equation:

$$V = Q \times T.$$

Q = Average sampling rate, m.³/min.

T = Sampling time, minutes.

* * *

Method B, Continued

The average sampling rate, Q, is determined from the recorder chart by estimation if the flow rate does not vary more than 0.11 m.³/min. (4 ft.³/min.) during the sampling period. If the flow rate does vary more than 0.11 m.³ (4 ft.³/min.) during the sampling period, read the flow rate from the chart at 2-hour intervals and take the average.

B. *Pressure and Temperature Corrections.* If the pressure or temperature during high-volume sampler calibration is substantially different from the pressure or temperature during orifice calibration, a correction of the flow rate, Q, may be required. If the pressures differ by no more than 15 percent and the temperatures differ by no more than 100 percent (°C), the error in the uncorrected flow rate will be no more than 15 percent. If necessary, obtain the corrected flow rate as directed below. This correction applies only to orifice meters having a constant orifice coefficient. The coefficient for the calibrating orifice described in 5.1.4 has been shown experimentally to be constant over the normal operating range of the high-volume sampler (0.6 to 2.2 m.³/min.; 20 to 78 ft.³/min.). Calculate corrected flow rate:

$$Q_2 = Q_1 \left[\frac{T_2 P_1}{T_1 P_2} \right]^{1/2}$$

Q_2 = Corrected flow rate, m.³/min.

Q_1 = Flow rate during high-volume sampler calibration (Section 8.1.2), m.³/min.

T_1 = Absolute temperature during orifice unit calibration (Section 8.1.1), °K or °R.

P_1 = Barometric pressure during orifice unit calibration (Section 8.1.1), mm. Hg.

T_2 = Absolute temperature during high-volume sampler calibration (Section 8.1.2), °K or °R.

P_2 = Barometric pressure during high-volume sampler calibration (Section 8.1.2), mm. Hg.

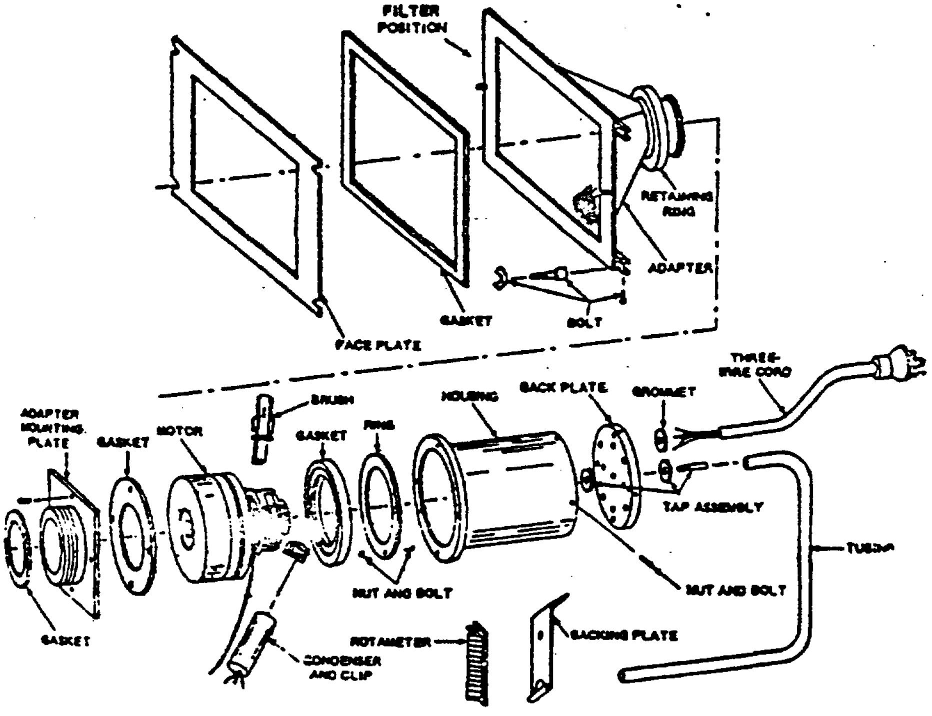

Figure B1. Exploded view of typical high-volume air sampler parts.

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Method B, Continued

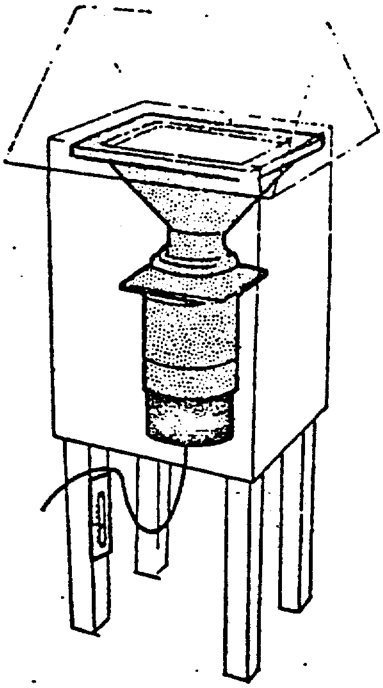

Figure B2. Assembled sampler and shelter.

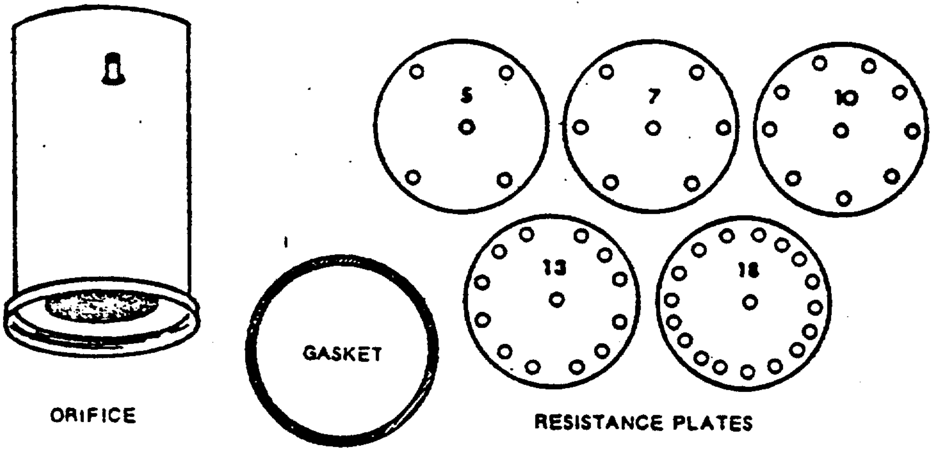

Figure B3. Orifice calibration unit.

10.9.79

Method C

MEASUREMENT PRINCIPLE AND CALIBRATION PROCEDURE FOR THE CONTINUOUS MEASUREMENT OF CARBON MONOXIDE IN THE ATMOSPHERE (NON-DISPERSIVE INFRARED SPECTOMETRY)

(40 CFR 50, Appendix C, July 1, 1976)

1. *Principle and applicability.*

1.1 This principle is based on the absorption of infrared radiation by carbon monoxide in a non-dispersive photometer. Both beams pass into matched cells, each containing a selective detector and CO. The CO in the cells absorb infrared radiation only at its characteristic frequencies and the detector is sensitive to those frequencies. With a non-absorbing gas in the reference cell, and with no CO in the sample cell, the signals from both detectors are balanced electronically. Any CO introduced into the sample cell will absorb radiation, which reduces the temperature and pressure in the detector cell and displaces a diaphram. This displacement is detected electronically and amplified to provide an output signal.

1.2 An analyzer based on this principle will be considered a reference method only if it has been designated as a reference method in accordance with Part 53 of this chapter.

2.—6. [Reserved]

7. *Procedure.*

7.1 Calibrate the instrument as described in 8.1. All gases (sample, zero, calibration, and span) must be introduced into the entire analyzer system. Figure C1 shows a typical flow diagram. For specific operating instructions, refer to the manufacturer's manual.

8. *Calibration.*

8.1 *Calibration Curve.* Determine the linearity of the detector response at the operating flow rate and temperature. Prepare a calibration curve and check the curve furnished with the instrument. Introduce zero gas and set the zero control to indicate a recorder reading of zero. Introduce span gas and adjust the span control to indicate the proper value on the recorder scale (e.g. on 0–58 mg./m.³ scale, set the 46 mg./m.³ standard at 80 percent of the recorder chart). Recheck zero and span until adjustments are no longer necessary. Introduce intermediate calibration gases and plot the values obtained. If a smooth curve is not obtained, calibration gases may need replacement.

9. *Calculations.*

9.1 Determine the concentrations directly from the calibration curve. No calculations are necessary.

9.2 Carbon monoxide concentrations in mg./m.³ are converted to p.p.m. as follows:

$$\text{p.p.m. CO} = \text{mg. CO/m.}^3 \times 0.873$$

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[36 FR 22391, Nov. 25, 1971, as amended at 40 FR 7042, Feb. 18, 1975]

10-9-79

Method D

MEASUREMENT PRINCIPLE AND CALIBRATION PROCEDURE FOR THE MEASUREMENT OF OZONE IN THE ATMOSPHERE

(40 CFR 50, Appendix D, February 8, 1979)

MEASUREMENT PRINCIPLE

1. Ambient air and ethylene are delivered simultaneously to a mixing zone where the ozone in the air reacts with the ethylene to emit light, which is detected by a photomultiplier tube. The resulting photocurrent is amplified and is either read directly or displayed on a recorder.

2. An analyzer based on this principle will be considered a reference method only if it has been designated as a reference method in accordance with Part 53 of this chapter and calibrated as follows:

CALIBRATION PROCEDURE

1. Principle. The calibration procedure is based on the photometric assay of ozone (O_3) concentrations in a dynamic flow system. The concentration of O_3 in an absorption cell is determined from a measurement of the amount of 254 nm light absorbed by the sample. This determination requires knowledge of (1) the absorption coefficient (α) of O_3 at 254 nm, (2) the optical path length (l) through the sample, (3) the transmittance of the sample at a wavelength of 254 nm, and (4) the temperature (T) and pressure (P) of the sample. The transmittance is defined as the ratio I/I_0, where I is the intensity of light which passes through the cell and is sensed by the detector when the cell contains an O_3 sample, and I_0 is the intensity of light which passes through the cell and is sensed by the detector when the cell contains zero air. It is assumed that all conditions of the system, except for the contents of the absorption cell, are identical during measurement of I and I_0. The quantities defined above are related by the Beer-Lambert absorption law,

$$\text{Transmittance} = \frac{I}{I_0} = e^{-\alpha c l} \qquad (1)$$

where:

α = absorption coefficient of O_3 at 254 nm = 308 ± 4 atm^{-1} cm^{-1} at 0°C and 750 torr.$^{(1, 2, 3, 4, 5, 6, 7)}$
c = O_3 concentration in atmospheres
l = optical path length in cm

In practice, a stable O_3 generator is used to produce O_3 concentrations over the required range. Each O_3 concentration is determined from the measurement of the transmittance (I/I_0) of the sample at 254 nm with a photometer of path length l and calculated from the equation,

: : :

: : :

$$c(\text{atm}) = -\frac{1}{\alpha l}\left(\ln I/I_0\right) \qquad (2a)$$

or,

$$c(\text{ppm}) = -\frac{10^6}{\alpha l}\left(\ln I/I_0\right) \qquad (2b)$$

The calculated O_3 concentrations must be corrected for O_3 losses which may occur in the photometer and for the temperature and pressure of the sample.

2. Applicability. This procedure is applicable to the calibration of ambient air O_3 analyzers, either directly or by means of a transfer standard certified by this procedure. Transfer standards must meet the requirements and specifications set forth in Reference 8.

3. Apparatus. A complete UV calibration system consists of an ozone generator, an output port or manifold, a photometer, an appropriate source of zero air, and other components as necessary. The configuration must provide a stable ozone concentration at the system output and allow the photometer to accurately assay the output concentration to the precision specified for the photometer (3.1). Figure 1 shows a commonly used configuration and serves to illustrate the calibration procedure which follows. Other configurations may require appropriate variations in the procedural steps. All connections between components in the calibration system downstream of the O_3 generator should be of glass, Teflon, or other relatively inert materials. Additional information regarding the assembly of a UV photometric calibration apparatus is given in Reference 9. For certification of transfer standards which provide their own source of O_3, the transfer standard may replace the O_3 generator and possibly other components shown in Figure 1; see Reference 8 for guidance.

3.1 UV photometer. The photometer consists of a low-pressure mercury discharge lamp, (optional) collimation optics, an absorption cell, a detector, and signal-processing electronics, as illustrated in Figure 1. It must be capable of measuring the transmittance, I/I_0, at a wavelength of 254 nm with sufficient precision such that the standard deviation of the concentration measurements does not exceed the greater of 0.005 ppm or 3% of the concentration. Because the low-pressure mercury lamp radiates at several wavelengths, the photometer must incorporate suitable means to assure that no O_3 is generated in the cell by the lamp, and that at least 99.5% of the radiation sensed by the detector is 254 nm radiation.

(This can be readily achieved by prudent selection of optical filter and detector response characteristics.) The length of the light path through the absorption cell must be known with an accuracy of at least 99.5%. In addition, the cell and associated plumbing must be designed to minimize loss of O_3 from contact with cell walls and gas handling components. See Reference 9 for additional information.

3.2 Air flow controllers. Devices capable of regulating air flows as necessary to meet the output stability and photometer precision requirements.

3.3 Ozone generator. Device capable of generating stable levels of O_3 over the required concentration range.

3.4 Output manifold. The output manifold should be constructed of glass, Teflon, or other relatively inert material, and should be of sufficient diameter to insure a negligible pressure drop at the photometer connection and other output ports. The system must have a vent designed to insure atmospheric pressure in the manifold and to prevent ambient air from entering the manifold.

3.5 Two-way valve. Manual or automatic valve, or other means to switch the photometer flow between zero air and the O_3 concentration.

3.6 Temperature indicator. Accurate to ±1°C.

3.7 Barometer or pressure indicator. Accurate to ±2 torr.

4. Reagents.

4.1 Zero air. The zero air must be free of contaminants which would cause a detectable response from the O_3 analyzer, and it should be free of NO, C_2H_4, and other species which react with O_3. A procedure for generating suitable zero air is given in Reference 9. As shown in Figure 1, the zero air supplied to the photometer cell for the I_0 reference measurement must be derived from the same source as the zero air used for generation of the ozone concentration to be assayed (I measurement). When using the photometer to certify a transfer standard having its own source of ozone, see Reference 8 for guidance on meeting this requirement.

5. Procedure.

5.1 General operation. The calibration photometer must be dedicated exclusively to use as a calibration standard. It should always be used with clean, filtered calibration gases, and never used for ambient air sampling. Consideration should be given to locating the calibration photometer in a clean laboratory where it can be stationary, protected from physical shock, operated by a responsible analyst, and used as a common standard for all field calibrations via transfer standards.

5.2 Preparation. Proper operation of the photometer is of critical importance to the accuracy of this procedure. The following steps will help to verify proper operation. The steps are not necessarily required prior to each use of the photometer. Upon initial operation of the photometer, these steps should be carried out frequently, with all quantitative results or indications recorded in a chronological record either in tabular form or plotted on a graphical chart. As the performance and stability record of the photometer is established, the frequency of these steps may be reduced to be consistent with the documented stability of the photometer.

5.2.1 Instruction manual: Carry out all set up and adjustment procedures or checks as described in the operation or instruction manual associated with the photometer.

5.2.2 System check: Check the photometer system for integrity, leaks, cleanliness, proper flowrates, etc. Service or replace filters and zero air scrubbers or other consumable materials, as necessary.

5.2.3 Linearity: Verify that the photometer manufacturer has adequately established that the linearity error of the photometer is less than 3%, or test the linearity by dilution as follows: Generate and assay an O_3 concentration near the upper range limit of the system (0.5 or 1.0 ppm), then accurately dilute that concentration with zero air and reassay it. Repeat at several different dilution ratios. Compare the assay of the original concentration with the assay of the diluted concentration divided by the dilution ratio, as follows

$$E = \frac{A_1 - A_2/R}{A_1} \times 100\% \qquad (3)$$

where:

E = linearity error, percent

A_1 = assay of the original concentration

A_2 = assay of the diluted concentration

R = dilution ratio = flow of original concentration divided by the total flow

The linearity error must be less than 5%. Since the accuracy of the measured flowrates will affect the linearity error as measured this way, the test is not necessarily conclusive. Additional information on verifying linearity is contained in Reference 9.

5.2.4 Intercomparison: When possible, the photometer should be occasionally intercompared, either directly or via transfer standards, with calibration photometers used by other agencies or laboratories.

5.2.5 Ozone losses: Some portion of the O_3 may be lost upon contact with the photometer cell walls and gas handling components. The magnitude of this loss must be determined and used to correct the calculated O_3 concentration. This loss must not exceed 5%. Some guidelines for quantitatively determining this loss are discussed in Reference 9.

5.3 Assay of O_3 concentrations.

5.3.1 Allow the photometer system to warm up and stabilizer.

* * *

5.3.2 Verify that the flowrate through the photometer absorption cell, F allows the cell to be flushed in a reasonably short period of time (2 liter/min is a typical flow). The precision of the measurements is inversely related to the time required for flushing, since the photometer drift error increases with time.

5.3.3 Insure that the flowrate into the output manifold is at least 1 liter/min grea er than the total flowrate required by t photometer and any other flow dema connected to the manifold.

5.3.4 Insure that the flowrate of zero a F_z is at least 1 liter/min greater than t flowrate required by the photometer.

5.3.5 With zero air flowing in the outp manifold, actuate the two-way valve allow the photometer to sample first t manifold zero air, then F_z. The two photo eter readings must be equal ($I = I_o$).

NOTE.—In some commercially availab photometers, the operation of the two-wa valve and various other operations in se tion 5.3 may be carried out automatically the photometer.

5.3.6 Adjust the O_3 generator to produ an O_3 concentration as needed.

5.3.7 Actuate the two-way valve to allo the photometer to sample zero air until t absorption cell is thoroughly flushed a record the stable measured value of I_o.

5.3.8 Actuate the two-way valve to allo the photometer to sample the ozone conce tration until the absorption cell is tho oughly flushed and record the stable mea ured value of I.

5.3.9 Record the temperature and pre sure of the sample in the photometer a sorption cell. (See Reference 9 for gui ance.)

5.3.10 Calculate the O_3 concentratio from equation 4. An average of several d terminations will provide better precision.

$$[O_3]_{OUT} = \left(\frac{-1}{al} \ln \frac{I}{I_o}\right) \left(\frac{T}{273}\right) \left(\frac{760}{P}\right) \times \frac{10^6}{L} \quad (4)$$

where:

$[O_3]_{OUT}$ = O_3 concentration, ppm
a = absorption coefficient of O_3 at 254 nm = 308 $atm^{-1}\,cm^{-1}$ at 0°C and 760 torr
l = optical path length, cm
T = sample temperature, K
P = sample pressure, torr
L = correction factor for O_3 losses from 5.2.5 = (1-fraction O_3 lost).

NOTE.—Some commercial photometers may automatically evaluate all or part of equation 4. It is the operator's responsibility to verify that all of the information required for equation 4 is obtained, either automatically by the photometer or manually. For "automatic" photometers which evaluate the first term of equation 4 based on a linear approximation, a manual correction may be required, particularly at higher O_3 levels. See the photometer instruction manual and Reference 9 for guidance.

5.3.11 Obtain additional O_3 concentration standards as necessary by repeating steps 5.3.6 to 5.3.10 or by Option 1.

5.4 Certification of transfer standards. A transfer standard is certified by relating the output of the transfer standard to one or more ozone standards as determined according to section 5.3. The exact procedu varies depending on the nature and desig of the transfer standard. Consult Referenc 8 for guidance.

5.5 Calibration of ozone analyzers. Ozon analyzers are calibrated as follows, usin ozone standards obtained directly accordin to section 5.3 or by means of a certifi transfer standard.

5.5.1 Allow sufficient time for the O_3 ana lyzer and the photometer or transfer stand ard to warmup and stabilize.

5.5.2 Allow the O_3 analyzer to sampl zero air until a stable response is obtaine and adjust the O_3 analyzer's zero contro Offsetting the analyzer's zero adjustment +5% of scale is recommended to facilitat observing negative zero drift. Record th stable zero air response as "Z".

5.5.3 Generate an O_3 concentratio standard of approximately 80% of the de sired upper range limit (URL) of the O_3 ana lyzer. Allow the O_3 analyzer to sample th O_3 concentration standard until a stable re sponse is obtained.

5.5.4 Adjust the O_3 analyzer's span con trol to obtain a convenient recorder re sponse as indicated below:

$$\text{recorder response (\% scale)} = \left(\frac{[O_3]_{OUT}}{URL} \times 100\right) + Z \quad (5)$$

where:

URL = upper range limit of the O_3 an er, ppm
Z = recorder response with zero air, % scale

Record the O_3 concentration and the corresponding analyzer response. If substantial adjustment of the span control is necessary, recheck the zero and span adjustments by repeating steps 5.5.2 to 5.5.4.

5.5.5 Generate several other O_3 con tration standards (at least 5 others are rec ommended) over the scale range of the O_3 analyzer by adjusting the O_3 source or b Option 1. For each O_3 concentration stand ard, record the O_3 and the correspondin analyzer response.

5.5.6 Plot the O_3 analyzer responses versus the corresponding O_3 concentrations and draw the O_3 analyzer's calibration curve or calculate the appropriate response factor.

5.5.7 *Option 1:* The various O_3 concentrations required in steps 5.3.11 and 5.5.5 may be obtained by dilution of the O_3 concentration generated in steps 5.3.6 and 5.5.3. With this option, accurate flow measurements are required. The dynamic calibration system may be modified as shown in Figure 2 to allow for dilution air to be metered in downstream of the O_3 generator. A mixing chamber between the O_3 generator and the output manifold is also required. The flowrate through the O_3 generator (F_O) and the dilution air flowrate (F_D) are measured with a reliable flow or volume standard traceable to NBS. Each O_3 concentration generated by dilution is calculated from:

$$[O_3]'_{OUT} = [O_3]_{OUT} \left(\frac{F_O}{F_O + F_D}\right) \qquad (6)$$

where:

$[O_3]'_{OUT}$ = diluted O_3 concentration, ppm
F_O = flowrate through the O_3 generator, liter/min
F_D = diluent air flowrate, liter/min

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Method D, Continued

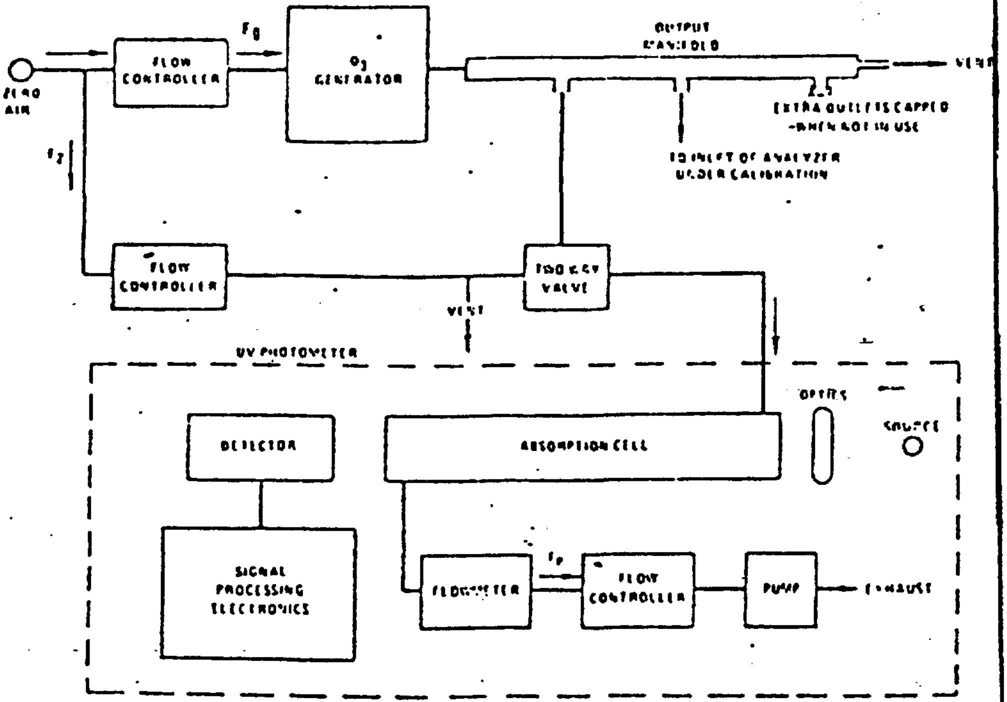

Figure 1 Schematic diagram of a typical UV photometric calibration system

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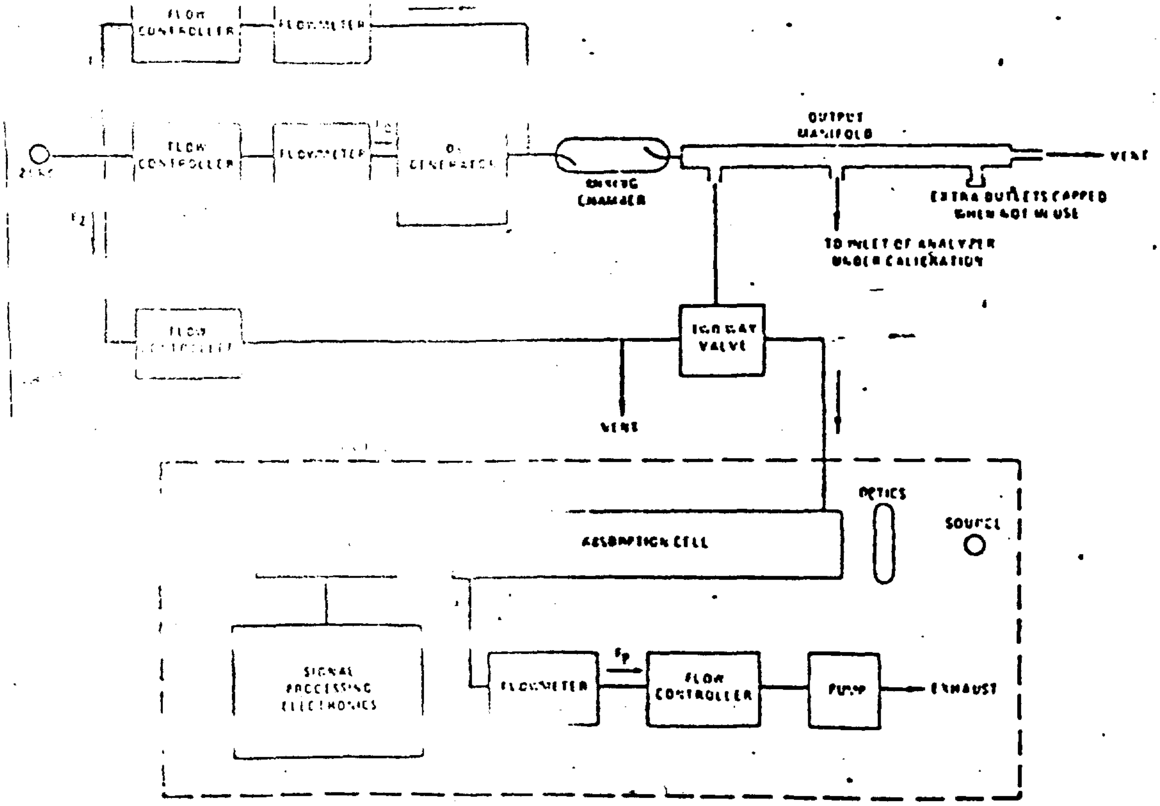

Figure 2. Schematic diagram of a typical UV photometric calibration system (OPTION 1)

10-9-79

Method E

REFERENCE METHOD FOR DETERMINATION OF HYDROCARBONS CORRECTED FOR METHANE

(40 CFR 50, Appendix E, July 1, 1976)

1. *Principle and Applicability.*

1.1 Measured volumes of air are delivered semicontinuously (4 to 12 times per hour) to a hydrogen flame ionization detector to measure its total hydrocarbon (THC) content. An aliquot of the same air sample is introduced into a stripper column which removes water, carbon dioxide, and hydrocarbons other than methane. Methane and carbon monoxide are passed quantitatively to a gas chromatographic column where they are separated. The methane is eluted first, and is passed unchanged through a catalytic reduction tube into the flame ionization detector. The carbon monoxide is eluted into the catalytic reduction tube where it is reduced to methane before passing through the flame ionization detector. Between analyses the stripper column is backflushed to prepare it for subsequent analysis. Hydrocarbon concentrations corrected for methane are determined by subtracting the methane value from the total hydrocarbon value.

Two modes of operation are possible: (1) A complete chromatographic analysis showing the continuous output from the detector for each sample injection; (2) The system is programed for automatic zero and span to display selected band widths of the chromatogram. The peak height is then used as the measure of the concentration. The former operation is referred to as the chromatographic or spectro mode and the latter as the barographic or "normal" mode depending on the make of analyzer.

1.2 The method is applicable to the semicontinuous measurement of hydrocarbons corrected for methane in ambient air. The carbon monoxide measurement, which is simultaneously obtained in this method, is not required in making measurements of hydrocarbons corrected for methane and will not be dealt with here.

2. *Range and Sensitivity.*

2.1 Instruments are available with various range combinations. For atmospheric analysis the THC range is 0–13.1 mg./m.^{3} (0–20 p.p.m.) carbon (as CH_4) and the methane range is 0–6.55 mg./m.^{3} (0–10 p.p.m.). For special applications, lower ranges are available and in these applications the range for THC is 0–1.31 mg./m.^{3} (0–2 p.p.m.) carbon (as CH_4) and for methane the range is 0–1.31 mg./m.^{3} (0–2 p.p.m.).

2.2 For the higher, atmospheric analysis ranges the sensitivity for THC is 0.065 mg./m.^{3} (0.1 p.p.m.) carbon (as CH_4) and for methane the sensitivity is 0.033 mg./m.^{3} (0.05 p.p.m.). For the lower, special analysis ranges the sensitivity is 0.016 mg./m.^{3} (0.025 p.p.m.) for each gas.

* * *

3. *Interferences.*

3.1 No interference in the methane measurement has been observed. The THC measurement typically includes all or a portion of what is generally classified as the air peak interference. This effect is minimized by proper plumbing arrangements or is negated electronically.

4. *Precision, Accuracy, and Stability.*

4.1 Precision determined with calibration gases is ±0.5 percent of full scale in the higher, atmospheric analysis ranges.

4.2 Accuracy is dependent on instrument linearity and absolute concentration of the calibration gases. An accuracy of 1 percent of full scale in the higher, atmospheric analysis ranges and 2 percent of full scale in the lower, special analysis ranges can be obtained.

4.3 Variations in ambient room temperature can cause changes in performance characteristics. This is due to shifts in oven temperature, flow rates, and pressure with ambient temperature change. The instrument should meet performance specifications with room temperature changes of ±3° C. Baseline drift is automatically corrected in the barographic mode.

5. *Apparatus.*

5.1 *Commercially Available THC, CH_4, and CO Analyzer.* Instruments should be installed on location and demonstrated, preferably by the manufacturer, or his representative, to meet or exceed manufacturer's specifications and those described in this method.

5.2 *Sample Introduction System.* Pump, flow control valves, automatic switching valves, and flowmeter.

5.3 *Filter (In-line).* A binder-free, glass-fiber filter with a porosity of 3 to 5 microns should be immediately downstream from the sample pump.

5.4 *Stripper or Precolumn.* Located outside of the oven at ambient temperature. The column should be repacked or replaced after the equivalent of 2 months of continuous operation.

5.5 *Oven.* For containing the analytical column and catalytic converter. The oven should be capable of maintaining an elevated temperature constant within ±0.5° C. The specific temperature varies with instrument manufacturer.

6. *Reagents.*

6.1 *Combustion Gas.* Air containing less than 1.3 mg./m.^{3} (2 p.p.m.) hydrocarbon as methane.

6.2 *Fuel.* Hydrogen or a mixture of hydrogen and inert gas containing less than 0.065 mg./m.^{3} (0.1 p.p.m.) hydrocarbons as methane.

6.3 *Carrier Gas.* Helium, nitrogen, air or hydrogen containing less than 0.006 mg./m.^{3} (0.1 p.p.m.) hydrocarbons as methane.

6.4 *Zero Gas.* Air containing less than 0.065 mg./m.³ (0.1 p.p.m.) total hydrocarbons as methane.

6.5 *Calibration Gases.* Gases needed for linearity checks (peak heights) are determined by the ranges used. Calibration gases corresponding to 10, 20, 40, and 80 percent of full scale are needed. Gases must be provided with certification or guaranteed analysis. Methane is used for both the total hydrocarbon measurement and methane measurement.

6.6 *Span Gas.* The calibration gas corresponding to 80 percent of full scale is used to span the instrument.

7. *Procedure.*

7.1 Calibrate the instrument as described in 8.1. Introduce sample into the system under the same conditions of pressure and flow rates as are used in calibration. (The pump is bypassed only when pressurized cylinder gases are used.) Figure E1 shows a typical flow diagram; for specific operating instructions refer to manufacturer's manual.

8. *Calibration.*

8.1 *Calibration Curve.* Determine the linearity of the system for THC and methane in the barographic mode by introducing zero gas and adjusting the respective zeroing controls to indicate a recorder reading of zero. Introduce the span gas and adjust the span control to indicate the proper value on the recorder scale. Recheck zero and span until adjustments are no longer necessary. Introduce intermediate calibration gases and plot the values obtained. If a smooth curve is not obtained, calibration gases may need replacement.

9. *Calculation.*

9.1 Determine concentrations of total hydrocarbons (as CH_4) and CH_4, directly from the calibration curves. No calculations are necessary.

9.2 Determine concentration of hydrocarbons corrected for methane by subtracting the methane concentration from the total hydrocarbon concentration.

9.3 Conversion between p.p.m. and mg./m.³ values for total hydrocarbons (as CH_4) methane and hydrocarbons corrected for methane are made as follows:

$$\text{p.p.m. carbon (as } CH_4) = [\text{mg. carbon (as } CH_4)/\text{m.}^3] \times 1.53$$

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Method E, Continued

ADDENDA

A. *Suggested Performance Specifications for Atmospheric Analyzers for Hydrocarbons Corrected for Methane:*

Range (minimum)	0–3 mg./m.³ (0–5 p.p.m.) THC 0–3 mg./m.³ (0–5 p.p.m.) CH_4
Output (minimum)	0–10 mv. full scale.
Minimum detectable sensitivity.	0.1 p.p.m. THC. 0.1 p.p.m. CH_4.
Zero drift (maximum)	Not to exceed 1 percent/24 hours.
Span drift (maximum)	Not to exceed 1 percent/24 hours.
Precision (minimum)	±0.5 percent.
Operational period (minimum).	3 days.
Operating temperature range (minimum).	5–40° C.
Operating humidity range (minimum).	10–100 percent.
Linearity (maximum)	1 percent of full scale.

B. *Suggested Definitions of Performance Specifications:*

Range—The minimum and maximum measurement limits.

Output—Electrical signal which is proportional to the measurement; intended for connection to readout or data processing devices. Usually expressed as millivolts or milliamps full scale at a given impedence.

Full Scale—The maximum measuring limit for a given range.

Minimum Detectable Sensitivity—The smallest amount of input concentration that can be detected as the concentration approaches zero.

Accuracy—The degree of agreement between a measured value and the true value; usually expressed at ± percent of full scale.

Lag Time—The time interval from a step change in input concentration at the instrument inlet to the first corresponding change in the instrument output.

Time to 90 Percent Response—The time interval from a step change in the input concentration at the instrument inlet to a reading of 90 percent of the ultimate recorded concentration.

Rise Time (90 percent)—The interval between initial response time and time to 90 percent response after a step decrease in the inlet concentration.

Zero Drift—The change in instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation, when the input concentration is zero; usually expressed as percent full scale.

Span Drift—The change in instrument output over a stated time period, usually 24 hours, of unadjusted continuous operation, when the input concentration is a stated upscale value; usually expressed as percent full scale.

Precision—The degree of agreement between repeated measurements of the same concentration. It is expressed as the average deviation of the single results from the mean.

Operational Period—The period of time over which the instrument can be expected to operate unattended within specifications.

Noise—Spontaneous deviations from a mean output not caused by input concentration changes.

Interference—An undesired positive or negative output caused by a substance other than the one being measured.

Interference Equivalent—The portion of indicated input concentration due to the presence of an interferent.

Operating Temperature Range—The range of ambient temperatures over which the instrument will meet all performance specifications.

Operating Humidity Range—The range of ambient relative humidity over which the instrument will meet all performance specifications.

Linearity—The maximum deviation between an actual instrument reading and the reading predicted by a straight line drawn between upper and lower calibration points.

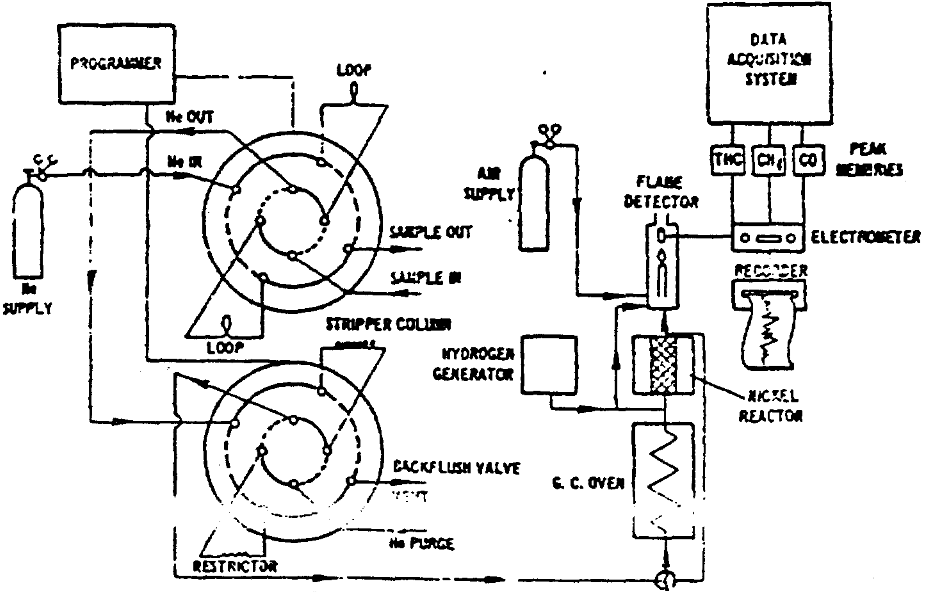

Figure E1. Typical flow diagram.

10-9-79

Method F

MEASUREMENT PRINCIPLE AND CALIBRATION PROCEDURE FOR THE MEASUREMENT OF NITROGEN DIOXIDE IN THE ATMOSPHERE (GAS PHASE CHEMILUMINESCENCE)

(41 FR, 52688, December 1, 1976)

Principle and Applicability

1. Atmospheric concentrations of nitrogen dioxide (NO_2) are measured indirectly by photometrically measuring the light intensity, at wavelengths greater than 600 nanometers, resulting from the chemiluminescent reaction of nitric oxide (NO) with ozone (O_3). (*1,2,3*) NO_2 is first quantitatively reduced to NO(*4,5,6*) by means of a converter. NO, which commonly exists in ambient air together with NO_2, passes through the converter unchanged causing a resultant total NO_x concentration equal to NO+NO_2. A sample of the input air is also measured without having passed through the converted. This latter NO measurement is subtracted from the former measurement (NO+NO_2) to yield the final NO_2 measurement. The NO and NO+NO_2 meausrements may be made concurrently with dual systems, or cyclically with the same system provided the cycle time does not exceed 1 minute.

2. Sampling considerations.

2.1 Chemiluminescence NO/NO_x/NO_2 analyzers will respond to other nitrogen containing compounds, such as peroxyacetyl nitrate (PAN), which might be reduced to NO in the thermal converter. (*7*) Atmospheric concentrations of these potential interferences are generally low relative to NO_2 and valid NO_2 measurements may be obtained. In certain geographical areas, where the concentration of these potential interferences is known or suspected to be high relative to NO_2, the use of an equivalent method for the measurement of NO_2 is recommended.

2.2 The use of integrating flasks on the sample inlet line of chemiluminescence NO/NO_x/NO_2 analyzers is optional and left to couraged. The sample residence time between the sampling point and the analyzer should be kept to a minimum to avoid erroneous NO_2 measurements resulting from the reaction of ambient levels of NO and O_3 in the sampling system.

2.3 The use of particulate filters on the sample inlet line of chemiluminescence NO/NO_x/NO_2 analyzers is optional and left to the discretion of the user or the manufacturer. Use of the filter should depend on the analyzer's susceptibility to interference, malfunction, or damage due to particulates. Users are cautioned that particulate matter concentrated on a filter may cause erroneous NO_2 measurements and therefore filters should be changed frequently.

3. An analyzer based on this principle will be considered a reference method only if it has been designated as a reference method in accordance with Part 53 of this chapter.

Calibration

1. *Alternative A*—Gas phase titration (GPT) of an NO standard with O_3.

Major equipment required: Stable O_3 generator. Chemiluminescence NO/NO_x/NO_2 analyzer with strip chart recorder(s). NO concentration standard.

1.1 Principle. This calibration technique is based upon the rapid gas phase reaction between NO and O_3 to produce stoichiometric quantities of NO_2 in accordance with the following equation: (*8*)

$$NO+O_3 \rightarrow NO_2+O_2 \qquad (1)$$

The quantitative nature of this reaction is such that when the NO concentration is known, the concentration of NO_2 can be determined. Ozone is added to excess NO in a dynamic calibration system, and the NO channel of the chemiluminescence NO/NO_x/NO_2 analyzer is used as an indicator of changes in NO concentration. Upon the addition of O_3, the decrease in NO concentration observed on the calibrated NO channel is equivalent to the concentration of NO_2 produced. The amount of NO_2 generated may be varied by adding variable amounts of O_3 from a stable uncalibrated O_3 generator. (*9*)

1.2 Apparatus. Figure 1, a schematic of a typical GPT apparatus, shows the suggested configuration of the components listed below. All connections between components in the calibration system downstream from the O_3 generator should be of glass, Teflon®, or other non-reactive material.

1.2.1 Air flow controllers. Devices capable of maintaining constant air flows within ±2% of the required flowrate.

1.2.2. NO flow controller. A device capable of maintaining constant NO flows within ±2% of the required flowrate. Component parts in contact with the NO should be of a non-reactive material.

1.2.3 Air flowmeters. Calibrated flowmeters capable of measuring and monitoring air flowrates with an accuracy of ±2% of the measured flowrate.

1.2.4 NO flowmeter. A calibrated flowmeter capable of measuring and monitoring NO flowrates with an accuracy of ±2% of the measured flowrate. (Rotameters have been reported to operate unreliably when measuring low NO flows and are not recommended.)

1.2.5. Pressure regulator for standard NO cylinder. This regulator must have a non-reactive diaphragm and internal parts and a suitable delivery pressure.

1.2.6 Ozone generator. The generator must be capable of generating sufficient and stable levels of O_3 for reaction with NO to generate NO_2 concentrations in the range required. Ozone generators of the electric discharge type may produce NO and NO_2 and are not recommended.

Method F, Continued

1.2.7 Valve. A valve may be used as shown in Figure 1 to divert the NO flow when zero air is required at the manifold. The valve should be constructed of glass, Teflon®, or other nonreactive material.

1.2.8 Reaction chamber. A chamber, constructed of glass, Teflon®, or other nonreactive material, for the quantitative reaction of O_3 with excess NO. The chamber should be of sufficient volume (V_{RC}) such that the residence time (t_R) meets the requirements specified in 1.4. For practical reasons, t_R should be less than 2 minutes.

1.2.9 Mixing chamber. A chamber constructed of glass, Teflon®, or other nonreactive material and designed to provide thorough mixing of reaction products and diluent air. The residence time is not critical when the dynamic parameter specification given in 1.4 is met.

1.2.10 Output manifold: The output manifold should be constructed of glass, Teflon®, or other non-reactive material and should be of sufficient diameter to insure an insignificant pressure drop at the analyzer connection. The system must have a vent designed to insure atmospheric pressure at the manifold and to prevent ambient air from entering the manifold.

1.3 Reagents.

1.3.1 NO concentration standard. Cylinder containing 50 to 100 ppm NO in N_2 with less than 1 ppm NO_2. The cylinder must be traceable to a National Bureau of Standards NO in N_2 Standard Reference Material (SRM 1683 or SRM 1684) or NO_2 Standard Reference Material (SRM 1629). Procedures for certifying the NO cylinder (working standard) against an NBS traceable NO or NO_2 standard and for determining the amount of NO_2 impurity are given in reference 13. The cylinder should be recertified on a regular basis as determined by the local quality control program.

1.3.2 Zero air. Air, free of contaminants which will cause a detectable response on the NO/NO_x/NO_2 analyzer or which might react with either NO, O_3, or NO_2 in the gas phase titration. A procedure for generating zero air is given in reference 13.

1.4 Dynamic parameter specification.

1.4.1 The O_3 generator air flowrate (F_O) and NO flowrate (F_{NO}) (see Figure 1) must be adjusted such that the following relationship holds:

$$P_R = [NO]_{RC} \times t_R \geq 2.75 \text{ ppm-minutes} \quad (2)$$

$$[NO]_{RC} = [NO]_{STD} \left(\frac{F_{NO}}{F_O + F_{NO}} \right) \quad (3)$$

$$t_R = \frac{V_{RC}}{F_O + F_{NO}} < 2 \text{ minutes} \quad (4)$$

: : :

: : :

where:

P_R = dynamic parameter specification, determined empirically, to insure complete reaction of the available O_3, ppm-minute

$[NO]_{RC}$ = NO concentration in the reaction chamber, ppm

t_R = residence time of the reactant gases in the reaction chamber, minute

$[NO]_{STD}$ = concentration of the undiluted NO standard, ppm

F_{NO} = NO flowrate, scm³/min

F_O = O_3 generator air flowrate, scm³/min

V_{RC} = volume of the reaction chamber, scm³

1.4.2 The flow conditions to be used in the GPT system are determined by the following procedure:

(a) Determine F_T, the total flow required at the output manifold (F_T = analyzer demand plus 10 to 50% excess).

(b) Establish $[NO]_{OUT}$ as the highest NO concentration (ppm) which will be required at the output manifold. $[NO]_{OUT}$ should be approximately equivalent to 90% of the upper range limit (*URL*) of the NO_2 concentration range to be covered.

(c) Determine F_{NO} as

$$F_{NO} = \frac{[NO]_{OUT} \times F_T}{[NO]_{STD}} \quad (5)$$

(d) Select a convenient or available reaction chamber volume. Initially, a trial V_{RC} may be selected to be in the range of approximately 200 to 500 scm³.

(e) Compute F_O as

$$F_O = \sqrt{\frac{[NO]_{STD} \times F_{NO} \times V_{RC}}{2.75}} - F_{NO} \quad (6)$$

(f) Compute t_R as

$$t_R = \frac{V_{RC}}{F_O + F_{NO}} \quad (7)$$

Verify that t_R < 2 minutes. If not, select a reaction chamber with a smaller V_{RC}.

(g) Compute the diluent air flowrate as

$$F_D = F_T - F_O - F_{NO} \quad (8)$$

where:

F_D = diluent air flowrate, scm³/min

(h) If F_O turns out to be impractical for the desired system, select a reaction chamber having a different V_{RC} and recompute F_O and F_D.

NOTE.—A dynamic parameter lower than 2.75 ppm-minutes may be used if it can be determined empirically that quantitative reaction of O_3 with NO occurs. A procedure for making this determination as well as a more detailed discussion of the above requirements and other related considerations is given in reference 13.

1.5 Procedure.

1.5.1 Assemble a dynamic calibration system such as the one shown in Figure 1.

1.5.2 Insure that all flowmeters are calibrated under the conditions of use against a reliable standard such as a soap-bubble meter or wet-test meter. All volumetric flowrates should be corrected to 25° C and 760 mm Hg. A discussion on the calibration of flowmeters is given in reference 13.

1.5.3 Precautions must be taken to remove O_2 and other contaminants from the NO pressure regulator and delivery system prior to the start of calibration to avoid any conversion of the standard NO to NO_2. Failure to do so can cause significant errors in calibration. This problem may be minimized by (1) carefully evacuating the regulator, when possible, after the regulator has been connected to the cylinder and before opening the cylinder valve; (2) thoroughly flushing the regulator and delivery system with NO after opening the cylinder valve; (3) not removing the regulator from the cylinder between calibrations unless absolutely necessary. Further discussion of these procedures is given in reference 13.

1.5.4 Select the operating range of the $NO/NO_x/NO_2$ analyzer to be calibrated. In order to obtain maximum precision and accuracy for NO_2 calibration, all three channels of the analyzer should be set to the same range. If operation of the NO and NO_x channels on higher ranges is desired, subsequent recalibration of the NO and NO_x channels on the higher ranges is recommended.

NOTE.—Some analyzer designs may require identical ranges for NO, NO_x, and NO_2 during operation of the analyzer.

1.5.5 Connect the recorder output cable(s) of the $NO/NO_x/NO_2$ analyzer to the input terminals of the strip chart recorder(s). All adjustments to the analyzer should be performed based on the appropriate strip chart readings. References to analyzer responses in the procedures given below refer to recorder responses.

1.5.6 Determine the GPT flow conditions required to meet the dynamic parameter specification as indicated in 1.4.

1.5.7 Adjust the diluent air and O_3 generator air flows to obtain the flows determined in 1.4.2. The total air flow must exceed the total demand of the analyzer(s) connected to the output manifold to insure that no ambient air is pulled into the manifold vent. Allow the analyzer to sample zero air until stable NO, NO_x, and NO_2 responses are obtained. After the responses have stabilized, adjust the analyzer zero control(s).

NOTE.—Some analyzers may have separate zero controls for NO, NO_x, and NO_2. Other analyzers may have separate zero controls only for NO and NO_x, while still others may have only one zero control common to all three channels.

Offsetting the analyzer zero adjustments to +5 percent of scale is recommended to facilitate observing negative zero drift. Record the stable zero air responses as Z_{NO}, Z_{NOx}, and Z_{NO_2}.

1.5.8 Preparation of NO and NO_x calibration curves.

1.5.8.1 Adjustment of NO span control. Adjust the NO flow from the standard NO cylinder to generate an NO concentration of approximately 80 percent of the upper range limit (*URL*) of the NO range. This exact NO concentration is calculated from:

$$[NO]_{OUT}=\frac{F_{NO}\times[NO]_{STD}}{F_{NO}+F_O+F_D} \qquad (9)$$

where:

$[NO]_{OUT}$ = diluted NO concentration at the output manifold, ppm

Sample this NO concentration until the NO and NO_x responses have stabilized. Adjust the NO span control to obtain a recorder response as indicated below:

recorder response (percent scale)

$$=\left(\frac{[NO]_{OUT}}{URL}\times 100\right)+Z_{NO} \qquad (10)$$

where:

URL = nominal upper range limit of the NO channel, ppm

NOTE:—Some analyzers may have separate span controls for NO, NO_x, and NO_2. Other analyzers may have separate span controls only for NO and NO_x, while still others may have only one span control common to all three channels. When only one span control is available, the span adjustment is made on the NO channel of the analyzer.

If substantial adjustment of the NO span control is necessary, it may be necessary to recheck the zero and span adjustments by repeating steps 1.5.7 and 1.5.8.1. Record the NO concentration and the analyzer's NO response.

1.5.8.2 Adjustment of NO_x span control. When adjusting the analyzer's NO_x span control, the presence of any NO_2 impurity in the standard NO cylinder must be taken into account. Procedures for determining the amount of NO_2 impurity in the standard NO cylinder are given in reference 13. The exact NO_x concentration is calculated from:

$$[NO_x]_{OUT}=\frac{F_{NO}\times([NO]_{STD}+[NO_2]_{IMP})}{F_{NO}+F_O+F_D} \qquad (11)$$

where:

$[NO_x]_{OUT}$ = diluted NO_x concentration at the output manifold, ppm

$[NO_2]_{IMP}$ = concentration of NO_2 impurity in the standard NO cylinder, ppm

Adjust the NO_x span control to obtain a recorder response as indicated below:

recorder response (% scale)

$$=\left(\frac{[NO_x]_{OUT}}{URL}\times 100\right)+Z_{NO_x} \qquad (12)$$

NOTE.—If the analyzer has only one span control, the span adjustment is made on the NO channel and no further adjustment is made here for NO_x.

If substantial adjustment of the NO_x span control is necessary, it may be necessary to recheck the zero and span adjustments by repeating steps 1.5.7 and 1.5.8.2. Record the NO_x concentration and the analyzer's NO_x response.

1.5.8.3 Generate several additional concentrations (at least five evenly spaced points across the remaining scale are suggested to verify linearity) by decreasing F_{NO} or increasing F_D. For each concentration generated, calculate the exact NO and NO_x concentrations using equations (9) and (11) respectively. Record the analyzer's NO and NO_x responses for each concentration. Plot the analyzer responses versus the respective calculated NO and NO_x concentrations and draw or calculate the NO and NO_x calibration curves. For subsequent calibrations where linearity can be assumed, these curves may be checked with a two-point calibration consisting of a zero air point and NO and NO_x concentrations of approximately 80% of the *URL*.

1.5.9 Preparation of NO_2 calibration curve.

1.5.9.1 Assuming the NO_2 zero has been properly adjusted while sampling zero air in step 1.5.7, adjust F_O and F_D as determined in 1.4.2. Adjust F_{NO} to generate an NO concentration near 90% of the *URL* of the NO range. Sample this NO concentration until the NO and NO_x responses have stabilized. Using the NO calibration curve obtained in 1.5.8, measure and record the NO concentration as $[NO]_{orig}$. Using the NO_x calibration curve obtained in 1.5.8, measure and record the NO_x concentration as $[NO_x]_{orig}$.

1.5.9.2 Adjust the O_3 generator to generate sufficient O_3 to produce a decrease in the NO concentration equivalent to approximately 80% of the URL of the NO_2 range. The decrease must not exceed 90% of the NO concentration determined in step 1.5.9.1. After the analyzer responses have stabilized, record the resultant NO and NO_x concentrations as $[NO]_{rem}$ and $[NO_x]_{rem}$.

1.5.9.3 Calculate the resulting NO_2 concentration from:

$$[NO_2]_{OUT} = [NO]_{orig} - [NO]_{rem} + \frac{F_{NO} \times [NO_2]_{IMP}}{F_{NO} + F_O + F_D} \quad (13)$$

where:

$[NO_2]_{OUT}$ = diluted NO_2 concentration at the output manifold, ppm

$[NO]_{orig}$ = original NO concentration, prior to addition of O_3, ppm

$[NO]_{rem}$ = NO concentration remaining after addition of O_3, ppm

Adjust the NO_2 span control to obtain a recorder response as indicated below:

NOTE: If the analyzer has only one or two span controls, the span adjustments are made on the NO channel or NO and NO_x channels and no further adjustment is made here for NO_2.

If substantial adjustment of the NO_2 span control is necessary, it may be necessary to recheck the zero and span adjustments by repeating steps 1.5.7 and 1.5.9.3. Record the NO_2 concentration and the corresponding analyzer NO_2 and NO_x responses.

1.5.9.4 Maintaining the same F_{NO}, F_O, and F_D as in 1.5.9.1, adjust the ozone generator to obtain several other concentrations of NO_2 over the NO_2 range (at least five evenly spaced points across the remaining scale are suggested). Calculate each NO_2 concentration using equation (13) and record the corresponding analyzer NO_2 and NO_x responses. Plot the analyzer's NO_2 responses versus the corresponding calculated NO_2 concentrations and draw or calculate the NO_2 calibration curve.

1.5.10 Determination of converter efficiency.

1.5.10.1 For each NO_2 concentration generated during the preparation of the NO_2 calibration curve (see 1.5.9) calculate the concentration of NO_2 converted from:

$$[NO_2]_{CONV} = [NO_2]_{OUT} - ([NO_x]_{orig} - [NO_x]_{rem}) \quad (15)$$

where:

$[NO_2]_{CONV}$ = concentration of NO_2 converted, ppm

$[NO_x]_{orig}$ = original NO_x concentration prior to addition of O_3, ppm

$[NO_x]_{rem}$ = NO_x concentration remaining after addition of O_3, ppm

NOTE.—Supplemental information on calibration and other procedures in this method are given in reference 13.

Plot $[NO_2]_{CONV}$ (y-axis) versus $[NO_2]_{OUT}$ (x-axis) and draw or calculate the converter efficiency curve. The slope of the curve times 100 is the average converter efficiency, E_C. The average converter efficiency must be greater than 96%; if it is less than 96%, replace or service the converter.

2. *Alternative B*—NO_2 permeation device.

Major equipment required:

Stable O_3 generator.

Chemiluminescence $NO/NO_x/NO_2$ analyzer with strip chart recorder(s).

NO concentration standard.

NO_2 concentration standard.

2.1 Principle. Atmospheres containing accurately known concentrations of nitrogen dioxide are generated by means of a permeation device. (*10*) The permeation device emits NO_2 at a known constant rate provided the temperature of the device is held constant (±0.1° C) and the device has been accurately calibrated at the temperature of use. The

$$\text{recorder response (\% scale)} = \left(\frac{[NO_2]_{OUT}}{URL} \times 100\right) + Z_{NO_2} \quad (14)$$

NO_2 emitted from the device is diluted with zero air to produce NO_2 concentrations suitable for calibration of the NO_2 channel of the $NO/NO_x/NO_2$ analyzer. An NO concentration standard is used for calibration of the NO and NO_x channels of the analyzer.

2.2 Apparatus. A typical system suitable for generating the required NO and NO_2 concentrations is shown in Figure 2. All connections between components downstream from the permeation device should be of glass, Teflon®, or other non-reactive material.

2.2.1 Air flow controllers. Devices capable of maintaining constant air flows within ±2% of the required flowrate.

2.2.2 NO flow controller. A device capable of maintaining constant NO flows within ±2% of the required flowrate. Component parts in contact with the NO must be of a non-reactive material.

2.2.3 Air flowmeters. Calibrated flowmeters capable of measuring and monitoring air flowrates with an accuracy of ±2% of the measured flowrate.

2.2.4 NO flowmeter. A calibrated flowmeter capable of measuring and monitoring NO flowrates with an accuracy of ±2% of the measured flowrate. (Rotameters have been reported to operate unreliably when measuring low NO flows and are not recommended.)

2.2.5 Pressure regulator for standard NO cylinder. This regulator must have a nonreactive diaphragm and internal parts and a suitable delivery pressure.

2.2.6 Drier. Scrubber to remove moisture from the permeation device air system. The use of the drier is optional with NO_2 permeation devices not sensitive to moisture. (Refer to the supplier's instructions for use of the permeation device.)

2.2.7 Constant temperature chamber. Chamber capable of housing the NO_2 permeation device and maintaining its temperature to within ±0.1°C.

2.2.8 Temperature measuring device. Device capable of measuring and monitoring the temperature of the NO_2 permeation device with an accuracy of ±0.05°C.

2.2.9 Valves. A valve may be used as shown in Figure 2 to divert the NO_2 from the permeation device when zero air or NO is required at the manifold. A second valve may be used to divert the NO flow when zero air or NO_2 is required at the manifold.

The valves should be constructed of glass, Teflon®, or other nonreactive material.

2.2.10 Mixing chamber. A chamber constructed of glass, Teflon®, or other nonreactive material and designed to provide thorough mixing of pollutant gas streams and diluent air.

2.2.11 Output manifold. The output manifold should be constructed of glass, Teflon®, or other non-reactive material and should be of sufficient diameter to insure an insignificant pressure drop at the analyzer connection. The system must have a vent designed to insure atmospheric pressure at the manifold and to prevent ambient air from entering the manifold.

2.3 Reagents.

2.3.1 Calibration standards. Calibration standards are required for both NO and NO_2. The reference standard for the calibration may be either an NO or NO_2 standard. The reference standard must be used to certify the other standard to ensure consistancy between the two standards.

2.3.1.1 NO_2 concentration standard. A permeation device suitable for generating NO_2 concentrations at the required flowrates over the required concentration range. If the permeation device is used as the reference standard, it must be traceable to a National Bureau of Standards NO_2 Standard Reference Material (SRM 1629) or NO in N_2 Standard Reference Material (SRM 1683 or SRM 1684). If an NO cylinder is used as the reference standard, the NO_2 permeation device must be certified against the NO standard according to the procedure given in reference 13. The use of the permeation device should be in strict accordance with the instructions supplied with the device. Additional information regarding the use of permeation devices is given by Scaringelli et al.(*11*) and Rook et al.(*12*).

2.3.1.2 NO concentration standard. Cylinder containing 50 to 100 ppm NO in N_2 with less than 1 ppm NO_2. If the cylinder is used as the reference standard, it must be traceable to a National Bureau of Standards NO in N_2 Standard Reference Material (SRM 1683 or SRM 1684) or NO_2 Standard Reference Material (SRM 1629). If an NO_2 permeation device is used as the reference standard, the NO cylinder must be certified against the NO_2 standard according to the procedure given in reference 13. The cylinder should be recertified on a regular basis as determined by the local quality control program. A procedure for determining the amount of NO_2 impurity in the NO cylinder is also given in reference 13.

2.3.3 Zero air. Air, free of contaminants which might react with NO or NO_2 or cause a detectable response on the $NO/NO_x/NO_2$ analyzer. When using permeation devices that are sensitive to moisture, the zero air passing across the permeation device must be dry to avoid surface reactions on the device. (Refer to the supplier's instructions for use of the permeation device.) A procedure for generating zero air is given in reference 13.

2.4 Procedure.

2.4.1 Assemble the calibration apparatus such as the typical one shown in Figure 2.

2.4.2 Insure that all flowmeters are calibrated under the conditions of use against a reliable standard such as a soapbubble meter or wet-test meter. All volumetric flowrates should be corrected to 25° C and 760 mm Hg. A discussion on the calibration of flowmeters is given in reference 13.

2.4.3 Install the permeation device in the constant temperature chamber. Provide a small fixed air flow (200–400 scm^3/min) across the device. The permeation device should always have a continuous air flow across it to prevent large buildup of NO_2 in the system and a consequent restabilization period. Record the flowrate as F_P. Allow the device to stabilize at the calibration temperature for at least 24 hours. The temperature must be adjusted and controlled to within ±0.1° C or less of the calibration temperature as monitored with the temperature measuring device.

2.4.4 Precautions must be taken to remove O_2 and other contaminants from the NO pressure regulator and delivery system prior to the start of calibration to avoid any conversion of the standard NO to NO_2. Failure to do so can cause significant errors in calibration. This problem may be minimized by (1) Carefully evacuating the regulator, when possible, after the regulator has been connected to the cylinder and before opening the cylinder valve; (2) Thoroughly flushing the regulator and delivery system with NO after opening the cylinder valve; (3) Not removing the regulator from the cylinder between calibrations unless absolutely necessary. Further discussion of these procedures is given in reference 13.

2.4.5 Select the operating range of the $NO/NO_x/NO_2$ analyzer to be calibrated. In order to obtain maximum precision and accuracy for NO_2 calibration, all three channels of the analyzer should be set to the same range. If operation of the NO and NO_x channels on higher ranges is desired, subsequent recalibration of the NO and NO_x channels on the higher ranges is recommended.

NOTE.—Some analyzer designs may require identical ranges for NO, NO_x, and NO_2 during operation of the analyzer.

2.4.6 Connect the recorder output cable(s) of the $NO/NO_x/NO_2$ analyzer to the input terminals of the strip chart recorder(s). All adjustments to the analyzer should be performed based on the appropriate strip chart readings. References to analyzer responses in the procedures given below refer to recorder responses.

2.4.7 Switch the valve to vent the flow from the permeation device and adjust the diluent air flowrate, F_D, to provide zero air at the output manifold. The total air flow must exceed the total demand of the analyzer(s) connected to the output manifold to insure that no ambient air is pulled into the manifold vent. Allow the analyzer to sample zero air until stable NO, NO_x, and NO_2 responses are obtained. After the responses have stabilized, adjust the analyzer zero control(s).

NOTE.—Some analyzers may have separate zero controls for NO, NO_x, and NO_2. Other analyzers may have separate zero controls only for NO and NO_x, while still others may have only one zero common control to all three channels.

Offsetting the analyzer zero adjustments to +5% of scale is recommended to facilitate observing negative zero drift. Record the stable zero air responses as Z_{NO}, Z_{NO_x}, and Z_{NO_2}.

2.4.8 Preparation of NO and NO_x calibration curves.

: : :

2.4.8.1 Adjustment of NO span control. Adjust the NO flow from the standard NO cylinder to generate an NO concentration of approximately 80% of the upper range limit (URL) of the NO range. The exact NO concentration is calculated from:

$$[NO]_{OUT}=\frac{F_{NO}\times[NO]_{STD}}{F_{NO}+F_D} \qquad (16)$$

where:

$[NO]_{OUT}$ = diluted NO concentration at the output manifold, ppm
F_{NO} = NO flowrate, scm³/min
$[NO]_{STD}$ = concentration of the undiluted NO standard, ppm
F_D = diluent air flowrate, scm³/min

Sample this NO concentration until the NO and NO_x responses have stabilized. Adjust the NO span control to obtain a recorder response as indicated below:

recorder response (% scale)

$$=\left(\frac{[NO]_{OUT}}{URL}\times 100\right)+Z_{NO} \qquad (17)$$

where:

URL = nominal upper range limit of the NO channel, ppm

NOTE.—Some analyzers may have separate span controls for NO, NO_x, and NO_2. Other analyzers may have separate span controls only for NO and NO_x, while still others may have only one span control common to all three channels. When only one span control is available, the span adjustment is made on the NO channel of the analyzer.

If substantial adjustment of the NO span control is necessary, it may be necessary to recheck the zero and span adjustments by repeating steps 2.4.7 and 2.4.8.1. Record the NO concentration and the analyzer's NO response.

2.4.8.2 Adjustment of NO_x span control. When adjusting the analyzer's NO_x span control, the presence of any NO_2 impurity in the standard NO cylinder must be taken into account. Procedures for determining the amount of NO_2 impurity in the standard NO cylinder are given in reference 13. The exact NO_x concentration is calculated from:

$$[NO_x]_{OUT}=\frac{F_{NO}\times([NO]_{STD}+[NO_2]_{IMP})}{F_{NO}+F_D} \qquad (18)$$

where:

$[NO_x]_{OUT}$ = diluted NO_x concentration at the output manifold, ppm
$[NO_2]_{IMP}$ = concentration of NO_2 impurity in the standard NO cylinder, ppm

Adjust the NO_x span control to obtain a convenient recorder response as indicated below:

recorder response (% scale)

$$=\left(\frac{[NO_x]_{OUT}}{URL}\times 100\right)+Z_{NO_x} \qquad (19)$$

NOTE.—If the analyzer has only one span control, the span adjustment is made on the NO channel and no further adjustment is made here for NO_x.

If substantial adjustment of the NO_x span control is necessary, it may be necessary to recheck the zero and span adjustments by repeating steps 2.4.7 and 2.4.8.2. Record the NO_x concentration and the anlyzer's NO_x response.

2.4.8.3 Generate several additional concentrations (at least five evenly spaced points across the remaining scale are suggested to verify linearity) by decreasing F_{NO} or increasing F_D. For each concentration generated, calculate the exact NO and NO_x concentrations using equations (16) and (18) respectively. Record the analyzer's NO and NO_x responses for each concentration. Plot the analyzer responses versus the respective calculated NO and NO_x concentrations and draw or calculate the NO and NO_x calibration curves. For subsequent calibrations where linearity can be assumed, these curves may be checked with a two-point calibration consisting of a zero point and NO and NO_x concentrations of approximately 80 percent of the URL.

2.4.9 Preparation of NO_2 calibration curve.

2.4.9.1 Remove the NO flow. Assuming the NO_2 zero has been properly adjusted while sampling zero air in step 2.4.7, switch the valve to provide NO_2 at the output manifold.

2.4.9.2 Adjust F_D to generate an NO_2 concentration of approximately 80 percent of the *URL* of the NO_2 range. The total air flow must exceed the demand of the analyzer(s) under calibration. The actual concentration of NO_2 is calculated from:

$$[NO_2]_{OUT}=\frac{R\times K}{F_P+F_D} \qquad (20)$$

where:

$[NO_2]_{OUT}$=diluted NO_2 concentration at the output manifold, ppm

R=permeation rate, µg/min

K=0.532 µl NO_2/µg NO_2 (at 25°C and 760 mm Hg)

F_P=air flowrate across permeation device, scm³/min

F_D=diluent air flowrate, scm³/min

Sample this NO_2 concentration until the NO_x and NO_2 responses have stabilized. Adjust the NO_2 span control to obtain a recorder response as indicated below:

recorder response (percent scale)

$$=\left(\frac{[NO_2]_{OUT}}{URL}\times 100\right)+Z_{NO_2} \qquad (21)$$

NOTE:—If the analyzer has only one or two span controls, the span adjustments are made on the NO channel or NO and NO_x channels and no further adjustment is made here for NO_2.

If substantial adjustment of the NO_2 span control is necessary it may be necessary to recheck the zero and span adjustments by repeating steps 2.4.7 and 2.4.9.2. Record the NO_2 concentration and the analyzer's NO_2 response. Using the NO_x calibration curve obtained in step 2.4.8, measure and record the NO_x concentration as $[NO_x]_M$.

2.4.9.3 Adjust F_D to obtain several other concentrations of NO_2 over the NO_2 range (at least five evenly spaced points across the remaining scale are suggested). Calculate each NO_2 concentration using equation (20) and record the corresponding analyzer NO_2 and NO_x responses. Plot the analyzer's NO_2 responses versus the corresponding calculated NO_2 concentrations and draw or calculate the NO_2 calibration curve.

2.4.10 Determination of converter efficiency.

2.4.10.1 Plot $[NO_x]_M$ (y-axis) versus $[NO_2]_{OUT}$ (x-axis) and draw or calculate the converter efficiency curve. The slope of the curve times 100 is the average converter efficiency, E_c. The average converter efficiency must be greater than 96 percent; if it is less than 96 percent, replace or service the converter.

NOTE.—Supplemental information on calibration and other procedures in this method are given in reference 13.

3. Frequency of calibration. The frequency of calibration, as well as the number of points necessary to establish the calibration curve and the frequency of other performance checks, will vary from one analyzer to another. The user's quality control program should provide guidelines for initial establishment of these variables and for subsequent alteration as operational experience is accumulated. Manufacturers of analyzers should include in their instruction/operation manuals information and guidance as to these variables and on other matters of operation, calibration, and quality control.

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(Sec. 4, Pub. L. 91-604, 84 Stat. 1678 (42 U.S.C. 1857c-4).)

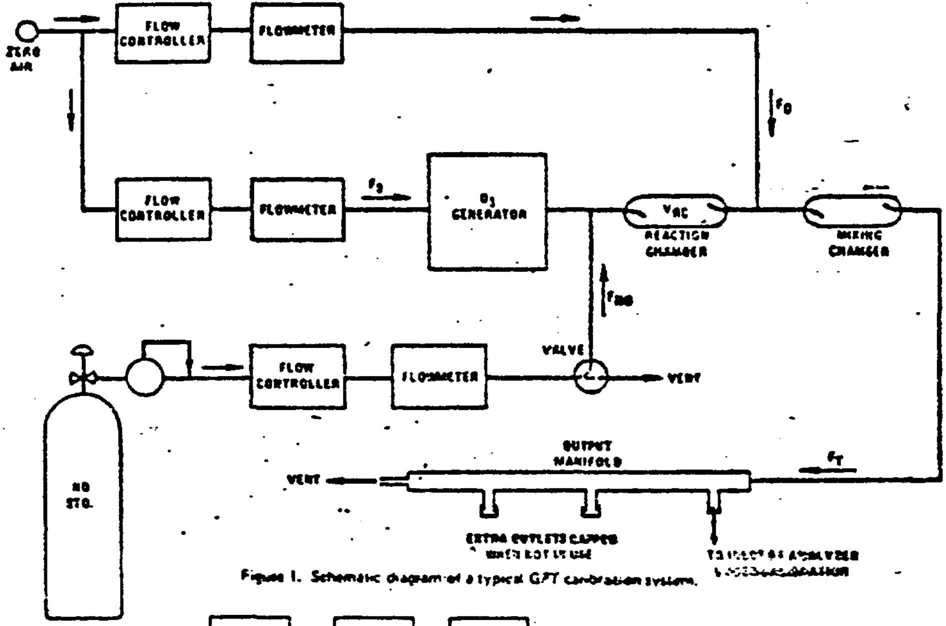

Figure 1. Schematic diagram of a typical GPT calibration system.

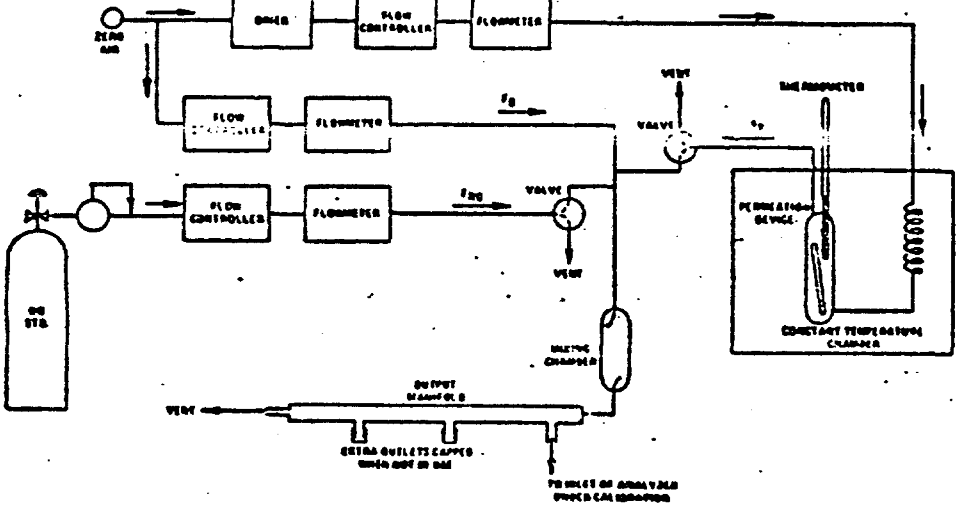

Figure 2. Schematic diagram of a typical calibration apparatus using an NO$_2$ permeation device.

[FR Doc.76-35029 Filed 11-30-76;8:43 am]

Method G

REFERENCE METHOD FOR THE DETERMINATION OF LEAD IN SUSPENDED PARTICULATE MATTER COLLECTED FROM AMBIENT AIR

(42 FR, 63083, December 14, 1977)

1. *Principle and Applicability.*

1.1 Ambient air suspended particulate matter is collected on a glass-fiber filter for 24 hours using a high volume air sampler.

1.2 Lead in the particulate matter is solubilized by extraction with nitric aid (HNO_3), facilitated by heat or ultrasonication.

1.3 The lead content of the sample is analyzed by atomic absorption spectrometry using an air-acetylene flame, the 283.3 or 217.0 nm lead absorption line, and the optimum instrumental conditions recommended by the manufacturer.

2. *Range, Sensitivity and Lower Detectable Limit.*

The values given below are typical of the methods capabilities. Absolute values will vary for individual situations depending on the type of instrument used, the lead line, and operating conditions.

2.1 Range. The typical range of the method is 0.03 to 7.5 µg Pb/m³ assuming an upper linear range of analysis of 15 µg ml and an air volume of 2400 m³.

2.2 Analytical sensitivity. Typical sensitivities for a 1% change in absorption (0.0044 absorbance units) are 0.2 and 0.5 µg Pb/ml for the 217.0 and 283.3 nm lines, respectively.

2.3 Lower Detectable Limit (LDL). A typical LDL is 0.03 µg Pb/m³. This LDL is for the 217 nm line. The LDL for the 283.3 nm line will be somewhat higher. The above value was calculated by doubling the between laboratory standard deviation obtained for the lowest measurable lead concentration in a collaborative test of the method.[14] An air volume of 2400 m³ was assumed.

3. *Interferences.*

Two types of interferences are possible: chemical, and light scattering.

3.1 Chemical. Reports on the absence [1,2,4,4,8] of chemical interferences far outweigh those reporting their presence,[3] therefore, no correction for chemical interferences is given here. If the analyst suspects that the sample matrix is causing a chemical interference, the interference can be verified and corrected for by carrying out the analysis using the method of standard additions.[7]

3.2 Light Scattering. Non-atomic absorption or light scattering, produced by high concentrations of dissolved solids in the sample, can produce a significant interference, especially at low lead concentrations.[3] The interference is greater at the 217.0 nm line than at the 283.3 nm line. No interference was observed using the 283.3 nm line with a similar method.[1]

Light scattering interferences can, however, be corrected for instrumentally. Since the dissolved solids can vary depending on the origin of the sample, the correction may be necessary, especially when using the 217.0 nm line. Dual beam instruments with a continuum source give the most accurate correction. A less accurate correction can be obtained by using a non-absorbing lead line that is near the lead analytical line. Information on use of these correction techniques can be obtained from instrument manufacturers manuals.

If instrumental correction is not feasible, the interference can be eliminated by use of the ammonium pyrrolidinecarbodithioate-methylisobutyl ketone, chelation-solvent extraction technique of sample preparation.[7]

4. *Precision and Bias.*

4.1 The high-volume sampling procedure used to collect ambient air particulate matter has a between laboratory relative standard deviation of 3.7% over the range 80 to 125 µg/m³.[9] The following equations give the precision of lead measurements made on ¾" x 8" strips cut from exposed glass fiber filters using the hot extraction procedure.[14]

$$x = 1.73 + 0.01c$$
$$y = 4.82 + 0.03c$$

where:

x = within laboratory standard deviation, µg Pb/strip

y = between laboratory standard deviation, µg Pb/strip

c = measured lead concentration, µg Pb/strip

Similar information is being obtained for the ultrasonic extraction procedure.

4.2 Single laboratory experiments indicate that there is no significant difference in lead recovery between the hot and ultrasonic extraction procedures.[14]

5. *Apparatus.*

5.1 Sampling.

5.1.1 High volume sampler. Use and calibrate the sampler as described in reference 10.

5.2 Analysis.

5.2.1 Atomic Absorption Spectrophotometer. Equipped with lead hollow cathode or electrodeless discharge lamp.

5.2.1 Acetylene. The grade recommended by the instrument manufacturer should be used. Change cylinder when pressure drops below 50–100 psig.

5.2.1.2 Air. Filtered to remove particulate, oil and water.

5.2.2 Glassware. Class A borosilicate glassware should be used throughout the analysis.

5.2.2.1 Beakers. 30 and 150 ml. graduated, Pyrex.

5.2.2.2 Volumetric flasks. 100-ml.

5.2.2.3 Pipettes. To deliver 50, 30, 15, 8, 4, 2, 1 ml.

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Method G, Continued

5.2.2.4 Cleaning. All glassware should be scrupulously cleaned. The following procedure is suggested. Wash with laboratory detergent, rinse, soak for 4 hours in 20% (w/w) HNO_3, rinse 3 times with distilled-deionized water, and dry in a dust free manner.

5.2.3 Hot plate.

5.2.4 Ultrasonication water bath, unheated. Commercially available laboratory ultrasonic cleaning baths of 450 watts or higher "cleaning power", i.e., actual ultrasonic power output to the bath have been found satisfactory.

5.2.5 Template. To aid in sectioning the glass-fiber filter. See Figure 1 for dimensions.

5.2.6 Pizza cutter. Thin wheel. Thickness <1 mm.

5.2.7 Watch glass.

5.2.8 Polyethylene bottles. For storage of samples. Linear polyethylene gives better storage stability than other polyethylenes and is preferred.

5.2.9 Parafilm "M".[1] American Can Co., Marathon Products, Nennah, Wis., or equivalent.

6. *Reagents.*

6.1 Sampling.

6.1.1 Glass fiber filters. The specifications given below are intended to aid the user in obtaining high quality filters with reproducible properties. These specifications have been met by EPA contractors.

6.1.1.1 Lead content. The absolute lead content of filters is not critical, but low values are, of course, desirable. EPA typically obtains filters with a lead content of <75 µg/filter.

It is important that the variation in lead content from filter to filter, within a given batch, be small.

6.1.1.2 Testing.

6.1.1.2.1 For large batches of filters (>500 filters) select at random 20 to 30 filters from a given batch. For small batches (<500 filters) a lesser number of filters may be taken. Cut one ¾" × 8" strip from each filter anywhere in the filter. Analyze all strips, separately, according to the directions in Sections 7 and 8.

6.1.1.2.2 Calculate the total lead in each filter as

$$F_b = \mu g\ Pb/ml \times \frac{100\ ml}{strip} \times \frac{12\ strips}{filter}$$

where:

F_b = Amount of lead per 72 in² of filter, micrograms.

6.1.1.2.3 Calculate the mean, $\overline{F_b}$, of the values and the relative standard deviation (standard deviation/mean × 100). If the relative standard deviation is high enough so that, in the analysts opinion, subtraction of $\overline{F_b}$ (Section 10.3), may result in a significant error in the µg Pb/m³, the batch should be rejected.

6.1.1.2.4 For acceptable batches, use the value of $\overline{F_b}$ to correct all lead analyses (Section 10.3) of particulate matter collected using that batch of filters. If the analyses are below the LDL (Section 2.3) no correction is necessary.

6.2 Analysis.

6.2.1 Concentrated (15.6 *M*) HNO_3. ACS reagent grade HNO_3 and commercially available redistilled HNO_3 has been found to have sufficiently low lead concentrations.

6.2.2 Distilled-deionized water. (D.I. water).

6.2.3 3 *M* HNO_3. Add 192 ml of concentrated HNO_3 to D.I. water in a 1 l volumetric flask. Shake well, cool, and dilute to volume with D.I. water. CAUTION: Nitric Acid Fumes Are Toxic. Prepare in a well ventilated fume hood.

6.2.4 0.45 *M* HNO_3. Add 29 ml of concentrated HNO_3 to D.I. water in a 1 l volumetric flask. Shake well, cool, and dilute to volume with D.I. water.

6.2.5 Lead Nitrate, $Pb(NO_3)_2$. ACS reagent grade, purity 99.0 percent. Heat for 4 hours at 120°C and cool in a desiccator.

6.3 Calibration standard.

6.3.1 Master standard, 1000 µg Pb/ml. Dissolve 1.598 g of $Pb(NO_3)_2$ in 0.45 *M* HNO_3 contained in a 1 l volumetric flask and dilute to volume with 0.45 *M* HNO_3. Store in a polyethylene bottle. Commercially available certified lead standard solutions may also be used.

7. *Procedure.*

7.1 Sampling. Collect samples for 24 hours using the procedure described in reference 10 with glass-fiber filters meeting the specifications in 6.1.1. Transport collected samples to the laboratory taking care to minimize contamination and loss of sample.

7.2 Sample Preparation.

7.2.1 Hot Extraction Procedure.

7.2.1.1 Cut a ¾" × 8" strip from the exposed filter using a template and a pizza cutter as described in Figures 1 and 2. Other cutting procedures may be used.

Lead in ambient particulate matter collected on glass fiber filters has been shown to be uniformly distributed across the filter[1,4,11] suggesting that the position of the strip is unimportant. However, other studies[12,13] have shown that when sampling near a road-way lead is not uniformly distributed across the filter. Therefore, when sampling near a road way, additional strips at different positions within the filter should be analyzed.

7.2.1.2 Fold the strip in half twice and place in a 150-ml beaker. Add 15 ml of 3 *M* HNO_3 to cover the sample. The acid should completely cover the sample. Cover the beaker with a watch glass.

7.2.1.3 Pleace beaker on the hot-plate, contained in a fume hood, and boil gently for 30 min. Do not let the sample evaporate to dryness. Caution: Nitric Acid Fumes Are Toxic.

7.2.1.4 Remove beaker from the hot plate and cool to near room temperature.

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[1] Mention of commercial products does not imply endorsement by the Environmental Protection Agency.

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Method G, Continued

7.2.1.5 Quantitatively transfer the sample as follows:

7.2.1.5.1 Rinse watch glass and sides of beaker with D.I. water.

7.2.1.5.2 Decent extract and rinsings into a 100-ml volumetric flask.

7.2.1.5.3 Add D.I. water to 40 ml mark on beaker, cover with watch glass, and set aside for a minimum of 30 minutes. This is a critical step and cannot be omitted since it allows the HNO_3 trapped in the filter to diffuse into the rince water.

7.2.1.5.4 Decent the water from the filter into the volumetric flask.

7.2.1.5.5 Rinse filter and beaker twice with D.I. water and add rinsings to volumetric flask until total volume is 80 to 85 ml.

7.2.1.5.6 Stopper flask and shake vigorously. Set aside for approximately 5 minutes or until foam has dissipated.

7.2.1.5.7 Bring solution to volume with D.I. water. Mix thoroughly.

7.2.1.5.8 Allow solution to settle for one hour before proceeding with analysis.

7.2.1.5.9 If sample is to be stored for subsequent analysis, transfer to a linear polyethylene bottle.

7.2.2 Ultrasonic Extraction Procedure.

7.2.2.1 Cut a ¾"×8" strip, fold and place in a beaker as described in Sections 7.2.1.1 and 7.2.1.2 except that a 30-ml beaker covered with Parafilm is used instead of a 150-ml beaker covered with a watch glass. The Parafilm should be placed over the beaker such that none of the Parafilm is in contact with water in the ultrasonic bath. Otherwise, rinsing of the Parafilm (Section 7.2.2.3.1) may contaminate the sample.

7.2.2.2 Place the beaker in the ultrasonication bath and operate for 30 minutes.

7.2.2.3 Quantitatively transfer the sample as follows:

7.2.2.3.1 Rinse Parafilm and sides of beaker with D.I. water.

7.2.2.3.2 Decant extract and rinsings into a 100-ml volumetric flask.

7.2.2.3.3 Add 20 ml D.I. water to cover the filter strip, cover with parafilm and set aside for a minimum of 30 minutes. This is a critical step and cannot be omitted. The sample is then processed as in Sections 7.2.1.5.4 through 7.2.1.5.9.

NOTE.—Samples prepared by either procedure are now in 0.45 *M* HNO_3.

8. *Analysis.*

8.1 Set the wavelength of the monochromator at 283.3 or 217.0 nm. Set or align other instrumental operating conditions as recommended by the manufacturer.

8.2 The sample can be analyzed directly from the volumetric flask, or an appropriate amount of sample decanted into a sample analysis tube. In either case, care should be taken not to disturb the settled solids.

8.3 Aspirate samples, calibration standards and blanks (Section 9.2) into the flame and record the equilibrium absorbance.

8.4 Determine the lead concentration in µg Pb/ml, from the calibration curve, Section 9.3.

8.5 Samples that exceed the linear calibration range should be diluted with HNO_3 of the same concentration as the calibration standards and reanalyzed.

9. *Calibration.*

9.1 Working standard, 20 µg Pb/ml. Prepare by diluting 2.0 ml of Master standard (6.3.1) to 100 ml with 0.45 *M* HNO_3. Prepare daily.

9.2 Calibration standards. Prepare daily by diluting the working standard with 0.45 *M* HNO_3 as indicated below. Other concentrations may be used.

Volume of 20 µg/ml working standard, milliliter	Final volume, milliliter	Concentration in micrograms of lead per milliliter
0	100	0.0
1.0	200	.1
2.0	200	.2
2.0	100	.4
4.0	100	.8
8.0	100	1.6
15.0	100	3.0
30.0	100	6.0
50.0	100	10.0
100	100	20.0

9.3 Preparation of calibration curve. Since the working range of analysis will vary depending on which lead line is used and the type of instrument, no one set of instructions for preparation of a calibration curve can be given. Select at least six standards (plus the reagent blank) to cover the linear absorption range indicated by the instrument manufacturer. Measure the absorbance of the blank and standards as in Section 8.0. Repeat until good agreement is obtained between replicates. Plot absorbance (y-axis) versus concentration in µg Pb/ml (x-axis). Draw (or compute) a straight line through the linear portion of the curve. Do not force the calibration curve through zero.

To determine stability of the calibration curve, remeasure—alternately—one of the following calibration standards for every 10th sample analyzed: concentration ≦ 1 µg Pb/ml; concentration ≦ 10 µg Pb/ml. If either standard deviates by more than 5% from the value predicted by the calibration curve, recalibrate and repeat the previous 10 analyses.

10. *Calculation.*

10.1 Measured air volume. Calculate the measured air volume as

$$V_m = \frac{Q_i + Q_f}{2} \times T$$

where:

V_m = Air volume sampled (uncorrected), m^3,
Q_i = Initial air flow rate, m^3/min.
Q_f = Final air flow rate, m^3/min.
T = Sampling Time, min.

The flow rates Q_i and Q_f should be corrected to the temperature and pressure conditions existing at the time of orifice calibration as directed in addendum B of reference 10, before calculation of V_m.

Method G, Continued

10.2 Air volume at STP. The measured air volume is corrected to reference conditions of 760 mm Hg and 25°C as follows. The units are standard cubic meters, sm³.

$$V_{STP} = V_m \times \frac{P_2 \times T_1}{P_1 \times T_2}.$$

V_{STP} = Sample volume, sm³, at 760 mm Hg and 298° K.
V_m = Measured volume from 10.1.
P_2 = Atmospheric pressure at time of orifice calibration, mm Hg.
P_1 = 760 mm Hg.
T_2 = Atmospheric temperature at time of orifice calibration, °K.
T_1 = 298 °K.

10.3 Lead Concentration. Calculate lead concentration in the air sample.

$$C = \frac{(\mu g\ Pb/ml \times 100\ ml/strip \times 12\ strips/filter) - \bar{F}_b}{V_{STP}}$$

where:

C = Concentration, µg Pb/sm³.
µg Pb/ml = Lead concentration determined from Section 8.
100 ml/strip = Total sample volume.

$$12\ strips/filter = \frac{\text{Usable filter area, } 7'' \times 9''}{\text{Exposed area of one strip, } 3/4'' \times 7''}$$

$\bar{F}_b$ = Lead concentration of blank filter, µg, from Section 6.1.1.2.3.
V_{STP} = Air volume from 10.2.

11. *Quality Control.*

3/4" x 8" glass fiber strips containing 00 to 2,000 µg Pb/strip (as lead salts) and blank strips with zero Pb content should be used to determine if the method—as being used—has any bias. Quality control charts should be established to monitor differences between measured and true values. The frequency of such checks will depend on the local quality control program.

To minimize the possibility of generating unreliable data, the user should follow practices established for assuring the quality of air pollution data,[13] and take part in EPA's semi-annual audit program for lead analyses.

12. *Trouble Shooting.*

1. During extraction of lead by the hot extraction procedure, it is important to keep the sample covered so that corrosion products—formed on fume hood surfaces which may contain lead—are not deposited in the extract.

2. The sample acid concentration of 0.45 M should minimize corrosion of the nebulizer. However, different nebulizers may require lower acid concentrations. [illegible]tions can be used provided samples and standards have the same acid concentration.

3. Ashing of particulate samples has been found, by EPA and contractor laboratories, to be unnecessary in lead analyses by Atomic Absorption. Therefore, this step was omitted from the method.

4. Filtration of extracted samples, to remove particulate matter, was specifically excluded from sample preparation, because some analysts have observed losses of lead due to filtration.

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Method G, Continued

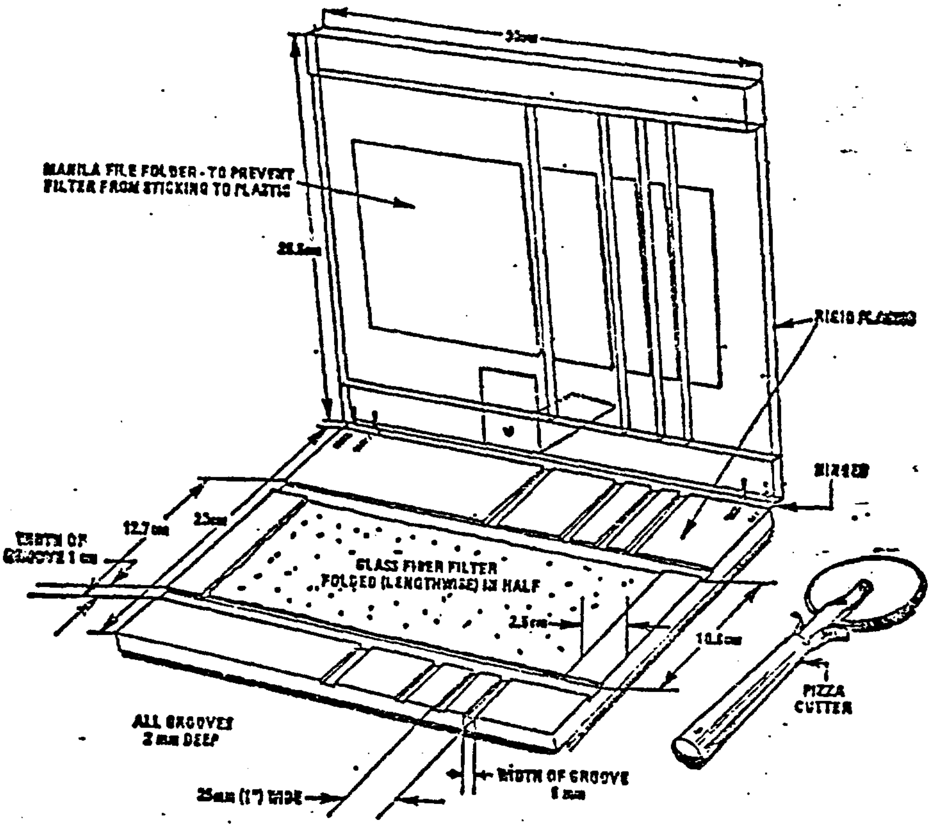

Figure 1

Method G, Continued

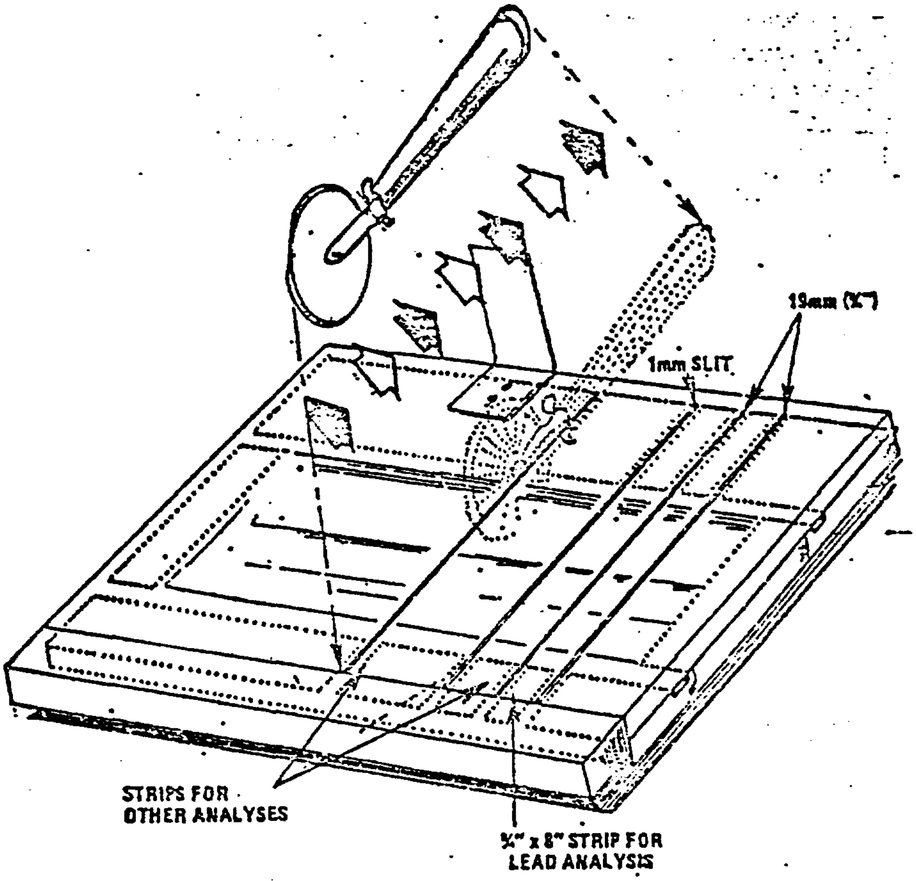

Figure 2

[FR Doc.77-35557 Filed 12-13-77;8:45 am]

Method H

INTERPRETATION OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR OZONE

(40 CFR 50, Appendix H, February 8, 1979)

1. *General*

This appendix explains how to determine when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm (235 μg/m³) is equal to or less than 1. An expanded discussion of these procedures and associated examples are contained in the "Guideline for Interpretation of Ozone Air Quality Standards." For purposes of clarity in the following discussion, it is convenient to use the term "exceedance" to describe a daily maximum hourly average ozone measurement that is greater than the level of the standard. Therefore, the phrase "expected number of days with maximum hourly average ozone concentrations above the level of the standard" may be simply stated as the "expected number of exceedances."

The basic principle in making this determination is relatively straightforward. Most of the complications that arise in determining the expected number of annual exceedances relate to accounting for incomplete sampling. In general, the average number of exceedances per calendar year must be less than or equal to 1. In its simplest form, the number of exceedances at a monitoring site would be recorded for each calendar year and then averaged over the past 3 calendar years to determine if this average is less than or equal to 1.

2. *Interpretation of Expected Exceedances*

The ozone standard states that the expected number of exceedances per year must be less than or equal to 1. The statistical term "expected number" is basically an arithmetic average. The following example explains what it would mean for an area to be in compliance with this type of standard. Suppose a monitoring station records a valid daily maximum hourly average ozone value for every day of the year during the past 3 years. At the end of each year, the number of days with maximum hourly concentrations above 0.12 ppm is determined and this number is averaged with the results of previous years. As long as this average remains "less than or equal to 1," the area is in compliance.

3. *Estimating the Number of Exceedances for a Year*

In general, a valid daily maximum hourly average value may not be available for each day of the year, and it will be necessary to account for these missing values when estimating the number of exceedances for a particular calendar year. The purpose of these computations is to determine if the expected number of exceedances per year is less than or equal to 1. Thus, if a site has two or more observed exceedances each year, the standard is not met and it is not necessary to use the procedures of this section to account for incomplete sampling.

The term "missing value" is used here in the general sense to describe all days that do not have an associated ozone measurement. In some cases, a measurement might actually have been missed but in other cases no measurement may have been scheduled for that day. A daily maximum ozone value is defined to be the highest hourly ozone value recorded for the day. This daily maximum value is considered to be valid if 75 percent of the hours from 9:01 a.m. to 9:00 p.m. (LST) were measured or if the highest hour is greater than the level of the standard.

In some areas, the seasonal pattern of ozone is so pronounced that entire months need not be sampled because it is extremely unlikely that the standard would be exceeded. Any such waiver of the ozone monitoring requirement would be handled under provisions of 40 CFR Part 58. Some allowance should also be made for days for which valid daily maximum hourly values were not obtained but which would quite likely have been below the standard. Such an allowance introduces a complication in that it becomes necessary to define under what conditions a missing value may be assumed to have been less than the level of the standard. The following criterion may be used for ozone:

> A missing daily maximum ozone value may be assumed to be less than the level of the standard if the valid daily maxima on both the preceding day and the following day do not exceed 75 percent of the level of the standard.

Let z denote the number of missing daily maximum values that may be assumed to be less than the standard. Then the following formula shall be used to estimate the expected number of exceedances for the year:

$$e = v + [(v/n)^{*}(N-n-z)] \qquad (1)$$

(*Indicates multiplication.)

Where:

e = the estimated number of exceedances for the year,
N = the number of required monitoring days in the year,
n = the number of valid daily maxima,
v = the number of daily values above the level of the standard, and
z = the number of days assumed to be less than the standard level.

*Indicates multiplication.

Method H, Continued

This estimated number of exceedances shall be rounded to one decimal place (fractional parts equal to 0.05 round up).

It should be noted that N will be the total number of days in the year unless the appropriate Regional Administrator has granted a waiver under the provisions of 40 CFR Part 58.

The above equation may be interpreted intuitively in the following manner. The estimated number of exceedances is equal to the observed number of exceedances (v) plus an increment that accounts for incomplete sampling. There were (N-n) missing values for the year but a certain number of these, namely z, were assumed to be less than the standard. Therefore, (N-n-z) missing values are considered to include possible exceedances. The fraction of measured values that are above the level of the standard is v/n. It is assumed that this same fraction applies to the (N-n-z) missing values and that (v/n)*(N-n-z) of these values would also have exceeded the level of the standard.

10-9-79

REGULATION 92: PERFORMANCE SPECIFICATIONS FOR CONTINUOUS MONITORING EQUIPMENT

Rule 921: General Specifications

A. A source operator who is required to install and operate continuous monitoring equipment (Regulation 51) shall comply with the performance specifications established in this REGULATION.

B. *CALIBRATION GASES*

For nitrogen oxides monitoring systems installed on fossil fuel-fired steam generators the pollutant gas used to prepare calibration gas mixtures (Section 2.1, Performance Specification 2) shall be nitric oxide (NO). For nitrogen oxides monitoring systems, installed on nitric acid plants the pollutant gas used to prepare calibration gas mixtures (Section 2.1, Performance Specification 2 of this CHAPTER) shall be nitrogen dioxide (NO_2). These gases shall also be used for daily checks under paragraph 3.7 as applicable.

For sulfur dioxide monitoring systems installed on fossil fuel-fired steam generators or sulfuric acid plants the pollutant gas used to prepare calibration gas mixtures (Section 2.1, Performance Specification 2 of this CHAPTER) shall be sulfur dioxide (SO_2). Span and zero gases should be traceable to National Bureau of Standards reference gases whenever these reference gases are available. Every six months from date of manufacture, span and zero gases shall be reanalyzed by conducting triplicate analyses using the reference methods of this CHAPTER as follows:

1. For sulfur dioxide, use Reference Method 6;
2. For nitrogen oxides, use Reference Method 7; and
3. For carbon dioxide or oxygen, use Reference Method 3. The gases may be analyzed at less frequent intervals if longer shelf lives are guaranteed by the manufacturer.

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: : :

C. *CYCLING TIMES*

Cycling times include the total time a montioring system requires to sample, analyze, and record an emission measurement.

1. Continuous monitoring systems for measuring opacity shall complete a minimum of one cycle of operation (sampling, analyzing, and data recording) for each successive 10-second period.
2. Continuous monitoring systems for measuring oxides of nitrogen, carbon dioxide, oxygen, or sulfur dioxide shall complete a minimum of one cycle of operation (sampling, analyzing, and data recording) for each successive 15-minute period.

D. *MONITOR LOCATION*

The Control Officer shall specify conditions such that each continuous monitoring system or monitoring device is installed in such a manner that representative measurements of emissions or process parameters (i.e., oxygen, or carbon dioxide) from the affected facility are obtained. Additional guidance for location of continuous monitoring systems to obtain representative samples are contained in the applicable Performance Specifications of this CHAPTER.

E. *COMBINED EFFLUENTS*

When the effluents from two or more affected facilities of similar design and operating characteristics are combined before being released to the atmosphere, the same monitoring system may be installed on the combined effluent. When the affected facilities are not of similar design and operating characteristics, or when the effluent from one affected facility is released to the atmosphere through more than one point, the Control Officer shall specify alternate procedures to implement the intent of these requirements.

F. *ZERO AND DRIFT*

Any owner, lessee, or operators of any continuous monitoring system shall record the zero and span drift in accordance with the method prescribed by the manufacturer of such instruments; shall subject the instrument(s) to the manufacturer's recommended zero and span check at least once daily unless the manufacturer has recommended adjustments at shorter intervals, in which case such recommendations shall be followed; to adjust the zero and span whenever the 24-hour zero drift or 24-hour calibration drift limits of the applicable performance specifications herein are exceeded; and shall adjust continous monitoring systems whenever the 24-hour zero drift or 24-hour calibration drift exceed 10 percent of the emission standard.

G. *SPAN*

Instrument span should be approximately 200 percent of the expected instrument data display output corresponding to the emission standard for the source.

H. *ALTERNATIVE PROCEDURES AND REQUIREMENTS*

In cases where source operators wish to utilize different, but equivalent, procedures, and requirements for continuous monitoring systems, the operator must provide a description of such alternative procedures for approval by the Control Officer. Some examples of situations that may require alternatives follow:

1. Alternative monitoring requirements to accommodate continuous monitoring systems that require corrections for stack moisture conditions (e.g., an instrument measuring steam generator SO_2 emissions on a wet basis could be used with an instrument measuring oxygen concentration on a dry basis if acceptable methods of measuring stack moisture conditions are used to allow accurate adjustment of the measured SO_2 concentration to dry basis).
2. Alternative locations for installing continuous monitoring systems or monitoring devices when the owner or operator can demonstrate that installation at alternative locations will enable accurate and representative measurements.
3. Alternative procedures for performing calibration checks (e.g., some instruments may demonstrate superior drift characteristics that require checking at less frequent intervals).

: : :

4. Alternative monitoring requirements when the effluent from one affected facility or the combined effluent from two or more identical affected facilities is released to the atmosphere through more than one point (e.g., an extractive, gaseous monitoring system used at several points may be approved if the procedures recommended are suitable for generating accurate emission averages).
5. Alternative continuous monitoring systems that do not meet the special response requirements in Performance Specification 1, but adequately demonstrate a definite and consistent relationship between their meausrements and the opacity measurements of a system complying with the requirements in Performance Specification 1. Such demonstration must be performed for each affected facility.

10-9-79

Rule 922: Performance Specification 1 (Opacity)

PERFORMANCE SPECIFICATIONS AND SPECIFICATION TEST PROCEDURES FOR TRANSMISSOMETER SYSTEMS FOR CONTINUOUS MEASUREMENT OF THE OPACITY OF STACK EMISSIONS

(40 CFR 60, Appendix B, July 1, 1976)

1. Principle and Applicability.

1.1 Principle. The opacity of particulate matter in stack emissions is measured by a continuously operating emission measurement system. These systems are based upon the principle of transmissometry which is a direct measurement of the attenuation of visible radiation (opacity) by particulate matter in a stack effluent. Light having specific spectral characteristics is projected from a lamp across the stack of a pollutant source to a light sensor. The light is attenuated due to absorption and scatter by the particulate matter in the effluent. The percentage of visible light attenuated is defined as the opacity of the emission. Transparent stack emissions that do not attenuate light will have a transmittance of 100 or an opacity of 0. Opaque stack emissions that attenuate all of the visible light will have a transmittance of 0 or an opacity of 100 percent. The transmissometer is evaluated by use of neutral density filters to determine the precision of the continuous monitoring system. Tests of the system are performed to determine zero drift, calibration drift, and response time characteristics of the system.

1.2 Applicability. This performance specification is applicable to the continuous monitoring systems specified in the subparts for measuring opacity of emissions. Specifications for continuous measurement of visible emissions are given in terms of design, performance, and installation parameters. These specifications contain test procedures, installation requirements, and data computation procedures for evaluating the acceptability of the continuous monitoring systems subject to approval by the Administrator.

2. Apparatus

2.1 Calibrated Filters. Optical filters with neutral spectral characteristics and known optical densities to visible light or screens known to produce specified optical densities. Calibrated filters with accuracies certified by the manufacturer to within ±3 percent opacity shall be used. Filters required are low, mid, and high-range filters with nominal optical densities as follows when the transmissometer is mounted at opacity levels specified by applicable subparts:

Span value (percent opacity)	Calibrated filter optical densities with equivalent opacity in parenthesis		
	Low-range	Mid-range	High-range
50	0.1 (20)	0.2 (37)	0.3 (50)
60	.1 (20)	.2 (37)	.3 (50)
70	.1 (20)	.3 (50)	.4 (60)
80	.1 (20)	.3 (50)	.6 (75)
90	.1 (20)	.4 (60)	.7 (80)
100	.1 (20)	.4 (60)	.9 (87.5)

It is recommended that filter calibrations be checked with a well-collimated photopic transmissometer of known linearity prior to use. The filters shall be of sufficient size to attenuate the entire light beam of the transmissometer.

2.2 Data Recorder. Analog chart recorder or other suitable device with input voltage range compatible with the analyzer system output. The resolution of the recorder's data output shall be sufficient to allow completion of the test procedures within this specification.

2.3 Opacity measurement System. An in-stack transmissometer (folded or single path) with the optical design specifications designated below, associated control units and apparatus to keep optical surfaces clean.

3. Definitions.

3.1 Continuous Monitoring System. The total equipment required for the determination of pollutant opacity in a source effluent. Continuous monitoring systems consist of major subsystems as follows:

3.1.1 Sampling Interface. The portion of a continuous monitoring system for opacity that protects the analyzer from the effluent.

3.1.2 Analyzer. That portion of the continuous monitoring system which senses the pollutant and generates a signal output that is a function of the pollutant opacity.

3.1.3 Data Recorder. That portion of the continuous monitoring system that processes the analyzer output and provides a permanent record of the output signal in terms of pollutant opacity.

3.2 Transmissometer. The portions of a continuous monitoring system for opacity that include the sampling interface and the analyzer.

3.3 Span. The value of opacity at which the continuous monitoring system is set to produce the maximum data display output. The span shall be set at an opacity specified in each applicable subpart.

3.4 Calibration Error. The difference between the opacity reading indicated by the continuous monitoring system and the known values of a series of test standards. For this method the test standards are a series of calibrated optical filters or screens.

3.5 Zero Drift. The change in continuous monitoring system output over a stated period of time of normal continuous operation when the pollutant concentration at the time of the measurements is zero.

3.6 Calibration Drift. The change in the continuous monitoring system output over a stated period of time of normal continuous operation when the pollutant concentration at the time of the measurements is the same known upscale value.

* * *

3.7 System Response. The time interval from a step change in opacity in the stack at the input to the continuous monitoring system to the time at which 95 percent of the corresponding final value is reached as displayed on the continuous monitoring system data recorder.

3.8 Operational Test Period. A minimum period of time over which a continuous monitoring system is expected to operate within certain performance specifications without unscheduled maintenance, repair, or adjustment.

3.9 Transmittance. The fraction of incident light that is transmitted through an optical medium of interest.

3.10 Opacity. The fraction of incident light that is attenuated by an optical medium of interest. Opacity (O) and transmittance (T) are related as follows:

$$O = 1 - T$$

3.11 Optical Density. A logarithmic measure of the amount of light that it attenuated by an optical medium of interest. Optical density (D) is related to the transmittance and opacity as follows:

$$D = -\log_{10} T$$

$$D = -\log_{10} (1-O)$$

3.12 Peak Optical Response. The wavelength of maximum sensitivity of the instrument.

3.13 Mean Spectral Response. The wavelength which bisects the total area under the curve obtained pursuant to paragraph 9.2.1.

3.14 Angle of View. The maximum (total) angle of radiation detection by the photodetector assembly of the analyzer.

3.15 Angle of Projection. The maximum (total) angle that contains 95 percent of the radiation projected from the lamp assembly of the analyzer.

3.16 Pathlength. The depth of effluent in the light beam between the receiver and the transmitter of the single-pass transmissometer, or the depth of effluent between the transceiver and reflector of a double-pass transmissometer. Two pathlengths are referenced by this specification:

3.16.1 Monitor Pathlength. The depth of effluent at the installed location of the continuous monitoring system.

3.16.2 Emission Outlet Pathlength. The depth of effluent at the location emissions are [illegible] to the atmosphere.

4. Installation Specification.

4.1 Location. The transmissometer must be located across a section of duct or stack that will provide a particulate matter flow through the optical volume of the transmissometer that is representative of the particulate matter flow through the duct or stack. It is recommended that the monitor pathlength or depth of effluent for the transmissometer include the entire diameter of the duct or stack. In installations using a shorter pathlength, extra caution must be used in determining the measurement location representative of the particulate matter flow through the duct or stack.

4.1.1 The transmissometer location shall be downstream from all particulate control equipment.

4.1.2 The transmissometer shall be located as far from bends and obstructions as practical.

4.1.3 A transmissometer that is located in the duct or stack following a bend shall be installed in the plane defined by the bend where possible.

4.1.4 The transmissometer should be installed in an accessible location.

4.1.5 When required by the Administrator, the owner or operator of a source must demonstrate that the transmissometer is located in a section of duct or stack where a representative particulate matter distribution exists. The determination shall be accomplished by examining the opacity profile of the effluent at a series of positions across the duct or stack while the plant is in operation at maximum or reduced operating rates or by other tests acceptable to the Administrator.

4.2 Slotted Tube. Installations that require the use of a slotted tube shall use a slotted tube of sufficient size and blackness so as not to interfere with the free flow of effluent through the entire optical volume of the transmissometer or reflect light into the transmissometer photodetector. Light reflections may be prevented by using blackened baffles within the slotted tube to prevent the lamp radiation from impinging upon the tube walls, by restricting the angle of projection of the light and the angle of view of the photodetector assembly to less than the cross-sectional area of the slotted tube, or by other methods. The owner or operator must show that the manufacturer of the monitoring system has used appropriate methods to minimize light reflections for systems using slotted tubes.

4.3 Data Recorder Output. The continuous monitoring system output shall permit expanded display of the span opacity on a standard 0 to 100 percent scale. Since all opacity standards are based on the opacity of the effluent exhausted to the atmosphere, the system output shall be based upon the emission outlet pathlength and permanently recorded. For affected facilities whose monitor pathlength is different from the facility's emission outlet pathlength, a graph shall be provided with the installation to show the relationships between the continuous monitoring system recorded opacity based upon the emission outlet pathlength and the opacity of the effluent at the analyzer location (monitor pathlength). Tests for measurement of opacity that are required by this performance specification are based upon the monitor pathlength. The graph necessary to convert the data recorder output to the monitor pathlength basis shall be established as follows:

$$\log (1-O_1) = (l_1/l_2) \log (1-O_2)$$

: : :

Performance Specification 1, Continued

where:

O_1 = the opacity of the effluent based upon l_1.
O_2 = the opacity of the effluent based upon l_2.
l_1 = the emission outlet pathlength.
l_2 = the monitor pathlength.

5. Optical Design Specifications.

The optical design specifications set forth in Section 6.1 shall be met in order for a measurement system to comply with the requirements of this method.

6. Determination of Conformance with Design Specifications.

6.1 The continuous monitoring system for measurement of opacity shall be demonstrated to conform to the design specifications set forth as follows:

6.1.1 Peak Spectral Response. The peak spectral response of the continuous monitoring systems shall occur between 500 nm and 600 nm. Response at any wavelength below 400 nm or above 700 nm shall be less than 10 percent of the peak response of the continuous monitoring system.

6.1.2 Mean Spectral Response. The mean spectral response of the continuous monitoring system shall occur between 500 nm and 600 nm.

6.1.3 Angle of View. The total angle of view shall be no greater than 5 degrees.

6.1.4 Angle of Projection. The total angle of projection shall be no greater than 5 degrees.

6.2 Conformance with the requirements of section 6.1 may be demonstrated by the owner or operator of the affected facility by testing each analyzer or by obtaining a certificate of conformance from the instrument manufacturer. The certificate must certify that at least one analyzer from each month's production was tested and satisfactorily met all applicable requirements. The certificate must state that the first analyzer randomly sampled met all requirements of paragraph 6 of this specification. If any of the requirements were not met, the certificate must show that the entire month's analyzer production was resampled according to the military standard 105D sampling procedure (MIL-STD-105D) inspection level II; was retested for each of the applicable requirements under paragraph 6 of this specification; and was determined to be acceptable [illegible] certificate of conformance must show the results of each test performed for the analyzers sampled during the month the analyzer being installed was produced.[1]

6.3 The general test procedures to be followed to demonstrate conformance with Section 6 requirements are given as follows: (These procedures will not be applicable to all designs and will require modification in some cases. Where analyzer and optical design is certified by the manufacturer to conform with the angle of view or angle of projection specifications, the respective procedures may be omitted.)

6.3.1 Spectral Response. Obtain spectral data for detector, lamp, and filter components used in the measurement system from their respective manufacturers.

6.3.2 Angle of View. Set the receiver up as specified by the manufacturer. Draw an arc with radius of 3 meters. Measure the receiver response to a small (less than 3 centimeters) non-directional light source at 5-centimeter intervals on the arc for 26 centimeters on either side of the detector centerline. Repeat the test in the vertical direction.

6.3.3 Angle of Projection. Set the projector up as specified by the manufacturer. Draw an arc with radius of 3 meters. Using a small photoelectric light detector (less than 3 centimeters), measure the light intensity at 5-centimeter intervals on the arc for 26 centimeters on either side of the light source centerline of projection. Repeat the test in the vertical direction.

7. Continuous Monitoring System Performance Specifications.

The continuous monitoring system shall meet the performance specifications in Table 1-1 to be considered acceptable under this method.

TABLE 1-1.—*Performance specifications*

Parameter	*Specifications*
a. Calibration error	≤3 pct opacity.[1]
b. Zero drift (24 h)	≤2 pct opacity.[1]
c. Calibration drift (24 h)	≤2 pct opacity.[1]
d. Response time	10 s (maximum).
e. Operational test period	168 h.

[1] Expressed as sum of absolute mean value and the 95 pct confidence interval of a series of tests.

8. Performance Specification Test Procedures. The following test procedures shall be used to determine conformance with the requirements of paragraph 7:

8.1 Calibration Error and Response Time Test. These tests are to be performed prior to installation of the system on the stack and may be performed at the affected facility or at other locations provided that proper notification is given. Set up and calibrate the measurement system as specified by the manufacturer's written instructions for the monitor pathlength to be used in the installation. Span the analyzer as specified in applicable subparts.

8.1.1 Calibration Error Test. Insert a series of calibration filters in the transmissometer path at the midpoint. A minimum of three calibration filters (low, mid, and high-range) selected in accordance with the table under paragraph 2.1 and calibrated within 3 percent must be used. Make a total of five nonconsecutive readings for each filter. Record the measurement system output readings in percent opacity. (See Figure 1-1.)

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[1] 42 FR, 5937, January 31, 1977

Values for $t_{.975}$

n	$t_{.975}$	n	$t_{.975}$
2	12.706	10	2.262
3	4.303	11	2.228
	3.182	12	2.201
5	2.776	13	2.179
6	2.571	14	2.160
7	2.447	15	2.145
8	2.365	16	2.131
9	2.306		

The values in this table are already corrected for n-1 degrees of freedom. Use n equal to the number of samples as data points.

9.2 Data Analysis and Reporting.

9.2.1 Spectral Response. Combine the spectral data obtained in accordance with paragraph 6.3.1 to develop the effective spectral response curve of the transmissometer. Report the wavelength at which the peak response occurs, the wavelength at which the mean response occurs, and the maximum response at any wavelength below 400 nm and above 700 nm expressed as a percentage of the peak response as required under paragraph 6.2.

9.2.2 Angle of View. Using the data obtained in accordance with paragraph 6.3.2, calculate the response of the receiver as a function of viewing angle in the horizontal and vertical directions (26 centimeters of arc with a radius of 3 meters equal 5 degrees). Report relative angle of view curves as required under paragraph 6.2.

9.2.3 Angle of Projection. Using the data obtained in accordance with paragraph 6.3.3, calculate the response of the photoelectric detector as a function of projection angle in the horizontal and vertical directions. Report relative angle of projection curves as required under paragraph 6.2.

9.2.4 Calibration Error. Using the data from paragraph 8.1 (Figure 1-1), subtract the known filter opacity value from the value shown by the measurement system for each of the 15 readings. Calculate the mean and 95 percent confidence interval of the five different values at each test filter value according to equations 1-1 and 1-2. Report the sum of the absolute mean difference and the 95 percent confidence interval for each of the three test filters.

9.2.5 Zero Drift. Using the zero opacity values measured every 24 hours during the field test (paragraph 8.2), calculate the differences between the zero point after cleaning, aligning, and adjustment, and the zero value 24 hours later just prior to cleaning, aligning, and adjustment. Calculate the mean value of these points and the confidence interval using equations 1-1 and 1-2. Report the sum of the absolute mean value and the 95 percent confidence interval.

9.2.6 Calibration Drift. Using the span value measured every 24 hours during the field test, calculate the differences between the span value after cleaning, aligning, and adjustment of zero and span, and the span value 24 hours later just after cleaning, aligning, and adjustment of zero and before adjustment of span. Calculate the mean value of these points and the confidence interval using equations 1-1 and 1-2. Report the sum of the absolute mean value and the confidence interval.

9.2.7 Response Time. Using the data from paragraph 8.1, calculate the time interval from filter insertion to 95 percent of the final stable value for all upscale and downscale traverses. Report the mean of the 10 upscale and downscale test times.

9.2.8 Operational Test Period. During the 168-hour operational test period, the continuous monitoring system shall not require any corrective maintenance, repair, replacement, or adjustment other than that clearly specified as required in the manufacturer's operation and maintenance manuals as routine and expected during a one-week period. If the continuous monitoring system is operated within the specified performance parameters and does not require corrective maintenance, repair, replacement, or adjustment other than as specified above during the 168-hour test period, the operational test period shall have been successfully concluded. Failure of the continuous monitoring system to meet these requirements shall call for a repetition of the 168-hour test period. Portions of the tests which were satisfactorily completed need not be repeated. Failure to meet any performance specification(s) shall call for a repetition of the one-week operational test period and that specific portion of the tests required by paragraph 8 related to demonstrating compliance with the failed specification. All maintenance and adjustments required shall be recorded. Output readings shall be recorded before and after all adjustments.

10. References.

10.1 "Experimental Statistics," Department of Commerce, National Bureau of Standards Handbook 91, 1963, pp. 3-31, paragraphs 3-3.1.4.

10.2 "Performance Specifications for Stationary-Source Monitoring Systems for Gases and Visible Emissions," Environmental Protection Agency, Research Triangle Park, N.C., EPA-650/2-74-013, January 1974.

Performance Specification 1, Continued

Calibrated Neutral Density Filter Data
(See paragraph 8.1.1)

Low Range ____% opacity
Mid Range ___% opacity
High Range ___% opacity
Span Value _____% opacity

Date of Test ________________ Location of Test ________________

	Calibrated Filter[1]	Analyzer Reading % Opacity	Differences[2] % Opacity
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

	Low	Mid	High
Mean difference	____	____	____
Confidence interval	____	____	____
Calibration error = Mean Difference[3] + C.I.	____	____	____

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[1] Low, mid or high range

[2] Calibration filter opacity - analyzer reading

[3] Absolute value

Figure 1-1. Calibration Error Test

Performanbe Specification 1, Continued

8.1.2 System Response Test. Insert the high-range filter in the transmissometer path five times and record the time required for the system to respond to 95 percent of final zero and high-range filter values. (See Figure 1-2.)

8.2 Field Test for Zero Drift and Calibration Drift. Install the continuous monitoring system on the affected facility and perform the following alignments:

8.2.1 Preliminary Alignments. As soon as possible after installation and once a year thereafter when the facility is not in operation, perform the following optical and zero alignments:

8.2.1.1 Optical Alignment. Align the light beam from the transmissometer upon the optical surfaces located across the effluent (i.e., the retroflector or photodetector as applicable) in accordance with the manufacturer's instructions.

8.2.1.2 Zero Alignment. After the transmissometer has been optically aligned and the transmissometer mounting is mechanically stable (i.e., no movement of the mounting due to thermal contraction of the stack, duct, etc.) and a clean stack condition has been determined by a steady zero opacity condition, perform the zero alignment. This alignment is performed by balancing the continuous monitor system response so that any simulated zero check coincides with an actual zero check performed across the monitor pathlength of the clean stack.

8.2.1.3 Span. Span the continuous monitoring system at the opacity specified in subparts and offset the zero setting at least 10 percent of span so that negative drift can be quantified.

8.2.2. Final Alignments. After the preliminary alignments have been completed and the affected facility has been started up and reaches normal operating temperature, recheck the optical alignment in accordance with 8.2.1.1 of this specification. If the alignment has shifted, realign the optics, record any detectable shift in the opacity measured by the system that can be attributed to the optical realignment, and notify the Administrator. This condition may not be objectionable if the affected facility operates within a fairly constant and adequately narrow range of operating temperatures that does not produce significant shifts in optical alignment during normal operation of the [illegible] the facility operations produce fluctuations in the effluent gas temperature that result in significant misalignments, the Administrator may require improved mounting structures or another location for installation of the transmissometer.

8.2.3 Conditioning Period. After completing the post-startup alignments, operate the system for an initial 168-hour conditioning period in a normal operational manner.

8.2.4 Operational Test Period. After completing the conditioning period, operate the system for an additional 168-hour period retaining the zero offset. The system shall monitor the source effluent at all times except when being zeroed or calibrated. At 24-hour intervals the zero and span shall be checked according to the manufacturer's instructions. Minimum procedures used shall provide a system check of the analyzer internal mirrors and all electronic circuitry including the lamp and photodetector assembly and shall include a procedure for producing a simulated zero opacity condition and a simulated upscale (span) opacity condition as viewed by the receiver. The manufacturer's written instructions may be used providing that they equal or exceed these minimum procedures. Zero and span the transmissometer, clean all optical surfaces exposed to the effluent, realign optics, and make any necessary adjustments to the calibration of the system daily. These zero and calibration adjustments and optical realignments are allowed only at 24-hour intervals or at such shorter intervals as the manufacturer's written instructions specify. Automatic corrections made by the measurement system without operator intervention are allowable at any time. The magnitude of any zero or span drift adjustments shall be recorded. During this 168-hour operational test period, record the following at 24-hour intervals: (a) the zero reading and span readings after the system is calibrated (these readings should be set at the same value at the beginning of each 24-hour period); (b) the zero reading after each 24 hours of operation but before cleaning and adjustment; and (c) the span reading after cleaning and zero adjustment, but before span adjustment. (See Figure 1-3.)

9. Calculation, Data Analysis, and Reporting.

9.1 Procedure for Determination of Mean Values and Confidence Intervals.

9.1.1 The mean value of the data set is calculated according to equation 1-1.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

Equation 1-1

where x_i = absolute value of the individual measurements.

Σ = sum of the individual values.

$\bar{x}$ = mean value, and

n = number of data points.

9.1.2 The 95 percent confidence interval (two-sided) is calculated according to equation 1-2:

$$C.I._{95} = \frac{t_{.975}}{n\sqrt{n-1}} \sqrt{n(\Sigma x_i^2) - (\Sigma x_i)^2}$$

Equation 1-2

where

Σx_i = sum of all data points,

$t_{.975} = t_{1-\alpha/2}$, and

$C.I._{95}$ = 95 percent confidence interval estimate of the average mean value.

Performance Specification 1, Continued

Date of Test ________ Location of Test ________

Span Filter ________ % Opacity

Analyzer Span Setting ________ % Opacity

Upscale 1 ________ seconds

2 ________ seconds

3 ________ seconds

4 ________ seconds

5 ________ seconds

Downscale 1 ________ seconds

2 ________ seconds

3 ________ seconds

4 ________ seconds

5 ________ seconds

Average response ________ seconds

Figure 1-2. Response Time Test

Zero Setting ________ (See paragraph 8.2.1) Date of Test ________

Span Setting ________

Date and Time	Zero Reading (Before cleaning and adjustment)	Zero Drift (ΔZero)	Span Reading (After cleaning and zero adjustment but before span adjustment)	Calibration Drift (ΔSpan)

Zero Drift = Mean Zero Drift* ________ + CI (Zero) ________ = ________.

Calibration Drift = Mean Span Drift* ________ + CI (Span) ________ = ________.

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*Absolute value

Figure 1-3. Zero and Calibration Drift Test

10.9.79

Rule 923: Performance Specification 2 (SO$_2$ and NO$_x$)

PERFORMANCE SPECIFICATIONS AND SPECIFICATION TEST PROCEDURES FOR MONITORS OF SO$_2$ AND NO$_x$ FROM STATIONARY SOURCES

(40 CFR 60, Appendix B, July 1, 1976)

1. Principle and Applicability.

1.1 Principle. The concentration of sulfur dioxide or oxides of nitrogen pollutants in stack emissions is measured by a continuously operating emission measurement system. Concurrent with operation of the continuous monitoring system, the pollutant concentrations are also measured with reference methods (Appendix A). An average of the continuous monitoring system data is computed for each reference method testing period and compared to determine the relative accuracy of the continuous monitoring system. Other tests of the continuous monitoring system are also performed to determine calibration error, drift, and response characteristics of the system.

1.2 Applicability. This performance specification is applicable to evaluation of continuous monitoring systems for measurement of nitrogen oxides or sulfur dioxide pollutants. These specifications contain test procedures, installation requirements, and data computation procedures for evaluating the acceptability of the continuous monitoring systems.

2. Apparatus.

2.1 Calibration Gas Mixtures. Mixtures of known concentrations of pollutant gas in a diluent gas shall be prepared. The pollutant gas shall be sulfur dioxide or the appropriate oxide(s) of nitrogen specified by paragraph 6 and within subparts. For sulfur dioxide gas mixtures, the diluent gas may be air or nitrogen. For nitric oxide (NO) gas mixtures, the diluent gas shall be oxygen-free (<10 ppm) nitrogen, and for nitrogen dioxide (NO$_2$) gas mixtures the diluent gas shall be air. Concen[illegible] gas mixture is used to set and to check the span and is referred to as the span gas.

2.2 Zero Gas. A gas certified by the manufacturer to contain less than 1 ppm of the pollutant gas or ambient air may be used.

2.3 Equipment for measurement of the pollutant gas concentration using the reference method specified in the applicable standard [illegible]

2.4 Data Recorder. Analog chart recorder or other suitable device with input voltage range compatible with analyzer system output. The resolution of the recorder's data output shall be sufficient to allow completion of the test procedures within this specification.

2.5 Continuous monitoring system for SO$_2$ or NO$_x$ pollutants as applicable.

3. Definitions.

3.1 Continuous Monitoring System. The total equipment required for the determination of a pollutant gas concentration in a source effluent. Continuous monitoring systems consist of major subsystems as follows:

3.1.1 Sampling Interface. That portion of an extractive continuous monitoring system that performs one or more of the following operations: acquisition, transportation, and conditioning of a sample of the source effluent or that portion of an in-situ continuous monitoring system that protects the analyzer from the effluent.

3.1.2 Analyzer. That portion of the continuous monitoring system which senses the pollutant gas and generates a signal output that is a function of the pollutant concentration.

3.1.3 Data Recorder. That portion of the continuous monitoring system that provides a permanent record of the output signal in terms of concentration units.

3.2 Span. The value of pollutant concentration at which the continuous monitoring system is set to produce the maximum data display output. The span shall be set at the concentration specified in each applicable subpart.

3.3 Accuracy (Relative). The degree of correctness with which the continuous monitoring system yields the value of gas concentration of a sample relative to the value given by a defined reference method. This accuracy is expressed in terms of error, which is the difference between the paired concentration measurements expressed as a percentage of the mean reference value.

3.4 Calibration Error. The difference between the pollutant concentration indicated by the continuous monitoring system and the known concentration of the test gas mixture.

3.5 Zero Drift. The change in the continuous monitoring system output over a stated period of time of normal continuous operation when the pollutant concentration at the time for the measurements is zero.

3.6 Calibration Drift. The change in the continuous monitoring system output over a stated time period of normal continuous operations when the pollutant concentration at the time of the measurements is the [illegible]

3.7 Response Time. The time interval from a step change in pollutant concentration at the input to the continuous monitoring system to the time at which 95 percent of the corresponding final value is reached as displayed on the continuous monitoring system data recorder.

3.8 Operational Period. A minimum period of time over which a measurement system is expected to operate within certain performance specifications without unscheduled maintenance, repair, or adjustment.

* * *

Performance Specification 2, Continued

3.9 Stratification. A condition identified by a difference in excess of 10 percent between the average concentration in the duct or stack and the concentration at any point more than 1.0 meter from the duct or stack wall.

4. Installation Specifications. Pollutant continuous monitoring systems (SO$_2$ and NO$_x$) shall be installed at a sampling location where measurements can be made which are directly representative (4.1), or which can be corrected so as to be representative (4.2) of the total emissions from the affected facility. Conformance with this requirement shall be accomplished as follows:

4.1 Effluent gases may be assumed to be nonstratified if a sampling location eight or more stack diameters (equivalent diameters) downstream of any air in-leakage is selected. This assumption and data correction procedures under paragraph 4.2.1 may not be applied to sampling locations upstream of an air preheater in a steam generating facility under Subpart D of this part. For sampling locations where effluent gases are either demonstrated (4.3) or may be assumed to be nonstratified (eight diameters), a point (extractive systems) or path (in-situ systems) of average concentration may be monitored.

4.2 For sampling locations where effluent gases cannot be assumed to be nonstratified (less than eight diameters) or have been shown under paragraph 4.3 to be stratified, results obtained must be consistently representative (e.g. a point of average concentration may shift with load changes) or the data generated by sampling at a point (extractive systems) or across a path (in-situ systems) must be corrected (4.2.1 and 4.2.2) so as to be representative of the total emissions from the affected facility. Conformance with this requirement may be accomplished in either of the following ways:

4.2.1 Installation of a diluent continuous [illegible] paragraph 4.2 of Performance Specification 3 of this appendix. If the pollutant and diluent monitoring systems are not of the same type (both extractive or both in-situ), the extractive system must use a multipoint probe.

4.2.2 Installation of extractive pollutant monitoring systems using multipoint sampling probes or in-situ pollutant monitoring systems that sample or view emissions which are consistently representative of the total emissions for the entire cross section. The Administrator may require data to be submitted to demonstrate that the emissions sampled or viewed are consistently representative for several typical facility process operating conditions.

4.3 The owner or operator may perform a traverse to characterize any stratification of effluent gases that might exist in a stack or duct. If no stratification is present, sampling procedures under paragraph 4.1 may be applied even though the eight diameter criteria is not met.

4.4 When single point sampling probes for extractive systems are installed within the stack or duct under paragraphs 4.1 and 4.2.1, the sample may not be extracted at any point less than 1.0 meter from the stack or duct wall. Multipoint sampling probes installed under paragraph 4.2.2 may be located at any points necessary to obtain consistently representative samples.

5. Continuous Monitoring System Performance Specifications.

The continuous monitoring system shall meet the performance specifications in Table 2-1 to be considered acceptable under this

6. Performance Specification Test Procedures. The following test procedures shall be used to determine conformance with the requirements of paragraph 5. For NO$_x$ analyzers that oxidize nitric oxide (NO) to nitrogen dioxide (NO$_2$), the response time test under paragraph 6.3 of this method shall be performed using nitric oxide (NO) span gas. Other tests for NO$_x$ continuous monitoring systems under paragraphs 6.1 and 6.2 and all tests for sulfur dioxide systems shall be performed using the pollutant span gas specified by each subpart.

6.1 Calibration Error Test Procedure. Set up and calibrate the complete continuous monitoring system according to the manufacturer's written instructions. This may be accomplished either in the laboratory or in the field.

6.1.1 Calibration Gas Analyses. Triplicate analyses of the gas mixtures shall be performed within two weeks prior to use using Reference Methods 6 for SO$_2$ and 7 for NO$_x$.

TABLE 2-1.—*Performance specifications*

Parameter	*Specification*
1. Accuracy [1]	≤20 pct of the mean value of the reference method test data.
2. Calibration error [1]	≤5 pct of each (50 pct, 90 pct) calibration gas mixture value.
3. Zero drift (2 h) [1]	2 pct of span
4. Zero drift (24 h) [1]	Do.
5. Calibration drift (2 h) [1]	Do.
6. Calibration drift (24 h) [1]	2.5 pct. of span
7. Response time	15 min maximum.
8. Operational period	168 h minimum.

[1] Expressed as sum of absolute mean value plus 95 pct confidence interval of a series of tests.

Performance Specification 2, Continued

Analyze each calibration gas mixture (50%, 90%) and record the results on the example sheet shown in Figure 2-1. Each sample test result must be within 20 percent of the averaged result or the tests shall be repeated. This step may be omitted for non-extractive monitors where dynamic calibration gas mixtures are not used (6.1.2).

6.1.2 Calibration Error Test Procedure. Make a total of 15 nonconsecutive measurements by alternately using zero gas and each calibration gas mixture concentration (e.g., 0%, 50%, 0%, 90%, 50%, 90%, 50%, 0%, etc.). For nonextractive continuous monitoring systems, this test procedure may be performed by using two or more calibration gas cells whose concentrations are certified by the manufacturer to be functionally equivalent to these gas concentrations. Convert the continuous monitoring system output readings to ppm and record the results on the example sheet shown in Figure 2-2.

6.2 Field Test for Accuracy (Relative), Zero Drift, and Calibration Drift. Install and operate the continuous monitoring system in accordance with the manufacturer's written instructions and drawings as follows:

6.2.1 Conditioning Period. Offset the zero setting at least 10 percent of the span so that negative zero drift can be quantified. Operate the system for an initial 168-hour conditioning period in normal operating manner.

6.2.2 Operational Test Period. Operate the continuous monitoring system for an additional 168-hour period retaining the zero offset. The system shall monitor the source effluent at all times except when being zeroed, calibrated, or backpurged.

6.2.2.1 Field Test for Accuracy (Relative). For continuous monitoring systems employing extractive sampling, the probe tip for the continuous monitoring system and the probe tip for the Reference Method sampling train should be placed at adjacent locations in the duct. For NO_x continuous monitoring sys- [illegible] ments, divided into three sets, using the applicable reference method. No more than one set of tests, consisting of three individual measurements, shall be performed in any one hour. All individual measurements of each set shall be performed concurrently, or within a three-minute interval and the results averaged. For SO_2 continuous moni- [illegible] measurements using the applicable reference method. No more than one measurement shall be performed in any one hour. Record the reference method test data and the continuous monitoring system concentrations on the example data sheet shown in Figure 2-3.

6.2.2.2 Field Test for Zero Drift and Calibration Drift. For extractive systems, determine the values given by zero and span gas pollutant concentrations at two-hour intervals until 15 sets of data are obtained. For nonextractive measurement systems, the zero value may be determined by mechanically producing a zero condition that provides a system check of the analyzer internal mirrors and all electronic circuitry including the radiation source and detector assembly or by inserting three or more calibration gas cells and computing the zero point from the upscale measurements. If this latter technique is used, a graph(s) must be retained by the owner or operator for each measurement system that shows the relationship between the upscale measurements and the zero point. The span of the system shall be checked by using a calibration gas cell certified by the manufacturer to be functionally equivalent to 50 percent of span concentration. Record the zero and span measurements (or the computed zero drift) on the example data sheet shown in Figure 2-4. The two-hour periods over which measurements are conducted need not be consecutive but may not overlap. All measurements required under this paragraph may be conducted concurrent with tests under paragraph 6.2.2.1.

6.2.2.3 Adjustments. Zero and calibration corrections and adjustments are allowed only at 24-hour intervals or at such shorter intervals as the manufacturer's written instructions specify. Automatic corrections made by the measurement system without operator intervention or initiation are allowable at any time. During the entire 168-hour operational test period, record on the example sheet shown in Figure 2-5 the values given by zero and span gas pollutant concentrations before and after adjustment at 24-hour intervals.

6.3 Field Test for Response Time.

6.3.1 Scope of Test. Use the entire continuous monitoring system as installed, including sample transport lines if used. Flow rates, line diameters, pumping rates, pressures (do not allow the pressurized calibration gas to change the normal operating pressure in the sample line), etc., shall be at the nominal values for normal operation as specified in [illegible] written instructions. If [illegible] is used to sample more than one pollutant source (stack), repeat this test for each sampling point.

6.3.2 Response Time Test Procedure. Introduce zero gas into the continuous monitoring system sampling interface or as close to the sampling interface as possible. When [illegible] output reading has stabilized, switch quickly to a known concentration of pollutant gas. Record the time from concentration switching to 95 percent of final stable response. For non-extractive monitors, the highest available calibration gas concentration shall be switched into and out of the sample path and response times recorded. Perform this test sequence three (3) times. Record the results of each test on the example sheet shown in Figure 2-6.

7. Calculations, Data Analysis and Reporting.

7.1 Procedure for determination of mean values and confidence intervals.

7.1.1 The mean value of a data set is calculated according to equation 2-1.

$$\bar{x}=\frac{1}{n}\sum_{i=1}^{n} x_i \qquad \text{Equation 2-1}$$

where:

x_i = absolute value of the measurements,
Σ = sum of the individual values,
$\bar{x}$ = mean value, and
n = number of data points.

7.1.2 The 95 percent confidence interval (two-sided) is calculated according to equation 2-2:

$$C.I._{95}=\frac{t_{.975}}{n\sqrt{n-1}}\sqrt{n(\sum x_i^2)-(\sum x_i)^2} \qquad \text{Equation 2-2}$$

where:

$\sum x_i$ = sum of all data points,
$t_{.975} = t_{1-\alpha/2}$, and
$C.I._{95}$ = 95 percent confidence interval estimate of the average mean value.

Values for $t_{.975}$

n	$t_{.975}$
2	12.706
3	4.303
4	3.182
5	2.776
6	2.571
7	2.447
8	2.365
9	2.306
10	2.262
11	2.228
12	2.201
13	2.179
14	2.160
15	2.145
16	2.131

The values in this table are already corrected for n-1 degrees of freedom. Use n equal to the number of samples as data points.

7.2 Data Analysis and Reporting.

7.2.1 Accuracy (Relative). For each of the nine reference method test points, determine the average pollutant concentration reported by the continuous monitoring system. These average concentrations shall be determined from the continuous monitoring system data recorded under 7.2.2 by integrating or averaging the pollutant concentrations over each [illegible] reference method testing period. Before proceeding to the next step, determine the basis (wet or dry) of the continuous monitoring system data and reference method test data concentrations. If the bases are not consistent, apply a moisture correction to either reference method concentrations or the continuous monitoring system concentrations as appropriate. Determine the correction factor by moisture tests concurrent with the reference method testing periods. Report the moisture test method and the correction procedure employed. For each of the nine test runs determine the difference for each test run by subtracting the respective reference method test concentrations (use average of each set of three measurements for NO_x) from the continuous monitoring system integrated or averaged concentrations. Using these data, compute the mean difference and the 95 percent confidence interval of the differences (equations 2-1 and 2-2). Accuracy is reported as the sum of the absolute value of the mean difference and the 95 percent confidence interval of the differences expressed as a percentage of the mean reference method value. Use the example sheet shown in Figure 2-3.

7.2.2 Calibration Error. Using the data from paragraph 6.1, subtract the measured pollutant concentration determined under paragraph 6.1.1 (Figure 2-1) from the value shown by the continuous monitoring system for each of the five readings at each concentration measured under 6.1.2 (Figure 2-2). Calculate the mean of these difference values and the 95 percent confidence intervals according to equations 2-1 and 2-2. Report the calibration error (the sum of the absolute value of the mean difference and the 95 percent confidence interval) as a percentage of each respective calibration gas concentration. Use example sheet shown in Figure 2-2.

7.2.3 Zero Drift (2-hour). Using the zero concentration values measured each two hours during the field test, calculate the differences between consecutive two-hour readings expressed in ppm. Calculate the mean difference and the confidence interval using equations 2-1 and 2-2. Report the zero drift as the sum of the absolute mean value and the confidence interval as a percentage of span. Use example sheet shown in Figure 2-4.

7.2.4 Zero Drift (24-hour). Using the zero concentration values measured every 24 hours during the field test, calculate the differences between the zero point after zero adjustment and the zero value 24 hours later just prior to zero adjustment. Calculate the mean value of these points and the confidence interval using equations 2-1 and 2-2. Report the zero drift (the sum of the absolute mean and confidence interval) as a percentage of span. Use example sheet shown in Figure 2-5.

7.2.5 Calibration Drift (2-hour). Using the calibration values obtained at two-hour intervals during the field test, calculate the differences between consecutive two-hour readings expressed in ppm. These values should be corrected for the corresponding zero drift during that two-hour period. Calculate the mean and confidence interval of these corrected difference values using equations 2-1 and 2-2. Do not use the differences between non-consecutive readings. Report the calibration drift as the sum of the absolute mean and confidence interval as a percentage of span. Use the example sheet shown in Figure 2-4.

7.2.6 Calibration Drift (24-hour). Using the calibration values measured every 24 hours during the field test, calculate the differences between the calibration concentration reading after zero and calibration adjustment, and the calibration concentration reading 24 hours later after zero adjustment

Performance Specification 2, Continued

but before calibration adjustment. Calculate the mean value of these differences and the confidence interval using equations 2-1 and 2-2. Report the calibration drift (the sum of the absolute mean and confidence interval) as a percentage of span. Use the example sheet shown in Figure 2-5.

7.2.7 Response Time. Using the charts from paragraph 6.3, calculate the time interval from concentration switching to 95 percent to the final stable value for all upscale and downscale tests. Report the mean of the three upscale test times and the mean of the three downscale test times. The two average times should not differ by more than 15 percent of the slower time. Report the slower time as the system response time. Use the example sheet shown in Figure 2-6.

7.2.8 Operational Test Period. During the 168-hour performance and operational test period, the continuous monitoring system shall not require any corrective maintenance, repair, replacement, or adjustment other than that clearly specified as required in the operation and maintenance manuals as routine and expected during a one-week period. If the continuous monitoring system operates within the specified performance parameters and does not require corrective maintenance, repair, replacement or adjustment other than as specified above during the 168-hour test period, the operational period will be successfully concluded. Failure of the continuous monitoring system to meet this requirement shall call for a repetition of the 168-hour test period. Portions of the test which were satisfactorily completed need not be repeated. Failure to meet any performance specifications shall call for a repetition of the one-week performance test period and that portion of the testing which is related to the failed specification. All maintenance and adjustments required shall be recorded. Output readings shall be recorded before and after all adjustments.

8. References.

8.1 [illegible] Instrumentation for the Measurement of Sulfur Dioxide in Stationary Source Emissions," Environmental Protection Agency, Research Triangle Park, N.C., February 1973.

8.2 "Instrumentation for the Determination of Nitrogen Oxides Content of Stationary Source Emissions," Environmental Protection Agency, Research Triangle Park, N.C., Volume 1, APTD-0847, October 1971; Volume 2, APTD-0942, January 1972.

8.3 "Experimental Statistics," Department of Commerce, Handbook 91, 1963, pp. 3-31, paragraphs 3-3.1.4.

8.4 "Performance Specifications for Stationary-Source Monitoring Systems for Gases and Visible Emissions," Environmental Protection Agency, Research Triangle Park, N.C., EPA-650/2-74-013, January 1974.

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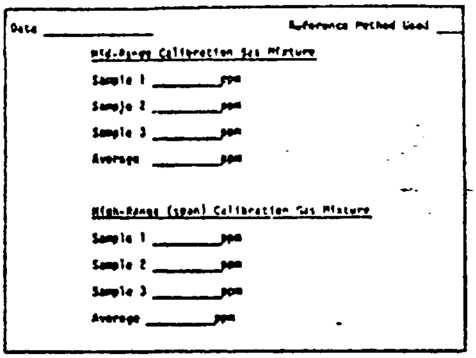

Date ____________ Reference Method Used ____

Mid-Range Calibration Gas Mixture

Sample 1 ________ ppm

Sample 2 ________ ppm

Sample 3 ________ ppm

Average ________ ppm

High-Range (span) Calibration Gas Mixture

Sample 1 ________ ppm

Sample 2 ________ ppm

Sample 3 ________ ppm

Average ________ ppm

Figure 2-1. Analysis of Calibration Gas Mixtures

Performance Specification 2, Continued

Calibration Gas Mixture Data (From Figure 2-1)

Mid (50%) _____ ppm   High (90%) _____ ppm

Run #	Calibration Gas Concentration, ppm	Measurement System Reading, ppm	Differences,[1] ppm
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

	Mid	High
Mean difference	_____	_____
Confidence interval	± _____	± _____
$\text{Calibration error} = \frac{\text{Mean Difference}^{[2]} + \text{C.I.}}{\text{Average Calibration Gas Concentration}} \times 100$	_____ %	_____ %

---

[1] Calibration gas concentration - measurement system reading

[2] Absolute value

Figure 2-2. Calibration Error Determination

Performance Specification 2, Continued

Test No.	Date and Time	Reference Method Samples					Analyzer 1-Hour Average (ppm)*		Difference (ppm)	
		SO_2 Sample 1 (ppm)	NO_x Sample 1* (ppm)	NO_x Sample 2 (ppm)	NO_x Sample 3 (ppm)	NO_x Sample Average (ppm)	SO_2	NO_x	SO_2	NO_x
1										
2										
3										
4										
5										
6										
7										
8										
9										
Mean reference method test value (SO_2) ____				Mean reference method test value (NO_x) ____			Mean of the differences ____			

95% Confidence Intervals = ± ____ ppm (SO_2) = ± ____ ppm (NO_x)

Accuracies = $\frac{\text{Mean of the differences + 95\% confidence interval}}{\text{Mean reference method value}}$ x 100 = ____% (SO_2) = ____% (NO_x)

* Explain and report method used to determine integrated averages

Figure 2-3. Accuracy Determination (SO_2 and NO_x)[1]

Data Set No.	Time Begin	End	Date	Zero Reading	Zero Drift (ΔZero)	Span Reading	Span Drift (ΔSpan)	Calibration Drift (Span- Zero)
1								
2								
3								
4								
5								
5								
7								
8								
9								
10								
11								
13								
14								
15								

Zero Drift = [Mean Zero Drift* ____ + CI (Zero) ____] ÷ [Span] x 100 = ____.

Calibration Drift = [Mean Span Drift* ____ + CI (Span) ____] ÷ [Span] x 100 = ____.

*Absolute Value.

Figure 2-4. Zero and Calibration Drift (2 hour)

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[1] 42 FR, 5937, January 31, 1977

Performance Specification 2, Continued

Date and Time	Zero Reading	Zero Drift (ΔZero)	Span Reading (After zero adjustment)	Calibration Drift (ΔSpan)

Zero Drift = [Mean Zero Drift* ________ + C.I. (Zero) ________]

÷ [Instrument Span] x 100 = ________.

Calibration Drift = [Mean Span Drift* ________ + C.I. (Span) ________]

÷ [Instrument Span] x 100 = ________.

* Absolute value

Figure 2-5. Zero and Calibration Drift (24-hour)

Date of Test ____________

Span Gas Concentration ________ ppm

Analyzer Span Setting ________ ppm

Upscale
1 ________ seconds
2 ________ seconds
3 ________ seconds

Average upscale response ________ seconds

Downscale
1 ________ seconds
2 ________ seconds
3 ________ seconds

Average downscale response ________ seconds

System average response time (slower time) = ________ seconds.

$$\%\text{deviation from slower system average response} = \left[\frac{\text{average upscale minus average downscale}}{\text{slower time}}\right] \times 100\% = \_\_\_\_\_.$$

Figure 2-6. Response Time

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Rule 924: Performance Specification 3 (CO_2 and O_2)

PERFORMANCE SPECIFICATIONS AND SPECIFICATION TEST PROCEDURES FOR MONITORS OF CO_2 AND O_2 FROM STATIONARY SOURCES

(40 CFR 60, Appendix B, July 1, 1976)

1. **Principle and Applicability.**

1.1 Principle. Effluent gases are continuously sampled and are analyzed for carbon dioxide or oxygen by a continuous monitoring system. Tests of the system are performed during a minimum operating period to determine zero drift, calibration drift, and response time characteristics.

1.2 Applicability. This performance specification is applicable to evaluation of continuous monitoring systems for measurement of carbon dioxide or oxygen. These specifications contain test procedures, installation requirements, and data computation procedures for evaluating the acceptability of the continuous monitoring systems subject to approval by the Administrator. Sampling may include either extractive or non-extractive (in-situ) procedures.

2. Apparatus.

2.1 Continuous Monitoring System for Carbon Dioxide or Oxygen.

2.2 Calibration Gas Mixtures. Mixture of known concentrations of carbon dioxide or oxygen in nitrogen or air. Midrange and 90 percent of span carbon dioxide or oxygen concentrations are required. The 90 percent of span gas mixture is to be used to set and check the analyzer span and is referred to as span gas. For oxygen analyzers, if the span is higher than 21 percent O_2, ambient air may be used in place of the 90 percent of span calibration gas mixture. Triplicate analyses of the gas mixture (except ambient air) shall be performed within two weeks prior to use using Reference Method 3 of this part.

2.3 Zero Gas. A gas containing less than 100 [illegible] or oxygen.

2.4 Data Recorder. Analog chart recorder or other suitable device with input voltage range compatible with analyzer system output. The resolution of the recorder's data output shall be sufficient to allow completion of the test procedures within this specification.

[illegible]

3.1 Continuous Monitoring System. The total equipment required for the determination of carbon dioxide or oxygen in a given source effluent. The system consists of three major subsystems:

3.1.1 Sampling Interface. That portion of the continuous monitoring system that performs one or more of the following operations: delineation, acquisition, transportation, and conditioning of a sample of the source effluent or protection of the analyzer from the hostile aspects of the sample or source environment.

: : :

3.1.2 Analyzer. That portion of the continuous monitoring system which senses the pollutant gas and generates a signal output that is a function of the pollutant concentration.

3.1.3 Data Recorder. That portion of the continuous monitoring system that provides a permanent record of the output signal in terms of concentration units.

3.2 Span. The value of oxygen or carbon dioxide concentration at which the continuous monitoring system is set that produces the maximum data display output. For the purposes of this method, the span shall be set no less than 1.5 to 2.5 times the normal carbon dioxide or normal oxygen concentration in the stack gas of the affected facility.

3.3 Midrange. The value of oxygen or carbon dioxide concentration that is representative of the normal conditions in the stack gas of the affected facility at typical operating rates.

3.4 Zero Drift. The change in the continuous monitoring system output over a stated period of time of normal continuous operation when the carbon dioxide or oxygen concentration at the time for the measurements is zero.

3.5 Calibration Drift. The change in the continuous monitoring system output over a stated time period of normal continuous operation when the carbon dioxide or oxygen continuous monitoring system is measuring the concentration of span gas.

3.6 Operational Test Period. A minimum period of time over which the continuous monitoring system is expected to operate within certain performance specifications [illegible] maintenance, repair, or adjustment.

3.7 Response time. The time interval from a step change in concentration at the input to the continuous monitoring system to the time at which 95 percent of the corresponding final value is displayed on the continuous monitoring system data recorder.

[illegible] Specification.

Oxygen or carbon dioxide continuous monitoring systems shall be installed at a location where measurements are directly representative of the total effluent from the affected facility or representative of the same effluent sampled by a SO_2 or NO_x continuous monitoring system. This requirement shall be complied with by use of applicable requirements in Performance Specification 2 of this appendix as follows:

4.1 Installation of Oxygen or Carbon Dioxide Continuous Monitoring Systems Not Used to Convert Pollutant Data. A sampling location shall be selected in accordance with the procedures under paragraphs 4.2.1 or 4.2.2, or Performance Specification 2 of this appendix.

Performance Specification 3, Continued

4.2 Installation of Oxygen or Carbon Dioxide Continuous Monitoring Systems Used to Convert Pollutant Continuous Monitoring System Data to Units of Applicable Standards. The diluent continuous monitoring system (oxygen or carbon dioxide) shall be installed at a sampling location where measurements that can be made are representative of the effluent gases sampled by the pollutant continuous monitoring system(s). Conformance with this requirement may be accomplished in any of the following ways:

4.2.1 The sampling location for the diluent system shall be near the sampling location for the pollutant continuous monitoring system such that the same approximate point(s) (extractive systems) or path (in-situ systems) in the cross section is sampled or viewed.

4.2.2 The diluent and pollutant continuous monitoring systems may be installed at different locations if the effluent gases at both sampling locations are nonstratified as determined under paragraphs 4.1 or 4.3, Performance Specification 2 of this appendix and there is no in-leakage occurring between the two sampling locations. If the effluent gases are stratified at either location, the procedures under paragraph 4.2.2, Performance Specification 2 of this appendix shall be used for installing continuous monitoring systems at that location.

5. Continuous Monitoring System Performance Specifications.

The continuous monitoring system shall meet the performance specifications in Table 3-1 to be considered acceptable under this method.

6. Performance Specification Test Procedures.

The following test procedures shall be used to determine conformance with the requirements of paragraph 4. Due to the wide variation existing in analyzer designs and principles of operation, these procedures are not [illegible] procedures, subject to the approval of the Administrator, may be employed. Any such alternative procedures must fulfill the same purposes (verify response, drift, and accuracy) as the following procedures, and must clearly demonstrate conformance with specifications in Table 3-1.

6.1 Calibration Check. Establish a calibra- [illegible] system using zero, midrange, and span concentration gas mixtures. Verify that the resultant curve of analyzer reading compared with the calibration gas value is consistent with the expected response curve as described by the analyzer manufacturer. If the expected response curve is not produced, additional calibration gas measurements shall be made, or additional steps undertaken to verify the accuracy of the response curve of the analyzer.

: : :

: : :

6.2 Field Test for Zero Drift and Calibration Drift. Install and operate the continuous monitoring system in accordance with the manufacturer's written instructions and drawings as follows:

TABLE 3-1.—*Performance specifications*

Parameter	*Specification*
1. Zero drift (2 h)[1]	≤0.4 pct O_2 or CO_2.
2. Zero drift (24 h)[1]	≤0.5 pct O_2 or CO_2.
3. Calibration drift (2 h)[1]	≤0.4 pct O_2 or CO_2.
4. Calibration drift (24 h)[1]	≤0.5 pct O_2 or CO_2.
5. Operational period	168 h minimum.
6. Response time	10 min.

[1] Expressed as sum of absolute mean value plus 95 pct confidence interval of a series of tests.

6.2.1 Conditioning Period. Offset the zero setting at least 10 percent of span so that negative zero drift may be quantified. Operate the continuous monitoring system for an initial 168-hour conditioning period in a normal operational manner.

6.2.2 Operational Test Period. Operate the continuous monitoring system for an additional 168-hour period maintaining the zero offset. The system shall monitor the source effluent at all times except when being zeroed, calibrated, or backpurged.

6.2.3 Field Test for Zero Drift and Calibration Drift. Determine the values given by zero and midrange gas concentrations at two-hour intervals until 15 sets of data are obtained. For non-extractive continuous monitoring systems, determine the zero value given by a mechanically produced zero condition or by computing the zero value from upscale measurements using calibrated gas cells certified by the manufacturer. The midrange checks shall be performed by using [illegible] gas cells functionally equivalent to less than 50 percent of span. Record these readings on the example sheet shown in Figure 3-1. These two-hour periods need not be consecutive but may not overlap. In-situ CO_2 or O_2 analyzers which cannot be fitted with a calibration gas cell may be calibrated by alternative procedures acceptable to the Administrator. Zero and calibration corrections and adjustments are allowed only at 24-hour intervals or at such shorter intervals as the manufacturer's written instructions specify. Automatic corrections made by the continuous monitoring system without operator intervention or initiation are allowable at any time. During the entire 168-hour test period, record the values given by zero and span gas concentrations before and after adjustment at 24-hour intervals in the example sheet shown in Figure 3-2.

6.3 Field Test for Response Time.

6.3.1 Scope of Test.

This test shall be accomplished using the continuous monitoring system as installed, including sample transport lines if used. Flow rates, line diameters, pumping rates, pressures (do not allow the pressurized calibration gas to change the normal operating pressure in the sample line), etc., shall be at the nominal values for normal operation as specified in the manufacturer's written instructions. If the analyzer is used to sample more than one source (stack), this test shall be repeated for each sampling point.

6.3.2 Response Time Test Procedure.

Introduce zero gas into the continuous monitoring system sampling interface or as close to the sampling interface as possible. When the system output reading has stabilized, switch quickly to a known concentration of gas at 90 percent of span. Record the time from concentration switching to 95 percent of final stable response. After the system response has stabilized at the upper level, switch quickly to a zero gas. Record the time from concentration switching to 95 percent of final stable response. Alternatively, for nonextractive continuous monitoring systems, the highest available calibration gas concentration shall be switched into and out of the sample path and response times recorded. Perform this test sequence three (3) times. For each test, record the results on the data sheet shown in Figure 3-3.

7. Calculations, Data Analysis, and Reporting.

7.1 Procedure for determination of mean values and confidence intervals.

7.1.1 The mean value of a data set is calculated according to equation 3-1.

$$\bar{x}=\frac{1}{n}\sum_{i=1}^{n}x_i \qquad \text{Equation 3-1}$$

where:

x_i = absolute value of the measurements,
Σ = sum of the individual values,
$\bar{x}$ = mean value, and
n = number of data points.

7.2.1 The 95 percent confidence interval (two-sided) is calculated according to equation 3-2:

$$C.I._{95}=\frac{t_{.975}}{n\sqrt{n-1}}\sqrt{n(\Sigma x_i^2)-(\Sigma x_i)^2}$$

Equation 3-2

where:

ΣX = sum of all data points,
$t_{.975} = t_1 - \alpha/2$, and
$C.I._{95}$ = 95 percent confidence interval estimates of the average mean value.

: : :

: : :

Values for t.975

n	t.975
2	12.706
3	4.303
4	3.182
5	2.776
6	2.571
7	2.447
8	2.365
9	2.306
10	2.262
11	2.228
12	2.201
13	2.179
14	2.160
15	2.145
16	2.131

The values in this table are already corrected for n-1 degrees of freedom. Use n equal to the number of samples as data points.

7.2 Data Analysis and Reporting.

7.2.1 Zero Drift (2-hour). Using the zero concentration values measured each two hours during the field test, calculate the differences between the consecutive two-hour readings expressed in ppm. Calculate the mean difference and the confidence interval using equations 3-1 and 3-2. Record the sum of the absolute mean value and the confidence interval on the data sheet shown in Figure 3-1.

7.2.2 Zero Drift (24-hour). Using the zero concentration values measured every 24 hours during the field test, calculate the differences between the zero point after zero adjustment and the zero value 24 hours later just prior to zero adjustment. Calculate the mean value of these points and the confidence interval using equations 3-1 and 3-2. Record the zero drift (the sum of the absolute mean and confidence interval) on the data sheet shown in Figure 3-2.

7.2.3 Calibration Drift (2-hour). Using the calibration values obtained at two-hour intervals during the field test, calculate the differences between consecutive two-hour readings expressed as ppm. These values should be corrected for the corresponding zero drift during that two-hour period. Calculate the mean and confidence interval of [illegible] using equations 3-1 and 3-2. Do not use the differences between non-consecutive readings. Record the sum of the absolute mean and confidence interval upon the data sheet shown in Figure 3-1.

7.2.4 Calibration Drift (24-hour). Using the calibration values measured every 24 hours during the field test, calculate the differences between the calibration concentration reading after zero and calibration adjustment and the calibration concentration reading 24 hours later after zero adjustment but before calibration adjustment. Calculate the mean value of these differences and the confidence interval using equations 3-1 and 3-2.

Record the sum of the absolute mean and confidence interval on the data sheet shown in Figure 3-2.

7.2.5 Operational Test Period. During the 168-hour performance and operational test period, the continuous monitoring system shall not receive any corrective maintenance, repair, replacement, or adjustment other than that clearly specified as required in the manufacturer's written operation and maintenance manuals as routine and expected during a one-week period. If the continuous monitoring system operates within the specified performance parameters and does not require corrective maintenance, repair, replacement or adjustment other than as specified above during the 168-hour test period, the operational period will be successfully concluded. Failure of the continuous monitoring system to meet this requirement shall call for a repetition of the 168 hour test period. Portions of the test which were satisfactorily completed need not be repeated. Failure to meet any performance specifications shall call for a repetition of the one-week performance test period and that portion of the testing which is related to the failed specification. All maintenance and adjustments required shall be recorded. Output readings shall be recorded before and after all adjustments.

7.2.6 Response Time. Using the data developed under paragraph 5.3, calculate the time interval from concentration switching to 95 percent to the final stable value for all upscale and downscale tests. Report the mean of the three upscale test times and the mean of the three downscale test times. The two average times should not differ by more than 15 percent of the slower time. Report the slower time as the system response time. Record the results on Figure 3-3.

8. References.

8.1 "Performance Specifications for Stationary Source Monitoring Systems for Gases and Visible Emissions," Environmental Protection Agency, Research Triangle Park, N.C., EPA-650/2-74-013, January 1974.

8.2 "Experimental Statistics," Department of Commerce, National Bureau of Standards Handbook 91, 1963, pp. 3-31, paragraphs 3-3.1.4.

Data Set No.	Time		Date	Zero Reading	Zero Drift (ΔZero)	Span Reading	Span Drift (ΔSpan)	Calibration Drift (ΔSpan-ΔZero)
	Begin	End						
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								

Zero Drift = [Mean Zero Drift* ________ + CI (Zero) ________] = ________.

Calibration Drift = [Mean Span Drift* ______ + CI (Span ________] = ________.

*Absolute Value.

Figure 3-1. Zero and Calibration Drift (2 Hour).

Performance Specification 3, Continued

Date and Time	Zero Reading	Zero Drift (ΔZero)	Span Reading (After zero adjustment)	Calibration Drift (ΔSpan)

Zero Drift = [Mean Zero Drift* ________ + C.I. (Zero) ________]

= ________.

Calibration Drift = [Mean Span Drift* ________ + C.I. (Span) ________]

= ________.

* Absolute value

Figure 3-2. Zero and Calibration Drift (24-hour)

Date of Test ____________

Span Gas Concentration ________ ppm

Analyzer Span Setting ________ ppm

Upscale
1. ________ seconds
2. ________ seconds
3. ________ seconds

Average upscale response ________ seconds

Downscale
1. ________ seconds
2. ________ seconds
3. ________ seconds

Average downscale response ________ seconds

System average response time (slower time) = ________ seconds

% deviation from slower system average response = $\frac{\text{average upscale minus average downscale}}{\text{slower time}} \times 100\%$

= ____________.

Figure 3-3. Response

EPA-450/2-78-027
OAQPS No. 1.2-080

Guideline on Air Quality Models

10.9.79

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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OAQPS GUIDELINE SERIES

The guideline series of reports is being issued by the Office of Air Quality Planning and Standards (OAQPS) to provide information to state and local air pollution control agencies; for example, to provide guidance on the acquisition and processing of air quality data and on the planning and analysis requisite for the maintenance of air quality. Reports published in this series will be available - as supplies permit - from the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161

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Preface

In late 1976 it became clear from needs expressed by the States and EPA Regional Offices, by many industries and trade associations and by deliberations of Congress that greater consistency in the use of air quality models is needed. Consistency is required so that air pollution control agencies, industry and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits.

To meet this need, EPA undertook a series of steps that would lead to a widely reviewed guide on the use of air quality models. After initial opinions from EPA's Regional Offices were received, the Office of Air Quality Planning and Standards prepared a draft guide. This guide was submitted for critical review to a conference of specialists.* The individual conferees were widely recognized experts in the development and use of air quality models. Based on the judgments and suggestions of the conferees, the guide was revised and presented for public comment at meetings** in Atlanta, Chicago, Denver, New York and San Francisco. These meetings were attended by approximately 500 representatives of control agencies, industry, environmental groups and the scientific community. Those attendees submitted extensive oral and written comments which were evaluated and considered in the preparation of this guide.

During the development of the guide, the Clean Air Act Amendments of 1977 were signed into law. These Amendments required EPA to conduct a Conference on Air Quality Modeling*** with special attention given to models applicable to prevention of significant deterioration. That Conference was held in Washington, D. C. on December 14-15, 1977, with the "Interim Guideline on Air Quality Models" (October, 1977) serving as the focal point. The Conference was attended by over 300 individuals with similar backgrounds and interests to those who participated in the five previous meetings. A verbatim transcript of the proceedings was maintained and written comments were accepted. Those comments and suggestions were considered in this revision to the guide.

The Clean Air Act Amendments also required the promulgation of regulations which specify air quality models to be used in analyses pertinent to prevention of significant deterioration. The guide is included by reference in 40 CFR 52.21 regulations concerning significant deterioration. The models discussed here are those recommended for use in PSD analyses.

Due to the continuing development of a wide variety of air quality models and numerous gaps in our ability to simulate atmospheric dispersion processes, EPA plans to review and update this guide periodically. EPA is also actively pursuing mechanisms by which (1) the technical community can take an active role in such reviews and updates and (2) a wider range of models, including those developed by groups other than EPA, can be incorporated. EPA and other groups within the technical community have ongoing programs in the areas of complex terrain, long range transport, fugitive dust, turbulence characterization, and model validation/improvement. It is anticipated that within about 18 months outputs which have practical applications will have resulted from these various programs. Thus EPA expects that further revision to this guide will be appropriate at that time. In the future, it appears that reviews and updates of this guide at 18-24 month intervals are also appropriate. These revisions will be synchronized with Conferences on Air Quality Modeling which EPA is required to conduct at least every three years.

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*Roberts, J. J., Ed. "Report to the U. S. EPA of the Specialists' Conference on the EPA Modeling Guidelines." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February, 1977.

**Slater, H. H., Chairman. "Comments and Recommendations Concerning the Draft Guidelines on Air Quality Models." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May/June, 1977.

***Environmental Protection Agency. "Conference on Air Quality Modeling." [illegible] Reporting Company, Washington, D. C. 20005, December, 1977.

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this guide is to recommend air quality modeling techniques that may be applied to air pollution control strategy evaluations and to new source reviews, including prevention of significant deterioration. It is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, by State and local agencies and by industry and its consultants. It is appropriate for use by other Federal agencies with environmental impact statement and land management responsibilities. Similarly, it serves to identify for all interested parties those techniques and data bases that EPA considers acceptable. The guide is not intended to be a compendium of modeling techniques. Rather it should serve as a basis by which air quality managers, supported by sound scientific judgment, have a common measure of acceptable technical analyses.

This guide make specific recommendations concerning (1) air quality models, (2) data bases and (3) general requirements for concentration estimates. It should be followed in all evaluations relative to State Implementation Plans (SIPs). However, it may be found that (1) the recommended air quality model is not appropriate for a particular application, (2) the required data base is unavailable, or (3) a better model or analytical procedure is available and applicable. In such cases, alternatives indicated in this guide or other data, models and techniques deemed appropriate by the Regional Administrator may be used. Thus, even though specific recommendations are made, they should not be considered rigid requirements. The preferred model is that which best simulates atmospheric transport and dispersion in the area of interest. However, deviations from this guide should be fully supported and documented.

The contents of this guide are summarized in Figure 1. The basic steps in applying an air quality model to a practical situation, and the necessary data bases and information, are shown. The numbers in parentheses refer to specific sections of the guide.

As indicated in Figure 1, it is generally advisable to first apply el requiring a minimum expenditure of resources (i.e., a preliminary screening technique). The purpose of a screening technique is to single out, with minimum effort, those sources that clearly will not cause or contribute to ambient concentrations in excess of the National Ambient Air Quality Standards (NAAQS) or allowable concentration increments. In doing so, unwarranted expenditure of resources (a refined analysis when a simple approach would suffice) can be avoided. Another advantage of first applying a relatively simple model is to obtain concentration estimates or receptor information that can be helpful in a more refined analysis.

If the screening analysis indicates that the source may pose an air quality problem, application of a relatively sophisticated model is then warranted for obtaining more refined concentration estimates. The selection of an appropriate model should be based upon all the factors indicated in Figure 1. Of particular importance are the source and meteorological data used in the application.

Given the selection of a refined air quality model, an appropriate receptor field must be designated. The model can then be applied giving appropriate consideration to background concentrations and future growth. The resulting concentration estimates can be used to analyze source impact as required by the particular application.

Any analytical technique may have deficiencies that cause estimated concentrations to be in error. Therefore, whenever possible, measured air quality data should be used to determine the accuracy of the model estimates. Information on the accuracy of the model should be available prior to evaluation of control strategies and determination of allowable emissions.

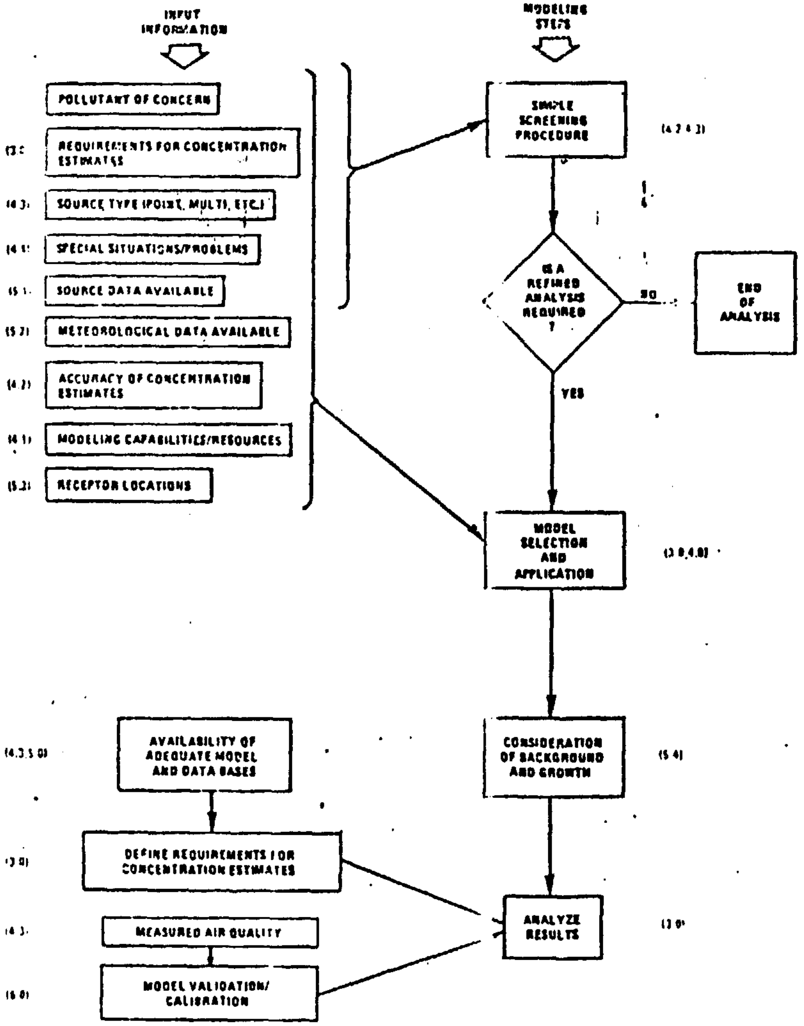

Figure 1. Selection and application of air quality models and data bases. (Applicable sections of the guideline are indicated in parentheses.)

2.0 OVERVIEW

Air quality models have been widely used to identify potential violations of the National Ambient Air Quality Standards (NAAQS) and to determine emission limits. The need for air quality models in the development and revision of SIP-related control strategies was identified very early.[1] However, due to the initial demands of the Clean Air Act (1970) on available resources, it has not generally been possible to use air quality models to the extent desired. Thus, many SIPs are based on an example region concept, a simple emissions rollback model and available measurements of air quality. In recent years, however, air quality models have been more widely used. As these models and associated data bases increase in sophistication, they allow more precision in estimating concentrations and in assessing the adequacy of control strategies.

In addition to their use in development and revision of control strategies, air quality models are also required in the New Source Review program to insure attainment and maintenance of NAAQS, and to prevent significant air quality deterioration. Judgments must be made concerning allowable emission rates and the placement of new sources that may cause specific air quality levels to be exceeded or that may contribute significantly to existing violations.

It must be noted that EPA has never encouraged the use of air quality models in place of measured data. In fact, EPA encourages the use of measured data in evaluating the effectiveness of control strategies and in determining emission limits. The two should be used in a complementary manner whenever possible. The air quality data can be especially useful in validating air quality models and thus have a direct impact on the air quality assessment. However, in some cases, the source does not yet exist or there are insufficient air quality data to evaluate the spatial distribution of concentrations and the impact of control strategies. Thus, the use of models as the primary analytical tool is unavoidable.

: : :

In the use of models it would be advantageous to categorize the various control programs and to apply a designated model to each proposed source which comes under a given program. However, the diversity of the nation's topography and climate, and variations in source configurations and operating characteristics dictate against a routine "cookbook" analysis. There is no single model capable of properly addressing all conceivable situations. Meteorological phenomena associated with threats to air quality standards are rarely amenable to simple mathematical treatment. Any modeling effort should be directed by highly competent individuals with a broad range of experience and knowlege in air pollution meteorology and coordinated closely with specialists in emissions characteristics and data processing. The judgment of well-trained professional analysts is essential.

Nevertheless, it is clear from the needs expressed by the States and EPA Regional Offices, by many industries and trade associations and by the deliberations of Congress[2] that greater consistency in the use of models and data bases is in order. Consistency is required so that air pollution control agencies and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits. This guide promotes the required consistency.

3.0 REQUIREMENTS FOR CONCENTRATION ESTIMATES

Specific air quality standards and increments of pollutant concentrations must be considered for control strategy evaluations and for new source reviews, including prevention of significant deterioration. This section specifies general requirements for concentration estimates and identifies the relationship between emission limits and air quality standards/increments for these applications.

3.1 Control Strategy Evaluations

SIP-related emission limits should be based on concentration estimates for the averaging time which results in the most stringent control requirements. In all cases these concentration estimates are assumed to be a sum of the concentration contributed by the source and an appropriate background concentration (see pp. 36-39).

If the annual average air quality standard is exceeded by a greater degree (percentage) than standards for other averaging times, the annual average is considered the restrictive standard. In this case the sum of the highest estimated annual average concentration and the annual average background provides the concentration which should be used to specify emission limits. However, if a short-term standard is exceeded by a greater degree and is thus identified as the restrictive standard, other considerations are required because the frequency of occurrence must also be taken into account.

Historically, when dispersion model estimates are used to assist in judging whether short-term NAAQS will be met, and ultimately in specifying appropriate emission limits, one of three types of concentration estimates is used: (1) the highest of all estimated concentrations, (2) the second-highest of all estimated concentrations, or (3) the highest of second-highest concentrations estimated for a field of receptor sites. The highest of second-highest concentrations for a field of receptors is obtained as follows: (1) frequency distributions of short-term concentrations are estimated for each site in a field of receptors; (2) the highest estimated concentration at each receptor is discarded; (3) the highest of the remaining concentration estimates from the field of receptor sites is identified. Throughout this guideline that concentration estimate is referred to as the "highest, second-highest" concentration.

The first two types of estimates have been applied most often in specifying emission limits. However, they may be unnecessarily restrictive in many situations. The third type of estimate is more consistent with the criteria for determining violations of the NAAQS, which are identified in "Guidelines for Interpretation of Air Quality Standards."[3] That guideline specifies that a violation of a short-term standard occurs at a site when the standard is exceeded a second time. Thus, emission limits which are to be based on an averaging time of 24-hours or less should be based on the highest, second-highest estimated concentration plus a background concentration which can reasonably be assumed to occur with that concentration. (See the section on background air quality for a discussion of the factors and variety of situations that should be considered.)

An estimate of the highest, second-highest concentration which is based on many well-chosen receptor sites may well reveal previously unidentified "hot spots." Such an estimate may provide a more conservative and realistic indication of the potential for NAAQS violations and of the appropriate emission limits than do actual measurements at a few monitoring sites. However, if the data available for modeling are limited to a short period, or source data are generalized, the estimated highest, second-highest concentration is unlikely to provide a true indication of the threat to air quality standards. Thus it is essential that an adequate data base be available (see Section 5.0). Data for a time period of sufficient length should be considered so that there is reasonable certainty that meteorological conditions associated with the greatest impacts on air quality are identified. Similarly, detailed source data are required so that the air quality impact can be assessed for the source conditions likely to result in the greatest impact.

There are two exceptions to the above requirement to use the highest, second-highest estimated concentrations. The first situation occurs where monitored air quality data from specific sites indicate that concentrations greater than those estimated can occur with little or no impact from the source(s) in question. For the purpose of specifying emission limits, these measured concentrations should be ranked ahead of the estimated concentrations in the frequency distribution of concentrations at that specific monitoring (receptor) site.

The second situation occurs where the Regional Administrator identifies inadequacies in the data base or the models for a particular application. As a result of these inadequacies he may determine that there is a lack of confidence in an emission limit based on the highest, second-highest concentration or that this concentration simply cannot be estimated. In this case, until such time as the necessary data bases are acquired or analytical techniques are improved, the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified.

3.2 New Source Reviews

Reviews for new sources that require an air quality impact analysis should determine if the source will (1) cause or exacerbate violations of a NAAQS or (2) cause air quality deterioration which is greater than allowable increments. For reviews relative to both the NAAQS and prevention of significant deterioration (PSD), the air quality impact analysis should generally be limited to the area where the impact exceeds "significant concentration increments." Such significant increments are defined in EPA's PSD regulations (40 CFR 52.21) and in EPA's Emission Offset Ruling (40 CFR Part 51, Appendix S). In addition, due to the uncertainties of estimates for large downwind distances, the air quality impact analysis should generally be limited to a downwind distance of 50 kilometers from the source, regardless of the above mentioned significant increments. The following subsections further identify requirements for concentration estimates associated with air quality standards and with prevention of significant deterioration.

3.2.1 Meeting Air Quality Standards

For each new source or major modification of a source which would increase allowable emissions by 50 tons per year, 500 pounds per day, or

100 pounds per hour, an air quality analysis should be performed to determine if the source will cause or exacerbate a violation of a NAAQS. For such new sources located in an attainment area, the concentration estimates should meet the same requirements that are applicable to control strategy evaluations. The determination of whether or not the source will cause an air quality violation should be based on (1) the highest estimated concentration for annual averages and (2) the highest, second-highest estimated concentration for averaging times of 24-hours or less. The most restrictive standard should be used in all cases to establish the potential for an air quality violation. Background concentrations should be added in assessing the source's impact. The two exceptions to the shorter-term averaging times which were noted in the preceding section also apply here; i.e., monitored data with higher concentrations and inadequacies in data bases or model.

3.2.2 Prevention of Significant Deterioration

Air quality models should be used in all significant deterioration evaluations. Allowable increments for sulfur dioxide and particulate matter are set forth in the Clean Air Act Amendments of 1977.[2] These maximum allowable increases in pollutant concentrations may be exceeded once per year, except for the annual increment. Thus, in significant deterioration evaluations for short-term periods the highest, second-highest increase in estimated concentrations should be less than or equal to the permitted increment.

Since the Clean Air Act Amendments express special concern for Class I PSD areas, any expected impacts for these areas must be considered. Thus, the distance limitation of 50 kilometers and the significant concentration increments discussed in the introduction to Section 3.2 do not apply. In addition, where an exemption to the Class I increments is requested and approved pursuant to section 165(d)(2)(D) of the Clean Air Act, the source may cause the Class I increments to be exceeded on a l of 18 days during any annual period. In this case, it is necessary to select the highest estimated concentration in the field of receptors for each of the 365 days. These 365 values are then ranked and the 19th highest is used to determine emission limits. However, the highest, second-highest concentration may not exceed a somewhat higher increment specified in section 165(d)(2)(D)(iii).

4.0 AIR QUALITY MODELS

This Section recommends air quality models* for a wide variety of specific applications. It identifies factors that determine the suitability of models for individual situations, presents classes and subclasses of models and addresses special modeling problems.

Air quality models recommended in this section are state-of-the-art analytical techniques that make it possible to perform control strategy evaluations and new source/reviews, including prevention of significant deterioration. However, the responsible Regional Administrator may find that (1) the recommended air quality model is not appropriate for the particular application, (2) the required data base is unavailable, or (3) a better model or analytical procedure is available and applicable. In such cases, alternatives indicated in this guide or other models deemed appropriate by the Regional Administrator may be used. However, all deviations from this guide should be fully supported and documented.

It must not be construed that the models recommended in this guide are to be permanently used to the exclusion of all others or that they are the only models available for relating emissions to air quality. Similar models that are available from other governmental agencies and private consultants have been summarized and discussed by Lamb, et al.,[6] Moses,[7] Stern[8] and others.

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*A discussion of each specific model or refined analytical technique is presented in Appendix A. Some of the models recommended here are also applicable to the development and use of Supplementary Control Systems (SCS). However, such control systems are not considered in the context of this guideline and the reader is referred to other publications on SCS.[4,5]

In all cases, and particularly when models and data bases other than those recommended in this guide are proposed, early discussions among the Regional Office staff, appropriate federal land managers, the control agencies and industry representatives can be invaluable and are encouraged. Concurrence on the data base, modeling techniques and overall technical approach, prior to the actual analyses, will help avoid disagreements concerning the final results and may reduce the later need for additional analyses. The Office of Air Quality Planning and Standards is routinely available to the Regional Offices for consultation on particularly difficult or complex problems.

It should be noted that models applicable to photochemical oxidants are not discussed in this guide. These models are undergoing a critical review. Requirements for such models and associated data bases will be specified at a later time.

4.1 Suitability of Models

The extent to which a specific air quality model is suitable for the evaluation of source impact and control strategies depends upon several factors that should be judged by the responsible Regional Administrator. These include (1) the detail and accuracy of the data base, i.e., emission inventory, meteorological data, air quality data; (2) the meteorological and topographic complexities of the area; (3) the technical competence of those undertaking such simulation modeling; and (4) the resources available. These factors, as well as others deemed appropriate by the responsible Regional Administrator, should be considered in determining the suitability of a particular model application.

The data base required for air quality models includes source data, meteorological data and air quality data (see Section 5.0). Appropriate data should be available before any attempt is made to apply a model. A model which requires detailed, precise input data should not be applied when such data are unavailable. However, assuming the data are adequate, greater the detail with which a model considers the spatial and temporal variations in emissions and meteorological conditions, the greater the ability to evaluate the source impact and to distinguish the effects of various control strategies.

Most air quality models that describe atmospheric transport and dispersion apply to areas with relatively simple topography. However, areas subject to major topographic or marine influence experience meteorological complexities that are extremely difficult to simulate. In the absence of a model capable of simulating such complexities, only a preliminary approximation may be feasible until such time that better models and data bases become available.

Models are highly specialized tools. Competent and experienced personnel are an essential prerequisite to the successful application of simulation models. Whenever a model is applied, the services of knowledgeable, well-trained air pollution engineers, meteorologists and air quality analysts should be engaged. The need for specialists is particularly critical when the more sophisticated models are used or the area being investigated has complicated meteorological or topographic features. A model applied improperly or with inappropriately chosen data can lead to serious misjudgments regarding the source impact or the effectiveness of a control strategy.

The resource demands generated by use of air quality models vary widely depending on the specific application. Resources required are dependent on the nature of the model and its complexity, the detail of the data base, the difficulty of the application, and the amount and level of expertise required. The costs of manpower and computational facilities are also important factors.

4.2 Classes of Models

The air quality modeling procedures discussed in this guide can be categorized into four generic classes: Gaussian, numerical, statistical or empirical, and physical. Within some of these classes a large number models is presented in Appendix A. More detailed information is referred to in some of the individual user's guides. However, additional studies which encompass a wider range of sources and climatic regimes are needed since there is a general lack of reported information on the accuracy of the models. This is true of all classes of models, including widely applied Gaussian models. Whenever possible, the user is encouraged to further validate models recommended in this guide, or other models that may be used.

4.3.1 Point Source Models for Sulfur Dioxide and Particulate Matter (All Averaging Times)

Gaussian models are considered to be state-of-the-art techniques for estimating concentrations of sulfur dioxide and particulate matter. They are the best choice for most point source evaluations. For all point sources two levels of sophistication in the use of models are suggested. The first level is composed of models which can provide a preliminary estimate of concentrations. If it is estimated by the screening technique that a source may cause a concentration that is an unacceptable portion of an allowable air quality increment, then that source should be subjected to a more refined analysis.

For flat terrain situations that have no significant meteorological complexities, there are several standard publications[9-11] and computerized models[12] that can be used for screening. In addition Pooler[13] and Carpenter et al.[14] have discussed simplified techniques for estimating concentrations during inversion-breakup fumigation. Lyons[15] has summarized information and techniques applicable to lake/sea breezes. Huber and Snyder[16,17] and Briggs[18] have presented various techniques applicable to aerodynamic downwash. Several authors[19-22] have outlined techniques that are useful for situations where long-range transport (greater than 50 kilometers) is important. The Valley Model[12,23] is applicable to some complex terrain situations; Egan[24] has summarized information on other applicable techniques. Volume 10 of the Guidelines for Air Quality Maintenance Planning and Analysis,[25] "Procedures for Evaluating Air Quality Impact of New Stationary Sources" has summarized, in a format useful for screening, techniques applicable to both flat terrain and more complex situations; these techniques are recommended for use.

In those cases where a more refined analysis is required and there are no significant meteorological or terrain complexities, the Single Source (CRSTER) Model[12,26] is recommended for use. In some cases specialized data outputs from models comparable to the Single Source (CRSTER) Model may be needed. Where these models* estimate essentially the same concentration as the Single Source (CRSTER) Model, their modified computer codes which provide more useable outputs are acceptable.

If meteorological or terrain complexities cause substantial uncertainties, then a model that is more detailed or more suitable than the Single Source (CRSTER) Model should be applied. No refined, widely available models applicable to complex situations are identified. It is recommended that each complex situation be treated on a case-by-case basis with the assistance of expert advice.

If the data bases required to apply the Single Source (CRSTER) Model are unavailable, or if other refined models applicable to a complex situation do not exist, then it may be necessary to base estimates of source impact and the evaluation of control strategies on only the estimates provided by the screening techniques. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

Models specified here and in the following subsection are also applicable to stationary sources of lead pollutants, provided the pollu-

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*One example of such a model is MULTIMAX. See Moser, J. H. "MULTIMAX: An Air Dispersion Modeling Program for Multiple Sources, Receptors, and Concentration Averages." Shell Development Company, Houston, Texas 77001, December, 1977.

of individual "computational algorithms" exist, each with its own specific applications. While each of these algorithms may have the same generic basis, e.g., Gaussian, it is accepted practice to refer to them individually as models. For example, the Climatological Dispersion Model, the Air Quality Display Model and the Texas Climatological Model are commonly referred to as individual models. In fact, they are all variations of a basic Gaussian model. In many cases the only real difference between models is the degree of detail considered in the input or output data.

Gaussian models are generally considered to be state-of-the-art techniques for estimating the impact of nonreactive pollutants. Numerical models are more appropriate than Gaussian models for multi-source applications which involve reactive pollutants. However, they frequently require more extensive resources and are not as widely applied. Statistical or empirical techniques are frequently employed in situations where incomplete scientific understanding of the physical and chemical processes make the use of a Gaussian or numerical model impractical. Various specific models of these three generic types are recommended in this guideline.

Physical modeling, the fourth generic type, involves the use of wind tunnel or other fluid modeling facilities. This type of modeling may be very useful in evaluating the air quality impact of a source or group of sources in a geographic area limited to a few square kilometers. Where physical modeling is available and applicable, it is recommended. However, physical modeling is a complex process which requires a high level of technical expertise and is beyond the scope of this guide.

In addition to the various classes of models, this guide considers two levels of sophistication. The first level consists of general, relatively simple estimation techniques that provide conservative estimates of the air quality impact of a specific source, or source category. The purpose of such techniques is to eliminate from further consideration those sources that clearly will not cause or contribute to ambient concentrations in excess of NAAQS or allowable concentration increments. Conversely, these techniques can be used to identify those control strategies that have the potential to meet NAAQS and allowable increments. The second level consists of those analytical techniques which provide more detailed treatment of physical and chemical atmospheric processes, require more detailed and precise input data, and provide more specialized concentration estimates. As a result they provide a more refined and, at least theoretically, a more accurate estimate of source impact and the effectiveness of control strategies.

In some cases, the first level of models may be equated with screening techniques to determine if a second or more refined analysis is required. However, while the use of screening techniques followed by a more refined analysis is desirable, there are situations where the screening techniques are practically and technically the only viable option for estimating source impact and evaluating control strategies. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3 Recommended Models

To meet the need for consistency identified in Section 2, selected point source and multi-source models applicable to specific pollutants and averaging times are recommended in this subsection. Ideally, air quality models that are recommended should meet prescribed standards of performance for particular applications and should be subjected to specific validation procedures. However, there are no generally accepted standards of performance and validation procedures (see pp. 41-43). The models recommended in this guideline are simply those which are (1) representative of the state-of-the-art for atmospheric simulation models and (2) most readily available to air pollution control agencies.

Nevertheless, the need for information on the accuracy of these models exists. Limited information on the accuracy of recommended tants can be assumed to behave as a gas.

4.3.2 Multi-Source Models for Sulfur Dioxide and Particulate Matter (Annual Average)

Due to the complexity of most multi-source situations and the wide acceptability of several models, a screening process is not generally conducted. If a preliminary assessment of the adequacy of a control strategy is desired, the Rollback Model[27] may be used. However, in most cases such a screening does not constitute an adequate control strategy demonstration.

The Climatological Dispersion Model (CDM/CDMQC),[12,28,29] the Air Quality Display Model (AQDM)[30] and the Texas Climatological Model (TCM)[31] are recommended for evaluating the long-term impact of urban multi-source complexes. In regions with major meteorological or topographic complexities, more detailed or suitable models may be used. If the meteorological or topographic complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.3 Multi-Source Models for Sulfur Dioxide and Particulate Matter (Short-Term Averages)

As noted in the preceding subsection, a Rollback Model may be used for the preliminary assessment of a control strategy. The Gaussian-Plume Multiple-Source Air Quality Algorithm (RAM)[12,32] is recommended for evaluating the impact of multi-source complexes on air quality averaged over short-term periods. Versions of this model are applicable to both urban and rural situations. The Texas Episodic Model (TEM)[33] may be used if the data bases required to apply RAM are unavailable. Also, if the resources required to operate RAM or TEM are not available, then CDMQC or AQDM may be used to estimate short-term concentrations of SO_2 and particulate matter. CDMQC and AQDM incorporate procedures, such as discussed by Larsen,[34] to estimate 3-hour and 24-hour average concentrations from annual average concentration estimates. Such statistical techniques are valid only in urban, multi-source areas and should not be used in situations dominated by large point sources.

In regions with major meteorological or topographic complexities, more detailed or suitable models may be used. If the meteorological or topographic complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.4 Models for Carbon Monoxide

The recommendations for point source screening procedures and models are also applicable to evaluate point sources of carbon monoxide (CO). The models, procedures and requirements described in Volume 9 of the Guidelines for Air Quality Maintenance Planning and Analysis,[35] "Guidelines for Review of the Impact of Indirect Sources on Ambient Air Quality," are recommended for screening all sources of CO which fulfill the definition of an indirect source. The indirect source guideline is based on the use of HIWAY[12,36] and other simple dispersion techniques. It is acceptable to apply these techniques independent of the indirect source guideline, if it is found that the guideline does not adequately consider a wide enough set of circumstances. If a preliminary assessment of the adequacy of a control strategy applicable to an urban area is desired, the Rollback Model may be used.

Specific refined modeling techniques are not recommended here. Situations that require more refined techniques should be considered on a case-by-case basis with the use of expert consultation. If a suitable model is available and the data and technical competence required for this model are available, it may be used. Examples of such refined techniques are APRAC-1A[12,37] and its revision, APRAC 2.[38] However, if a region-wide analysis is necessary and the complexities are such th the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.5 Models for Nitrogen Dioxide (Annual Average)

The recommendations for point source screening techniques and models are also applicable to evaluate point sources of nitrogen oxides (NO_x) under limited circumstances. The circumstances require an assumption that all NO_x is emitted in the form of NO_2 or is converted to NO_2 by the time it reaches the ground and that NO_2 is a nonreactive pollutant.

For sources located where atmospheric photochemical reactions are significant, a Rollback Model may be used as a preliminary assessment to evaluate the control strategies for multiple sources (mobile and stationary) of NO_x. Another acceptable screening technique for multiple sources is to make an assumption similar to that required for point sources and then to use a model for nonreactive pollutants, such as CDM.

Specific refined modeling techniques are not recommended here. Situations that require more refined techniques should be considered on a case-by-case basis with the use of expert consultation. If a suitable model is available and the data and technical competence required for this model are available, it may be used to estimate average concentrations of NO_2. However, if a region-wide analysis is necessary and the complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.4 Special Situations

Models with a wide applicability are not generally available for dealing with long-range transport, deposition, wind-blown particulate matter, unique topographic or meteorological circumstances, and nontypical sources such as open burning.[39] Thus, with proper support and documentation, the Regional Administrator may determine that a particular model, not specifically recommended here, is appropriate for a special situation. Examples of these situations are discussed for clarification.

The administration of the national prevention of significant deterioration policy may require that the air quality impact of a source be estimated for great distances downwind. It is uncertain, however, what the impact of sources at such great distances is. Knowledge of the dispersion coefficients for air quality models* becomes increasingly tenuous with downwind distance. Plume transport beyond about 50 kilometers usually requires substantial travel time. As travel time increases, diurnal variations in meteorological conditions and movement of weather systems are more likely to alter plume trajectories and dispersion characteristics. Even though the impact at greater than 50-100 kilometers may be relatively small, the impact can still be significant for large sources and for situations where the merging of plumes occurs. Techniques are available to examine these impacts, but only limited experience in their use is currently available. If it appears that a large source (for example, a 2000-MW coal-fired power plant meeting new source performance standards) may constitute a threat to ambient-air quality standards or prevention of significant deterioration increments at large distances, that source should be considered on a case-by-case basis with available techniques.[19-22,25]

The models presented in this guide for estimating ambient concentrations of suspended particulate matter assume that the particles disperse as a gas and emanate from well-defined sources. Unfortunately,

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*Vertical dispersion in these situations is more appropriately treated with numerical models. There are also inherent difficulties with Gaussian models in cases where plume depletion through chemical and physical removal processes is significant. Plume depletion would normally be significant at distances beyond about 50 kilometers for tall stacks under conditions of appreciable vertical mixing, and at considerably shorter distances for near-ground sources.

In many areas, particularly where the air quality standards are not being attained, these assumptions may not hold. Windblown dust, reentrained street dust, dry-land farming, and raw-material handling operations, all of which are often referred to as fugitive dust sources, can be significant sources of particulate matter.[40] EPA has several on-going studies concerned with fugitive sources of dust; however, the rate and distribution of particulate emissions from these sources is not yet fully known. As a result, a widely applicable model for routinely estimating particulate concentrations attributable to fugitive sources is not available.[41]

Terrain dominated flows and wakes that develop in the vicinity of pollutant sources are involved in many situations.[16-18,23,24] The basic theoretical principles of these flows are generally understood. However, the variety of terrain features is so great and the spectrum of atmospheric circumstances so broad that no generally applicable model is available that can adequately deal with the range of conditions encountered.

EPA will provide guidance on data bases and assessment procedures to deal with special situations as the results of on-going field investigations and research on these matters become available.

5.0 DATA REQUIREMENTS

It is essential that appropriate source and meteorological data be used with any recommended model. Such data, and related procedures for estimating these data, constitute an integral part of the model. It is often overlooked that few of the variables input to a model are directly measured or routinely available. Submodels must appropriately convert the available source and meteorological data to a form that the air quality model can accept. It is also important that a variety of load/emissions conditions, and that a wide range of meteorological conditions based on several years of data, be considered in evaluating control strategies and in determining source impact for new source reviews, including prevention of significant deterioration. In addition, there is a need to judiciously choose receptor sites and to specify background air quality. This section identifies requirements for these data bases.

5.1 Source Data

Sources of pollutants generally can be classified as point, line and area sources. Point sources are generally considered to be those that emit a substantial amount of an air pollutant, e.g., 50 tons per year, from a stack or group of stacks. Line sources are generally confined to roadways and streets along which there are well-defined movements of motor vehicles. Area sources include the multitude of minor sources with individually small emissions that are impractical to consider as separate point or line sources. Area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within each grid square. Descriptions of individual models should be referenced for specific emissions inventory requirements.

For situations involving one or a few point sources the following are minimum requirements for new source review and control strategy evaluations. Design process rate or design load conditions must be considered in determining pollutant emissions. Other operating conditions that may result in high pollutant concentrations should also be identified.* A range of operating conditions, emission rates, and physical plant characteristics based on the most recently available data, should be used in the model with the multiple years of meteorological data (see Section 5.2) to estimate the source impact. The following example (power plant) typifies the kind of data on source characteristics and operating conditions that are required:

1. Plant layout. The connection scheme between boilers and stacks, and the distance and direction between stacks, building parameters (length, width, height, location and orientation relative to stacks) for plant structures which house boilers, control equipment, etc.

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*Malfunctions which may result in excess emissions are not considered to be a normal operating condition. They generally should not be considered in determining allowable emissions. However, if the excess emissions are the result of poor maintenance, careless operation, or other preventable condition, it may be necessary to consider them in determining source impact.

2. Stack parameters. For all stacks, the stack height and diameter (meters), and the temperature (K) and volume flow rate (actual cubic meters per second) or exit gas velocity (meters per second) for operation at 100 percent, 75 percent and 50 percent load.

3. Boiler size. For all boilers, the associated megawatts and pounds of steam per hour, and the design and/or actual fuel consumption rate for 100 percent load for coal (tons/hour), oil (barrels/ hour), and natural gas (thousand cubic feet/hour).

4. Boiler parameters. For all boilers, the percent excess air used, the boiler type (e.g., wet bottom, cyclone, etc.), and the type of firing (e.g., pulverized coal, front firing, etc.).

5. Operating conditions. For all boilers, the type, amount and pollutant contents of fuel, the total hours of boiler operation and the boiler capacity factor during the year, and the percent load for winter and summer peaks.

6. Pollution control equipment parameters. For each boiler served and each pollutant affected, the type of emission control equipment, the year of its installation, its design efficiency and mass emission rate, the date of the last test and the tested efficiency, the number of hours of operation during the latest year, and the best engineering estimate of its projected efficiency if used in conjunction with coal combustion; data for any anticipated modifications or additions.

7. Data for new boilers or stacks. For all new boilers and stacks under construction and for all planned modifications to existing boilers or stacks, the scheduled date of completion, and the data or best estimates available for items 1 through 6 above following completion of construction or modification.

Typically for line sources, such as streets and highways, data are required on the width of the roadway and its center strip, the types and amounts (grams per second per meter) of pollutant emissions, the number of lanes, the emissions from each lane and the height of emissions. The location of the ends of the straight roadway segments must be specified in appropriate grid coordinates. More detailed information and data requirements for modeling mobile sources of pollution are provided in the guideline[35] on indirect sources.

For multi-source urban situations, detailed source data are often impractical to obtain. In these cases, source data should be based on annual average conditions. Area source information required are types and amounts of pollutant emissions, the physical size of the area over which emissions are prorated, representative stack height for the area, the location of the centroid or the southwest corner of the source in appropriate grid coordinates. If the model accepts data on area-wide diurnal variations in emissions, such as those estimated by emissions models which are based on urban activity levels and other factors, those data should be used.

In cases where the required source data are not available and cannot be obtained, the data limitation should be identified. Due to the uncertainties associated with such a limitation the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified until such time that a better data base becomes available.

For control strategy evaluations the impact of growth on emissions should be considered for the next 10-20 year period. Increases in emissions due to planned expansion of the sources considered or planned fuel switches should be identified. Increases in emissions at each source which may be due to planned expansion of the sources considered or planned fuel switches should be identified. Increases in emissions at each source which may be associated with general industrial/commercial/residential expansion in multi-source urban areas should also be considered. However, for new source reviews, the impact of growth on emissions should generally be considered for the period prior to the start-up date for the source.* Such changes in emissions should consider increased area source emissions, changes in existing point source emissions which were not subject to preconstruction review, and emissions due to sources with permits to construct, but have not yet started operation.

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*A new source may result in specific and well defined secondary emissions which can be accurately quantified. Secondary emissions are those resulting from operation of the source, but not directly emitted by the source, e.g., emissions from shipping at a port terminal. The reviewing authority should consider such secondary emissions in determining whether the source would cause or contribute to a violation of the NAAQS. However, since EPA's authority to perform indirect source review relating to parking-type facilities has been restricted by statute, consideration of parking-type secondary impacts is not required.

source, (2) the area of maximum impact of nearby sources, and (3) the area where all sources combine to cause maximum impact. It may be necessary to identify these locations through a trial and error analysis.

If the point source is located in or near an urban multi-source area, there are several possibilities for estimating the impact of all other sources. If a comprehensive air monitoring network is available, it may be possible to rely entirely on the measured data. It is necessary that the network include monitors judiciously located so as to measure air quality at the locations of the point source's maximum impact and locations of the highest concentrations in the area. If the point source is not yet operating, its calculated impact can be added to these measured concentrations. If the source already exists and is contributing to the measured concentrations, its calculated contribution should be subtracted from the measured values to estimate the concentration caused by other man-made sources and by background.

If the monitored data are inadequate for such an analysis, then multi-source models can be used to establish the impact of all other sources. These models should be used for appropriate pollutants and averaging times to identify concentrations at the times and locations of maximum point source impact. The times and locations of maximum impact due to all other sources must also be identified. If a model is not available for the appropriate averaging times, statistical techniques can be used with an appropriate model to extrapolate from one averaging time to another. All statements in this guide regarding the data requirements and validity of air quality models are applicable to analyses of this type.

For control strategy evaluations, the impact of growth on area-wide emissions and on concentrations caused by nearby sources should also be considered for the next 10-20 year period. To determine concentrations in future years, existing air quality should be proportionately adjusted by the anticipated percent change in emissions in the vicinity of individual oring sites. However, for new source reviews, changes in existing air quality should generally be considered for the period prior to the start-up date of the source (see Section 5.1).

6.0 MODEL VALIDATION/CALIBRATION

Any application of an air quality model may have deficiencies which cause estimated concentrations to be in error. When practical to obtain a measure of confidence in the estimates, they should be compared with observed air quality data and their validity determined.

The model validation process* consists of a series of analytical steps: (1) Comparing estimated concentrations with measured air quality data, (2) determining the cause of discrepancies, (3) correcting and improving data bases, (4) modifying the model (if necessary) in a manner that provides a better mathematical representation of physical reality, and (5) documenting, for others, the accuracy of the estimates. Statistical methods available for validation of models include skill scores, contingency tables, correlation analyses, time series and spatial analyses, and others. If evaluation by one or more statistical techniques indicates that the concentration estimates are not a satisfactory representation of observed concentrations, then it is likely that one or both of the following problems exist: the source, meteorological or air quality data are not appropriate, reliable and complete; or the model itself is inadequate for the area under consideration.

The availability and accuracy of the input data significantly influence the accuracy of the model estimates. The source factors that have the greatest impact on the accuracy of the estimates are the

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*There is a clear need for specific and uniform validation procedures and for standards of performance. The feasibility of specifying such procedures and standards for air quality models is being studied by EPA. However, for the present time, the generalized recommendations presented in this section are suggested for use.

maximum concentrations occur, both short- and long-term. The receptors selected must allow sufficient spatial detail and resolution so that the location of the maximum or highest, second-highest concentration is identified.

The receptor sites in the vicinity of large point sources at which maximum concentrations are likely to occur can be identified by (1) estimating concentrations for a sufficiently dense array of receptors to identify concentration gradients and (2) subsequently refining the location of the maximum by estimating concentrations for a finer array of receptors in the general areas of maximum concentration. Another technique is to use a simple model such as PTMAX[12] in combination with joint frequency distributions of wind speed, wind direction and stability to identify the downwind distance and direction at which the highest concentrations are most likely to occur. However, other areas around the source(s) should not be ignored, particularly if they are on elevated terrain. In addition a receptor should be specified at any site where a monitor is located.

4 Background Air Quality

To adequately assess the significance of the air quality impact of a source, background concentrations must be considered. Background air quality relevant to a given source includes those pollutant concentrations due to natural sources and distant, unidentified man-made sources. For example, it is commonly assumed that the annual mean background concentration of particulate matter is 30-40 μg/m³ over much of the Eastern United States.[43] Typically, air quality data are used to establish background concentrations in the vicinity of the source under consideration. However, where the source is not isolated, it may be necessary to use a multi-source model to establish the impact of all other nearby sources during dispersion conditions conducive to high concentrations.

If the point source is truly isolated and not affected by other readily identified man-made sources, two options for determining background concentrations from air quality data are available. The preferable option is to use air quality data collected in the vicinity of the source to determine mean background concentrations for the averaging times of interest when the point source itself is not impacting on the monitor. The second option applies when no monitors are located in the vicinity of the source. In that case, average measured concentrations from a "regional" site can be used to establish a background concentration.

For the first option it is a relatively straightforward effort to identify an annual average background from available air quality data. For shorter averaging times, background concentrations are determined by the following procedure. First, meteorological conditions are identified for the day and similar days when the highest, second-highest estimated concentration due to the source occurs. Then the average background concentration on days with similar meteorological conditions is determined from air quality measurements. The background for each hour is assumed to be an average of hourly concentrations measured at sites outside of a 90° sector downwind of the source. The 1-hour concentrations are then averaged to obtain the background concentration for the averaging time of concern.

If air quality data from a local monitoring network are not available, then monitored data from a "regional" site may be used for the second option. Such a site should characterize air quality across a broad area, including that in which the source is located. The technique of characterizing meteorological conditions and determining associated background concentrations can then be employed.

If a small number of other identifiable sources are located nearby, the impact of these sources should be specifically determined. The background concentration due to natural or distant sources can be determined using procedures already described. The impact of the nearby sources must be summed for locations where interactions between the effluents of the point source under consideration and those of nearby sources can occur. Significant locations include (1) the area of maximum impact of the point

5.2 Meteorological Data

For a dispersion model to provide useful and valid results, the meteorological data used in the model must be representative of the transport and dispersion conditions in the vicinity of the source that the model is attempting to simulate. The representativeness of the data is dependent on (1) the proximity of the meteorological monitoring site to the area under consideration, (2) the complexity of the terrain in the area, (3) the exposure of the meteorological monitoring site and (4) the period of time during which the data are collected. The representativeness of the data can be adversely affected by large distances between the source and receptors of interest and valley-mountain, land-water, and urban-rural characteristics of the area.

For new source review and control strategy evaluation, the meteorological data required as a minimum to describe transport and dispersion in the atmosphere are wind direction, wind speed, atmospheric stability, mixing height or related indicators of atmospheric turbulence and mixing. Site-specific data are preferable to data collected off-site. The availability of such meso- and micro-meteorological data collections permits more detailed meteorological analyses and subsequent improvement of model estimates. Local universities, industry, pollution control agencies and consultants may be sources of such data. The parameters typically required can also be derived from routine measurements by National Weather Service stations. The data are available as individual observations and in summarized form from the National Climatic Center, Asheville, N. C. Descriptions of individual models should be referred to for specific meteorological data requirements. Many models require either hourly meteorological data or annual stability wind roses.

It is preferable for the meteorological data base used with the air quality models to include several years of data. Such a multi-year data base allows the consideration of variations in meteorological conditions that occur from year to year. The exact number of years needed to account for such variations in meteorological conditions is uncertain and depends on the climatic extremes in a given area. Generally five years[42] yields an adequate meteorological data base. However, if long-term data records are not available, it may be necessary to limit the modeling and subsequent analyses to a single year of meteorological data. The use of one year of data might also be justified if the climatological representativeness of that data can be demonstrated. A longer record from a nearby National Weather Service site could be used to check for representativeness.

The number of National Weather Service stations for which multiple years of hourly weather data are available is increasing significantly. Several EPA offices have ordered such data for a large number of stations. It is clear that more detailed analyses than previously considered for SIP evaluations and new source review are necessary. Thus, for areas where meteorological conditions are adequately represented by weather stations, the use of multiple years of meteorological data appears to be viable and justified.

Where representative meteorological observations are not available, the concentration estimates may be limited to consideration of worst case conditions. An analysis of worst case conditions should be based on reasonable interpretations of climatological data and should consider such critical plume characteristics as looping, coning, limited mixing, fumigation, aerodynamic downwash and plume impaction on terrain. Due to the uncertainties of this approach, the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified until such time that a better data base becomes available.

5.3 Receptor Sites

A receptor site is a location for which an air pollution concentration is estimated. The choice of locations for receptor sites significantly affects the evaluation of source impact and control strategy effectiveness. It is most important to identify the location where accuracy and completeness of the (1) emission data, (2) physical plant parameters, and (3) site coordinates of the sources. Often the validation will reveal deficiencies in the emission inventory, which can be corrected to improve the accuracy of the model estimates. The accuracy of the concentration estimates is also affected by the location and exposure of the instrumentation used for obtaining the meteorological data and the overall representativeness and completeness of these data. Similarly, the validation of the dispersion model is affected by the location, exposure and representativeness of the air quality sampling sites and by the accuracy and completeness of the air quality data itself. These data should be available for the same averaging times as the concentration estimates and should describe the spatial variation of pollutant concentrations across the area. If the air quality data are in any way unsuitable or incorrect, the accuracy of the dispersion model estimates cannot be determined.

The following factors most frequently cause a model to be considered inadequate or inappropriate for a given area: (1) The model is applied to an area with complex or unique terrain or meteorological conditions; (2) the source emissions vary markedly or irregularly with time; (3) the pollutant is subject to major or highly variable atmospheric chemical reactions or removal processes; (4) the model is applied to pollutants with characteristics other than those considered in its development. If any of these circumstances are encountered, it may be necessary to select a more appropriate model or appropriately modify the model being used.

When any analytical technique is employed, the analyst is responsible for recognizing and quantifying limitations in the accuracy, precision and sensitivity of the procedure. Thus, in all applications of models an effort should be made to identify the reliability of the model estimates for that particular area or similar areas and to deter- [illegible] the magnitude and sources of error associated with the use of the model. In addition, sensitivity analyses are useful for determining the effect of variations or uncertainties in the data bases on the range of likely concentrations. Such information may be very useful in determining source impact and evaluating control strategies. Where possible, information on sensitivity should be made available by the modeler.

Due to limitations of the data base, lack of scientific knowledge or limitations on time and resources, it may not always be possible to perform a thorough and complete model validation. Thus, in some situations, it has been necessary to revert to calibration of the model. Calibration of a model is the process of identifying systematic errors and applying a correction factor. In many cases this involves the application of regression analysis or other statistical techniques to adjust model estimates in order to increase agreement with measured data.

Calibration of long-term multi-source models is a widely used procedure. It is acceptable provided that reasonable resources have been expended to validate the model, e.g., the five steps listed at the beginning of this section. Limitations imposed by statistical theory on the reliability of the calibration process for long-term estimates have been identified.[44] In some cases, though, calibration may be the only alternative for improving the accuracy of estimated concentrations and the control strategy evaluation. However, if the model accounts for less than 50 percent of the variation of measured concentrations, it is doubtful that there is justification for using the model.

Calibration of short-term models has not been widely performed and is subject to a greater amount of error and misunderstanding. There have been attempts by some to compare short-term estimates and measurements on an event-by-event basis and then to calibrate the model with results of the comparison. This approach is severely limited by uncertainties in source and meteorological data and thus one's ability t precisely estimate the concentration at an exact location for a specific increment of time. These uncertainties make attempts to calibrate a short-term model questionable. As a result, it appears that the most reliable direct comparison between estimated and measured short-term concentrations involves the upper percentile of the respective frequency distributions. Even here, considerable variation may be found from site-to-site and plant-to-plant. In such comparisons[45,46] for one basic Gaussian point source model it was found that short-term estimates of highest concentrations are generally accurate within a factor of two. This accuracy is consistent with the empirical basis[47,48] for these models. However, in general, estimates which are both too high and too low may be expected.

7.0 REFERENCES*

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Glossary of Selected Terms

Air Quality - Ambient pollutant concentrations and their temporal and spatial distributions.

Algorithm - A specific mathematical calculation procedure.

Background - Ambient pollutant concentrations due to natural sources and distant, unidentified man-made sources.

Calibration - An adjustment applied to concentration estimates, based on a comparison with measured air quality data, in order to improve the accuracy of the model.

Computer code - A set of statements that comprise a computer program.

Model - A quantitative or mathematical representation or simulation which attempts to describe the characteristics or relationships of physical events.

Receptor - A location at which ambient air quality is measured or estimated.

Rollback - A simple model that assumes that if emissions from each source affecting a given receptor are decreased by the same percentage, ambient air quality concentrations decrease proportionately.

Screening Procedure - A relatively simple analysis technique to determine if a given source is likely to pose a threat to air quality.

Validation - Determination of the reliability of a model by comparing the model estimates with measured air quality data.

Appendix A

~~Summaries* of Recommended~~
Air Quality Models

A.1 AIR QUALITY DISPLAY MODEL (AQDM)

Reference: TRW Systems Group. "Air Quality Display Model." Prepared for National Air Pollution Control Administration, DHEW, U.S. Public Health Service, Washington, D.C., November 1969, (NTIS PB 189194).

Abstract: AQDM is a climatological steady state Gaussian plume model that estimates annual arithmetic average sulfur dioxide and particulate concentrations at ground level in urban areas. A statistical model based on Larsen[1] is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

For both point and area sources:

$$\chi = \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{5} \phi_{k\ell m}\, \chi_{k\ell m}$$

where:

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{2Q}{\sqrt{2\pi}\,\sigma_z\, u_\ell} \left(\frac{c-y}{c}\right) \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{for } x \leq x_L$$

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{Q}{u_\ell L} \left(\frac{c-y}{c}\right) \quad \text{for } x \geq 2x_L$$

linear interpolation for $x_L < x < 2x_L$

x_L defined by $\sigma_z(x_L) = 0.47L$

y = crosswind distance between receptor and sector k centerline

c = sector width at receptor location

$\sigma_z(x) = ax^b + c$; a,b,c = functions of stability class
a,b,c for neutral conditions split into
$x > 1000$m case and $x \leq 1000$m case.

Q = emission rate (g/s)

H = plume height (m)

u = wind speed (m/s)

ϕ = relative frequency of occurrence from stability wind rose

σ_z = vertical standard deviation of plume concentrations (m)

x = downwind distance (m)

a. Source-Receptor Relationship

Arbitrary location and stack height for each point source
Arbitrary location and size for each area source
Up to 225 receptors located on uniform rectangular grid
Up to 12 user-specified receptor locations
Unique release height for each point, area source
Unique separation for each source-receptor pair
Receptors at ground level
No terrain differences between source and receptor

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*Summaries presented in this appendix are largely based on similar information summarized by J. J. Roberts (Ed.) in "Report to the U.S. EPA of the Specialists' Conference on the EPA Modeling Guidelines," Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1977.

Appendix A

~~Summaries* of Recommended~~ Air Quality Models

A.1 AIR QUALITY DISPLAY MODEL (AQDM)

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Equations:

For both point and area sources:

$$\chi = \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{5} \phi_{k\ell m} \, \chi_{k\ell m}$$

where:

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{2Q}{\sqrt{2\pi}\,\sigma_z u_\ell} \left(\frac{c-y}{c}\right) \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{for } x \leq x_L$$

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{Q}{u_\ell L} \left(\frac{c-y}{c}\right) \qquad \text{for } x \geq 2x_L$$

linear interpolation for $x_L < x < 2x_L$

x_L defined by $\sigma_z(x_L) = 0.47L$

y = crosswind distance between receptor and sector k centerline

c = sector width at receptor location

$\sigma_z(x) = ax^b + c$; a,b,c = functions of stability class
a,b,c for neutral conditions split into
$x > 1000$m case and $x \leq 1000$m case.

Q = emission rate (g/s)

H = plume height (m)

u = wind speed (m/s)

ϕ = relative frequency of occurrence from stability wind rose

σ_z = vertical standard deviation of plume concentrations (m)

x = downwind distance (m)

a. Source-Receptor Relationship

Arbitrary location and stack height for each point source
Arbitrary location and size for each area source
Up to 225 receptors located on uniform rectangular grid
Up to 12 user-specified receptor locations
Unique release height for each point, area source
Unique separation for each source-receptor pair
Receptors at ground level
No terrain differences between source and receptor

---

*Summaries presented in this appendix are largely based on similar information summarized by J. J. Roberts (Ed.) in "Report to the U.S. EPA of the Specialists' Conference on the EPA Modeling Guidelines," Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1977.

b. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
Each source treated by effective single point source approximation
No temporal variation allowed

c. Chemical Composition

Treats one or two inert pollutants simultaneously

d. Plume Behavior

Use of the Briggs plume rise formulation is recommended
Calculations based on single arbitrary values of stack diameter, stack gas exit velocity and stack gas temperature for each point source
No plume rise calculated for area sources
Does not treat fumigation or downwash
If stack height plus plume rise is greater than mixing height, ground level concentration assumed equal to zero

e. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes

No variation in wind speed with height
Constant, uniform (steady-state) wind assumed

f. Vertical Wind Speed

Assumed equal to zero.

g. Horizontal Dispersion

Climatological approach
Uniform 22.5° wide plume assumed
Frequency of occurrence interpolated between sector centerlines
Averaging times from 1 month to 1 year or longer

h. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner[2]
Neutral stability split internally into 60% day, 40% night
Dispersion coefficients from Pasquill and Gifford
Neutral dispersion coefficients used for stable class
No provision for variations in surface roughness

i. Chemistry/Reaction Mechanism

No provision for treatment

j. Physical Removal

No provision for treatment

k. Background

Input single constant background value for each pollutant

l. Boundary Conditions

Lower boundary (ground): perfect reflection
Upper boundary (mixing height): no effect until $\sigma_z \geq 0.47L$ (this occurs at $x = x_L$) For $x_L < x < 2x_L$, σ_z is linearly interpolated between its value at x_L and its value at $2x_L$

m. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Emission rate - not correlated with any other factor
Non-sequential (climatological) limited correlation
Mixing height adjusted according to stability class:
  Class A - 1.5 times the afternoon climatological value
  Classes B, C, and D(day) - equal to the afternoon climatological value
  Class E - 100 meters

n. Validation/Calibration

Calibration option available
Validation is routinely done in most applications. Thus a large number of validations have been carried out, although few appear in the literature. This model, with the Briggs plume rise formulas, typically estimates concentrations ranging from nearly correct to a factor of two high.

o. Output

1 month to 1 year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen procedure (typically 1 - 24 hours)
  Assumes
  (1) lognormal concentration distribution,
  (2) power law dependence of median and maximum concentrations on averaging time
Up to 225 gridded receptor locations, 12 arbitrary locations
Individual point, area source culpability list for each receptor

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Useable for urban areas only
In general, CDM/CDMQC is preferred over AQDM

A.2 APRAC-1A

Reference: Mancuso, R. L. and F. L. Ludwig. "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program." Publication No. EPA-650/3-73-001 (NTIS PB 213091), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1972.

Abstract: APRAC is a model which computes hourly average carbon monoxide concentrations for any urban location. The model calculates contributions from dispersion on various scales: extraurban, mainly from sources upwind of the city of interest; intraurban, from freeway, arterial, and feeder street sources; and local, from dispersion within a street canyon. APRAC requires an extensive traffic inventory for the city of interest.

Equations:

Extraurban - $x_e = \frac{5.15 \times 10^{-11} F}{uL}$

F = annual fuel consumption within 22.5° sector extending from 32 km to 1000 km upwind of receptor.

Intraurban - $x_{ij} = \frac{0.8Q_i}{u\,a_{ij}} \; \frac{x_{i+1}^{\,1-b_{ij}} - x_i^{\,1-b_{ij}}}{1-b_{ij}}$

Until this expression equals the "box model value"

$$\frac{Q_i}{uL}(x_{i+1} - x_i)$$

Thereafter the box model formula is used.

i = upwind area segment label

j = stability class label

a_{ij} and b_{ij} from $(\sigma_z)_{ij} = a_{ij}\, x^{b_{ij}}$ for x within segment i

Street Canyon - Lee side $x_L = \frac{KQ_s}{(u+0.5)[(x^2+z^2)^{1/2} + L_0]}$

Windward side $x_W = \frac{KQ_s(H-z)}{(u+0.5)\,WH}$

Intermediate wind direction(less than ± 30° from street (direction)

$$x_L = \frac{1}{2}(x_L + x_W)$$

where:

x = horizontal distance from traffic lane (m)

z = height above pavement (m)

K = constant = 7

L_0 = vehicle size = 2m

u = rooftop wind speed (m/s)

Q_s = CO emission rate (g/s-m)

W = Street width (m)

H = average building height = 38.8 m

a. Source-Receptor Relationship

User specifies set of traffic links (line sources) by providing link end points, road type, daily traffic volume

The traffic links may have arbitrary length and orientation

Off-link traffic allocated to two mile square grid

Link traffic emissions are aggregated into a receptor oriented area source array

The boundaries of the area sources actually treated are (1) arcs at radial distances from the receptor which increase in geometric progression, (2) the sides of a 22.5° sector oriented upwind for distances greater than 1000 m, and (3) the sides of a 45° sector oriented upwind for distances less than 1000 m.

A similar area source array is established for each receptor

Sources assumed at ground level

Up to 10 receptors

Receptors at ground level

Receptor locations are arbitrary

Four internally defined receptor locations on each user-designated street are used in a special street canyon sub-model

b. Emission Rate

Daily traffic volume for each link and off-link grid square is input and modified by various factors to produce hour-by-hour emissions from each link

Link emissions aggregated as described above: sector area source contributions obtained analytically

Off-link traffic emissions on the two mile square grid are added into sector area sources

In street canyon sub-model, a separate hourly emission rate is provided by user for the link in question

c. Chemical Composition

Treats one inert pollutant

d. Plume Behavior

Does not treat plume rise

Does not treat fumigation or downwash except in street canyon sub-model

In street canyon sub-model, a helical circulation pattern is assumed

e. Horizontal Wind Field

Hourly wind speed and direction in tens of degrees are input

No variation of wind speed or direction with height

Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero except in street canyon sub-model

Helical circulation assumed by street canyon sub-model

g. Horizontal Dispersion

Sector averaging uniform distribution within sectors

22.5° sectors beyond 1 km

45.0° sectors within 1 km

h. Vertical Dispersion

Semi-empirical/Gaussian plume
6 stability classes; stability class determined internally from user-supplied meteorological data [modified from Turner[2]]
Dispersion coefficients from McElroy and Pooler[3], modified using information in Leighton and Ditmar[4]
No adjustments made for variations in surface roughness
Downwind distance variation of σ_z assumed to be ax^b for purposes of doing analytic integration
In street canyon sub-model, empirical function of wind speed and street width and direction is used

i. Chemistry/Reaction Mechanism

Single inert pollutant

j. Physical Removal

Not treated

k. Background

Box model used to estimate contribution from upwind sources beyond 32 km based on wind speed, mixing height, annual fuel consumption
In street canyon sub-model, contribution from other streets is included in background

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection; ignores effect until concentration equals that calculated using box model; uses box model (uniform vertical distribution) thereafter
Mixing height determined from morning radiosonde data as follows:
midnight to dawn: constant at pre-dawn value obtained using minimum urban temperature
dawn to sunset: afternoon maximum temperature used to obtain maximum height; hourly values obtained from surface temperature variations
sunset to midnight: linear interpolation with time

m. Emission and Meteorological Correlation

Emissions a function of hour of the day and day of the week
Meteorological parameters are functions of hour of the day

n. Validation/Calibration

No calibration option provided
One validation study documented by authors of the model

o. Output

Hourly concentration values at each receptor
Frequency distribution based on hourly values can be obtained

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Limited to urban areas
No means for including point sources

A.3 CLIMATOLOGICAL DISPERSION MODEL (CDM)

References: Busse, A. D. and J. R. Zimmerman. "User's Guide for the Climatological Dispersion Model." Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1973.

Brubaker, K. L., P. Brown, and R. R. Cirillo. "Addendum to User's Guide for Climatological Dispersion Model." Publication No. EPA-450/3-77-015, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May 1977.

Abstract: CDM is a climatological steady-state Gaussian plume model for determining long-term (seasonal or annual) arithmetic average pollutant concentrations at any ground-level receptor in an urban area. An expanded version (CDMQC) includes a statistical model based on Larsen[1] to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

$$\chi_{point} = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{\ell=1}^{6} \sum_{m=1}^{6} Q_n \phi_{kn\ell m} S_{\ell m}(\rho_n)/\rho_n$$

$$\chi_{area} = \frac{16}{2\pi} \int \left[\sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m} S_{\ell m}(\rho) \right] d\rho$$

$$\text{with } q_k(\rho) = \int_{\text{sector } k} Q(\rho,\theta) d\theta$$

$$S_{\ell m}(\rho) = \frac{2}{\sqrt{2\pi}\, \sigma_z u_\ell} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \exp\left[-\frac{0.692\, \rho}{u_\ell T_{1/2}}\right]$$

$$\text{for } \sigma_z \leq 0.8L$$

$$S_{\ell m}(\rho) = \frac{1}{u_\ell L} \exp\left[-\frac{0.692\, \rho}{u_\ell T_{1/2}}\right] \text{ for } \sigma_z > 0.8L$$

$\sigma_z = a\rho^b$; a,b = functions of stability class (m) and downwind distance (ρ) - three ranges of distance used: 100-500 m, 500-5000 m, and 5000-50,000 m

k_n = wind sector appropriate to the nth point source

Q_n = emission rate of the nth point source (g/s)

ρ_n = distance from the receptor to the nth point source (m)

q_k = emission rate of the area source per unit area and unit time (g/s-m²)

ρ = distance from the receptor to an infinitesimal area source (m)

θ = angle relative to polar coordinates centered on the receptor

ℓ = index identifying the wind speed class

m = index identifying the class of the Pasquill stability category

$\phi(k,\ell,m)$ = joint frequency function

z = height of receptor above ground level (m)

u_ℓ = representative wind speed (m/s)

h = effective stack height of source distribution, i.e., the average height of area source emissions in the kth wind direction sector at radial distance ρ from the receptor (m)

L = the afternoon mixing height (m)

$T_{1/2}$ = assumed half life of pollutant hours (s)

a. Source-Receptor Relationship

Arbitrary location for each point source
Arbitrary location for each receptor
Area sources input as multiples of a user-defined unit size
Arbitrary release heights for point and area sources
Actual separation between each source-receptor pair used
Receptors are at ground level
No terrain differences between source/receptor

b. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
area integrations are done numerically one 22.5° sector at a time; sampling at discrete points defined by specific radial and angular intervals on a polar grid centered on the receptor
Day/night variations in emissions, same variation assumed for all sources

c. Chemical Composition

Treats one or two inert pollutants simultaneously

d. Plume Behavior

Only Briggs neutral/unstable formula used for point sources
If stack height plus plume rise is greater than mixing height, ground level concentrations assumed equal to zero
Alternative to Briggs - input value of plume rise times wind speed for each point source
No plume rise calculated for area sources
Does not treat fumigation or downwash

e. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes
Wind speed corrected for release height based on power law variation exponents from DeMarrais[5]
Constant, uniform (steady-state) wind assumed

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Climatological approach
Uniform distribution within each of 16 sectors
Averaging time = 1 month to 1 year or longer

h. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner[2]
Day and night cases of neutral stability input separately
Dispersion coefficients taken from Turner[6]
Area sources - stability class is decreased by 1 category from input values (to account for urban effects)
Neutral dispersion coefficients are used for stable classes
No further adjustments made for variations in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay, user-input half life

j. Physical Removal

Exponential decay, user-input half life
Always applies the same rate constant

k. Background

Input single constant background value for each pollutant

l. Boundary Conditions

Lower boundary (ground): assumes perfect reflection
Upper boundary (mixing height): no effect until dispersion coefficient equals 0.8 of the mixing height, uniform vertical mixing assumed beyond this point

m. **Emission and Meteorological Correlation**

Wind speed, direction, stability correlated via wind rose
Mixing height is adjusted according to stability class:
  Class A - 1.5 times afternoon climatological value
  Classes B, C, and D(day) - equal to the afternoon climatological value
  Class D(night) - average of morning and afternoon climatological value
  Class E - morning climatological value
Emission rates: day-night allowed; all sources vary by same factor
Non-sequential (climatological) limited correlation

n. **Validation/Calibration**

Calibration option available (CDMQC)
Two validation studies documented in the user's guide
Some unpublished validation experience

o. **Output**

One month to one-year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen[1] procedure (typically 1 - 24 hr.) (CDMQC)
  Assumes
    (1) lognormal concentration distribution,
    (2) power law dependence of median and maximum concentrations on averaging time
Arbitrary number and location of receptors
Individual point, area source culpability list for each receptor (CDMQC)
Point, area concentration rose for each receptor

p. **Computer Requirements**

Digital computer required
Core requirements are moderate

q. **Limitations**

Useable for urban areas only
Area source emission densities must not vary rapidly from one area source to the next

A.4 GAUSSIAN-PLUME MULTIPLE SOURCE AIR QUALITY ALGORITHM (RAM)

Reference: Turner, D. B., and J. H. Novak, "User's Guide for RAM." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1978.

Abstract: RAM is a steady state Gaussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day from point and area sources. Level or gently rolling terrain is assumed. Calculations are performed for each hour. Both rural and urban versions are available.

Equations:

The area source contributions are determined using the narrow-plume hypothesis similar to applications by Gifford and Hanna[7]. Contribution. Contribution from a single upwind area source

$$\chi_A = \frac{q}{u} \int_{x_1}^{x_2} f\, dx \quad \text{integral evaluated numerically}$$

x_1, x_2 = points of intersection of ray from receptor through area source in question

q = emission rate per unit area of the area source (g/s-m^2)

u = mean wind speed (m/s)

For stable conditions: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_2$

$$\chi_{point} = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z} g_1 g_2$$

For neutral or unstable conditions, $\sigma_z \leq 1.6L$: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_3$

$$\chi_{point} = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z} g_1 g_3$$

For neutral or unstable conditions, $\sigma_z > 1.6L$: $f = \frac{1}{L}$

$$\chi_{point} = \frac{Q}{\sqrt{2\pi}\, uL\, \sigma_y} g_1$$

In which

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\}$$

a. Source-Receptor Relationship

Arbitrary location for point sources
Receptors may be
(1) arbitrarily located
(2) internally located near individual source maxima
(3) on a program-generated hexagonal grid to give good coverage to a user-specified portion of the region of interest
Receptors all at same height above (or at) ground
Flat terrain assumed
Unique stack height for each point source
User may specify up to three effective release heights for area sources, each assumed appropriate for a 5 m/sec wind speed. Value used for any given area source must be one of these three
Unique separation for each source-receptor pair

b. Emission Rate

Unique, constant emission rate for each point, area source
Area source treatment-
Narrow plume approximation
Area source used as input; not subdivided into uniform elements
Arbitrary emission heights input by user
Areas must be squares; side lengths = integer multiples of a basic unit
Effective emission height = that appropriate for 5 m/s wind
Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for contribution from area source with given effective release height

c. Chemical Composition

Treats a single inert pollutant

d. Plume Behavior

Briggs[8,9,10] plume rise formulas
Does not treat fumigations or downwash
If plume height exceeds mixing height, ground level concentration is assumed zero

e. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10°), internally modified by addition of a random integer value between -4° and +5°
Wind speeds corrected for release height based on power law variation, different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally by Turner[2] procedure, six classes used
Dispersion coefficients from McElroy and Pooler[3] (urban) or Turner[6] (rural). No further adjustments made for variations in surface roughness or transport time

h. Vertical Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally
Dispersion coefficients from McElroy and Pooler[3] (urban) or Turner[6] (rural). No further adjustments made for variations in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay, user-input half-life

j. Physical Removal

Exponential decay, user-input half-life

k. Background

Not treated

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection
Neutral and unstable conditions
Multiple reflections numerically accounted for by summation of series until σ_z = 1.6 times mixing height
Uniform mixing assumed in vertical thereafter
Stable conditions: there is no upper boundary
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day
Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability class for the hour just preceding sunrise

m. Emission and Meteorological Correlation

User supplies hourly values of wind speed, wind direction, mixing height and other meteorological variables required for determination of stability class and plume rise

n. Validation/Calibration

No calibration option provided
Limited experience with validation or comparison with observed data

o. Output

Hourly and average (up to 24 hours) concentrations at each receptor
Limited individual source contribution list
Cumulative frequency distribution based on 24-hour averages and up to 1 year of data at a limited number of receptors

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Flat or gently rolling terrain

A.5 SINGLE SOURCE (CRSTER) MODEL

Reference: Environmental Protection Agency. "User's Manual for Single Source (CRSTER) Model." Publication No. EPA-450/2-77-013 (NTIS PB 271360). Office of Air Quality Planning and standards, Research Triangle Park, North Carolina 27711, July 1977.

Abstract: CRSTER is a steady state Gaussian plume technique applicable to both rural and urban areas in uneven terrain. The purpose of the technique is: (1) to determine the maximum concentrations, for certain averaging times between 1-hour and 24-hours, over a one year period due to a single point source of up to 19 stacks, (2) to determine the meteorological conditions which cause the maximum concentrations, and (3) to store concentration information useful in calculating frequency distributions for various averaging times. The concentration for each hour of the year is calculated and midnight - to - midnight averages are determined for each 24-hour period.

Equations:

$$\chi = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z}\, g_1\, g_3 \qquad \text{for } \sigma_z \leq 1.6L$$

$$\chi = \frac{Q}{\sqrt{2\pi}\, uL\, \sigma_y}\, g_1 \qquad \text{for } \sigma_z > 1.6L$$

χ = 0 (stability class 7)

L = mixing height (m)

H = (stack height + plume rise)-(difference in elevation between receptor and base of stack)

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty} \exp\left\{\left[-\frac{1}{2}\ \frac{2nL-H}{\sigma_z}\ ^2\right] + \exp\left[-\frac{1}{2}\ \frac{2nL+H}{\sigma_z}\ ^2\right]\right\}$$

a. Source-Receptor Relationship

Up to 19 point sources, no area sources
All point sources assumed at the same location
Unique stack height for each source
Receptor locations restricted to 36 azimuths (every 10°) and 5 user-specified radial distances
Unique topographic elevation for each receptor; must be below top of stack

b. Emission Rate

Unique average emission rate for each source
Monthly variation in emission rate allowed

c. Chemical Composition

Treats a single inert pollutant

d. Plume Behavior

Briggs[8, 9, 10] final plume rise formulas
Does not treat fumigation or downwash
If plume height exceeds mixing height, concentrations further downwind assumed equal to zero

e. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10°), internally modified by addition of a random integer value between -4° and +5°
Wind speeds corrected for release height based on power law variation, exponents from DeMarrais[5], different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Semi-empirical/Gaussian plume
7 stability classes used; Turner Class 7: extremely stable, elevated plume assumed not to touch the ground
Dispersion coefficients from Turner; no further adjustments made for variations in surface roughness, transport or averaging time

h. Vertical Dispersion

Semi-empirical/Gaussian plume
7 stability classes
Dispersion coefficients from Turner; no further adjustments made

i. Chemistry/Reaction Mechanism

Not treated

j. Physical Removal

Not treated

k. Background

Not treated

l. Boundary Conditions

Lower boundary: perfect reflection at the same height as the receptor
Upper boundary: perfect reflection
  Multiple reflections handled by summation of series until
  σ_z = 1.6 x mixing height
  Uniform vertical distribution thereafter
Mixing height is constant and follows topographic variations:
  Taken from base of stack for determining whether plume punches through
  Taken from receptor elevation for determining vertical concentration distribution
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day. Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability class for the hour just preceding sunrise.

m. Emission and Meteorological Correlation

User supplies hourly values of wind speed, direction, mixing height and other meteorological variables required for determination of stability class and plume rise
Monthly emission variation allows limited emission - meteorology correlation

n. Validation/Calibration

No calibration option provided
Comparison with observations around at least 5 separate power plants have been made

o. Output

Highest and second highest concentrations for the year at each receptor for averaging times of 1, 3, and 24-hours, plus a user-selected averaging time which may be 2, 4, 6, 8, or 12 hours
Annual arithmetic average at each receptor
For each day, the highest 1-hour and 24-hour concentrations over the receptor field
Hourly concentrations for each receptor on magnetic tape

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Not applicable to area and line sources
Use care when applying to low-level sources

A.6 TEXAS CLIMATOLOGICAL MODEL

References: Porter, R. A. and Christiansen, J. H.. "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976.

Christiansen, J. H. and Porter, R. A.. Users Guide to the Texas Climatological Model, Texas Air Control Board, Austin Texas, May, 1976.

Abstract: The TCM is a climatological model that predicts long-term arithmetic mean concentrations of nonreactive pollutants from point sources and area sources.

Equations:

Area sources are handled by an algorithm proposed by Gifford and Hanna[7]. The concentration due to area sources is given by

$$\chi_A = FQ/U$$

where χ_A = concentration ($\mu g/m^3$)
Q = area source emission rate in the vicinity of the receptor ($\mu g/s\text{-}m^2$)
U = mean ground-level wind speed (m/s)
F = a dimensionless constant

Gifford and Hanna have suggested a value of F = 50 for SO_2 and 225 for total suspended particulate (TSP). The area emission rate, Q, is determined by averaging the emissions in the area source square containing the receptor and in the neighboring squares. The extent of the region around each receptor to use for emission rate averaging is an input parameter.

The TCM uses steady-state Gaussian plume point source logic, with the crosswind distribution averaged across 22.5° azimuthal sectors. The only meteorological input required for area source calculations is the mean wind speed, but the point source calculations require a meteorological joint frequency function with sixteen 22.5° wind sectors, six wind speed classes (0-3, 4-6, 7-10, 11-16, 17-21, and > 21 knots), and six stability classes (Turner classes A, B, C, D (day), D (night), and E plus F).

The basic equation is:

$$\chi = Q_i \sum_{m=1}^{6} (K(x,H,m)\phi(k,m)/U_m)\cdot(\text{decay term})$$

where $K(x,H,m) = (32\text{x}10^6/[(2\pi)^{3/2}\text{x } \sigma_z]) \exp(-H_i^2/2\sigma_z^2)$

(K is precalculated for 20 distances, 9 effective source heights, and six stability classes)

U_m is a wind speed characteristic of an entire stability class, and is computed in the model by the equation:

$$U_m = \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)\right] \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)/U_\ell\right]^{-1}$$

with χ = concentration, $\mu g/m^3$

k = the wind sector index appropriate to source i at the receptor

ℓ = wind speed class index

m = stability class index

ϕ = meteorological joint frequency function

Q_i = emission rate of source i, g/s

H_i = effective height of source i, m

σ_z = standard deviation of vertical Gaussian concentration distribution, m

$T_{1/2}$ = half-life for first-order pollutand decay, s

U_ℓ = central wind speed of class ℓ, m/s

x = downwind distance, m

a. Source-Receptor Relationship

Arbitrary location for each point source
Unlimited number of sources
Arbitrary location and square grid width for each area source
The model will allocate area sources into a uniform square grid
Receptor location is arbitrary grid (max. 50 x 50)
Release heights for point sources
The area source algorithm (Gifford-Hanna) does not consider height of release
Receptors are at ground level
No terrain difference between sources and receptors

b. Emission Rate

All sources have a single average emission rate for the averaging time period (i.e., month, season, year)

c. Chemical Composition

One, two, or three inert pollutants are treated simultaneously

d. Plume Behavior

Plume rise calculated according to Briggs[9] neutral/unstable equation
Effective stack heights less than 10 meters are considered 10 meters
Effective stack heights greater than 300 meters are considered 300 meters
No plume rise for area sources
Down-wash and fumigation not considered

e. Horizontal Wind Field

Climatological approach
16 wind directions
Mean wind speed calculated for each stability class from the joint frequency function of stability, wind direction, and wind speed
Wind speed corrected for physical stack height (same as CDM)

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Assumed to be uniform within each 22.5 degree sector (same as CDM)

h. Vertical Dispersion

Gaussian plume
6 stability classes (Pasquill-Gifford-Turner) A, B, C, D-Day, D-Night, E and F
No provision for variation in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay according to user input half-life (same as CDM)

j. Physical Removal

Same as i above

k. Background

Background may be entered by calibration coefficient for each pollutant

l. Boundary Conditions

Perfect reflection assumed at ground
Mixing height not considered

m. Emission and Meteorological Correlation

Emissions not varied

n. Validation/Correlation

Model is self-calibrating with input of field receptor observations
High correlation achieved for areas dominated by point sources
Poorer correlations have been shown where area sources are dominant

o. Output

Arithmetic mean concentration for the averaging time of the climatological input and emission data (one month to one year)
Any combination of the following outputs are available:
(1) Listing of concentration for an arbitrarily spaced square grid of up to 50 by 50 elements
(2) A print plot of the grid concentrations
(3) Punched card output for isopleth maping (same as CDM)
(4) A listing of the five high contributors to the concentration (by % concentration) at each grid point

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Flat terrain, relatively constant emissions
Use not recommended where area sources dominate

A.7 TEXAS EPISODIC MODEL (TEM)

References: Porter, R. A. and Christiansen, J. H. "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976.

Christiansen, J. H. Users Guide to the Texas Episodic Model, Texas Air Control Board, May, 1976.

Abstract: The Texas Episodic Model TEM is a short-term (10 minute to 24 hour averaging time) Gaussian Plume Model for prediction of concentrations of nonreactive pollutants due to up to 300 elevated point sources and up to 200 area sources. Concentrations are calculated for 1 to 24 scenarios of meteorological conditions, averaging time, and mixing height

Equations:

The area source algorithm is due to Gifford and Hanna.[7] Each area source square is affected by its own diffuse emissions and those in the N area source squares directly upwind of it:

$$\chi = \left(\frac{2}{\pi}\right)^{1/2} \frac{(\Delta x/2)^{1-b}}{U_o\, a(1-b)} \left\{ Q_o + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b}\right] \right\}$$

with Δx = length of side of area source grid squares (m)

U_o = surface wind speed (m/s)

Q_o = area emission rate of square containing the receptor ($\mu g/s\text{-}m^2$)

Q_i = area emission rates of the upwind area sources ($\mu g/s\text{-}m^2$)

a,b = stability and downwind distance-dependent parameters from the equation $\sigma_z = ax^b$

The TEM employs steady-state bivariate Gaussian plume point source logic. The concentration due to an elevated point source is given by

$$\chi = \frac{10^6\, Q}{\pi \sigma_y \sigma_z U} \exp(-y^2/2\sigma_y^2) \exp(-H^2/2\sigma_z^2) \exp(-.692x/UT_{1/2})$$

where χ = concentration ($\mu g/m^3$)

Q = emission rate (g/s)

U = wind speed at physical source height (m/s)

H = effective source height (m)

x = downwind distance (m)

y = crosswind distance (m)

$T_{1/2}$ = first-order pollutant decay half-life (s)

σ_y, σ_z = the standard deviations of the plume concentration distribution,

$$\sigma_z = ax^b$$

$$\sigma_y = cx^d$$

with stability and downwind distance-dependent coefficients a, b, c, and d from Busse and Zimmerman[11] and Turner[6]. The wind speed U is the surface wind speed adjusted to the physical source height. Let K_y and K_z be defined by

$$K_y = \frac{1000}{\sigma_y} \exp(-y^2/2\sigma_y^2),$$

$$K_z = \frac{1000}{\pi\sigma_z} \exp(-H^2/2\sigma_z^2)$$

Then, $\chi = \frac{K_y K_z Q}{U}$ (decay term)

K_y was calculated for each of the 1120 combinations of twenty downwind distances from 2 to 60 km, eight crosswind angles ($\mathrm{Tan}^{-1} y/x$) from 0° to 7°, with δ varying from 1° to 5° depending on stability, and seven stability classes. For total vertical mixing below a mixing height of L meters,

$$\chi = \frac{10^6 Q}{\sqrt{2\pi}\, \sigma_y L U} \exp(-y^2/2\sigma_y^2)$$

This can be represented in the equation $\chi = \frac{K_y K_z Q}{u}$ (decay term)

by setting $K_z = 398L$

a. Source-Receptor Relationship

Up to 300 arbitrarily located point sources
Up to 200 arbitrarily located area sources
A uniform square receptor grid of arbitrary spacing with up to 50 by 50 rows or columns
Terrain assumed flat
Unique release height for each source
All receptors at ground level

b. Emission Rate

Unique emission rate for each source

c. Chemical Composition

One, two, or three inert pollutants treat simultaneously

d. Plume Behavior

Plume rise according to one of six equations from Briggs selected according to stability and distance from source. Effective stack heights less than 10 meters are considered 10 meters. Effective stack heights greater than 2000 meters are considered 2000 m.
Mixing height penetration factor (P) is a user input. If effective source height (h) is greater than P times the mixing height the plume escapes. Otherwise the .47L mixing scheme from Turner[6] is used.
Does not treat downwash or fumigation

e. Horizontal Wind Field

User supplied stability, wind speed, and direction for the averaging time period (10 minutes to 3 hours) or for each 3 hour period to build a 24-hour day.
Power law variation of wind speed with release height (same as CDM).
Steady state wind for each scenario

f. Vertical Wind Speed

Equal to zero

g. Horizontal Dispersion

Semi-empirical Gaussian plume
User supplied stability class for each scenario (Pasquill-Gifford-Turner)
Turner[6] dispersion coefficients
No adjustment for surface roughness

h. Vertical Dispersion

Semi-empirical Gaussian plume
User supplied stability classes (Pasquill-Gifford-Turner) for each scenario
Turner[6] dispersion coefficients
No adjustment for surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay with user supplied half-life

j. Physical Removal

Same as i above

k. Background

May be input with calibration factor

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: reflection from top of mixed layer by the .47L scheme of Turner[6] except as described in d above

m. Emission/Meteorological Correlation

User supplied values of wind speed, wind direction, stability class, mixing height, ambient temperature for each scenario up to 24 scenarios

n. Validation/Calibration

Calibration by user supplied coefficients (A, B) so that
$\chi_{cal} = A + B\chi_{predicted}$
Limited experience with validation or comparison with observed data

o. Output

Concentration mean for each receptor grid point for averaging times of:
10 minutes
30 minutes
1 hour
3 hours
24 hours (based on eight 3-hour scenarios)
output is available for from 1 to 24 scenarios in the following formats:
listing
print plot
punched cards for isopleth maps
culpability list of the high five contributors to the concentration at each receptor grid point

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Relatively uncomplicated terrain
Reliability is not established for cases where area sources are dominant

A.8 References

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15. SUPPLEMENTARY NOTES

This is a revision of the Interim Guideline on Air Quality Models, published in October, 1977.

16. ABSTRACT

The guideline recommends air quality modeling techniques that may be applied to air pollution control strategy evaluations and new source reviews, including prevention of significant deterioration. It is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, by State and local agencies, and by industry and its consultants. It also identifies modeling techniques and data bases that EPA considers acceptable. The guideline makes specific recommendations concerning air quality models, data bases, and general requirements for concentration estimates.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Rule 932: Workbook for Comparison of Air Quality Models

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Workbook for Comparison of Air Quality Models

10.9.79

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Monitoring and Data Analysis Division
Research Triangle Park, North Carolina 27711

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OAQPS GUIDELINE SERIES

The guideline series of reports is being issued by the Office of Air Quality Planning and Standards (OAQPS) to provide information to state and local air pollution control agencies; for example, to provide guidance on the acquisition and processing of air quality data and on the planning and analysis requisite for the maintenance of air quality. Reports published in this series will be available - as supplies permit - from the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

Number

LIST OF FIGURES

Number

LIST OF TABLES (Cont'd)

Number

1 INTRODUCTION

A wide variety of air quality dispersion models are used by regulatory agencies, consulting firms and industry to estimate the air quality impacts of pollutant sources. It is often desired to compare two or more models to determine which is the most acceptable for a given application. It is particularly useful to be able to compare a given model with those which, by virtue of their extensive use, are familiar to most of the modeling community.

This workbook describes a technique for the qualitative comparison of modeling approaches on technical grounds. The methodology is based upon an applications approach. The results of the model comparison depend upon the application for which the model is to be used as well as upon the model characteristics. In each application of the technique, the model of interest (the "study" model) is compared with a "reference" model. Any models may be specified as study or reference models, as long as they are compatible with the application of interest.

The approach taken in this workbook is restricted to models that mathematically simulate the physical phenomena which determine atmospheric pollutant concentrations. Simulation models may require locally measured air quality data in order to fix the initial and boundary conditions or to determine appropriate background pollutant levels. Models excluded from that category are any that make use of locally measured air quality data to optimize or determine adjustable parameters unrelated to the physical processes being simulated. Thus, for example, calibration or averaging time conversion procedures are not considered as part of a simulation model but rather as statistical procedures which are applied to the calculations of a simulation model. Rollback models are also excluded from the category of simulation models. General considerations involved in the comparison of rollback and statistical or empirical models are discussed briefly in Section 7.

Although the amount and detail of the technical material, particularly that in Appendix A, may appear rather formidable to the user, it has been included for reference purposes and as an aid in dealing with unfamiliar treatments or situations. The user should refer to the examples in Appendix C. If examples of the application of the methodology are examined, it should become clear that use of this workbook is not difficult.

It is important to understand that the methodology described in this workbook does not enable the user to evaluate the results obtained using a particular air quality model. That would require an evaluation of the quality and suitability of the input data as well as of the model. The methodology enables the user to determine only if the model used is as technically adequate as another model for the application of interest.

The workbook contains seven main sections and four appendices. Section 2 contains an overall description of the methodology and general instructions for its implementation. Sections 3-6 contain specific instructions and guidelines for carrying out various steps in the procedure. Section 3 deals with the classification of the user's application. Section 4 is concerned with the general suitability and compatibility of a model with the given application. It also considers the importance of various aspects of atmospheric dispersion in that application. Selected reference models for the various applications are also suggested in Section 4. Section 5 provides guidelines for identifying the treatments of various physical phenomena by a given model. Section 6 contains instructions and guidelines for making the comparative evaluation. Finally, Section 7 contains a discussion of some of the considerations involved in comparing rollback/statistical models.

The appendices contain general reference material useful in implementing the methodology. Appendix A contains technical discussions of the physical phenomena that determine atmospheric pollutant concentrations. It also contains a discussion of the importance of each phenomenon in different types of applications. Appendix B contains information on the treatments of these phenomena by selected reference models, including the working equations. Appendix C provides several examples of the use of the methodology in various common applications. Finally, copies of each of the various forms used in the methodology are provided for the user's convenience in Appendix D.

2 PROCEDURE

2.1 GENERAL

This section provides a general overview of the methodology, outlines the steps involved, and explains the types of information and decisions required at each step. The user is required to exercise judgment and to make qualitative decisions at each step, since model comparison is not, and cannot be made routine. Information and guidelines are provided for each step in the procedure. Prior to the initial use of the methodology, the user should read and understand the guidelines in this section. The experienced user can proceed directly to the comparison with occasional consultation of the reference materials.

The procedure is application-specific; that is, the results depend upon the specific situation to be modeled. Initially, the user identifies both the application of interest and an associated "reference model." This reference model serves as a standard of comparison against which the user gages the "study model" being evaluated. The way in which the study model treats twelve aspects of atmospheric dispersion called "application elements," or simply "elements" is determined. These application elements represent physical and chemical phenomena that govern atmospheric pollutant concentrations and include such aspects as horizontal and vertical dispersion, emission rate, and chemical reactions. The importance of each element to the application is defined in terms of an "importance rating." Tables giving the importance ratings for each element are provided, although the user may modify them under some circumstances. The heart of the procedure involves an element-by-element comparison of the way in which each element is treated by the two models. These individual comparisons, together with the importance ratings for each element in the given application, form the basis upon which the final comparative evaluation of the two models is made.

It is especially important that the user understand the physical phenomena involved, because the comparison of two models with respect to the way that they treat these phenomena is basic to the procedure. Sufficient information is provided in the text to permit these comparisons to be made and the availability of expert advice in the event of difficulties is assumed.

2.2 OVERVIEW

Comparison of a study model to a reference model is carried out in nine steps. Table 2.1 lists the section and tables to be used for each step in the comparison. Figure 2.1 illustrates schematically the steps in the comparison and their relation to each other. Greater detail, specific guidelines, and tables are given in Sections 3-6 and Appendices A and B. Forms for organizing and documenting a comparison are provided in Appendix D.

Table 2.1. Workbook Section and Form for Each Step in Comparison

Step		Workbook Sections	Form in Appendix D
Number	Action		
1	Classify application	3	Application Classification Form
	Record study model information	2.3	Evaluation Form A
2	Document study model equations	2.3	Reverse side of Evaluation Form A
3	Check study model compatibility	4.2	Evaluation Form A
4	Classify study model type[a]	4.3	Evaluation Form A
5	Identify reference model	4.4	Evaluation Form A
6	Review importance ratings	4.5	Evaluation Form B
7	Determine treatments of elements	5	Evaluation Form C
8	Compare treatments on element-by-element basis	6.2.1	Evaluation Form C
9	Synthesize individual comparisons into overall comparison	6.2.2	Evaluation Form D

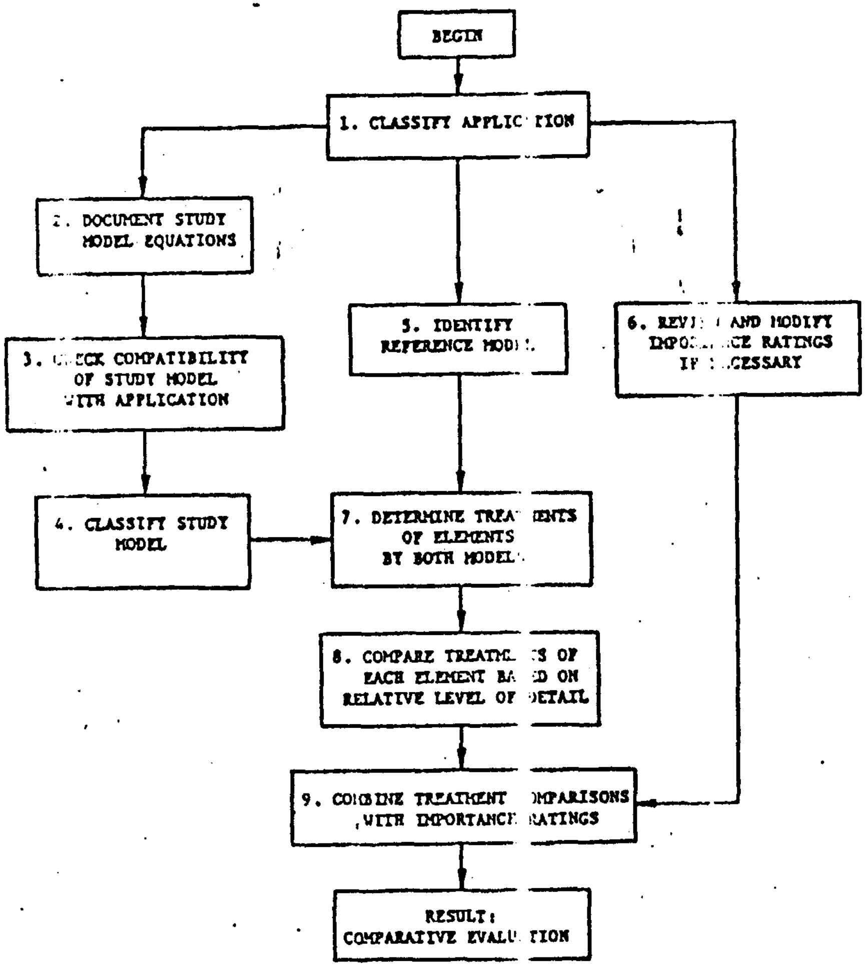
[a] If the study model has been classified as a rollback/statistical model, the user should proceed directly to Section 7 wherein such models are discussed.

2.3 STEP-BY-STEP INSTRUCTIONS

Step 1 - Classify Application; Record Basic Information

The user first classifies the application of interest. Specifically, the user considers each of the following four aspects of the application:

- Pollutant characteristics,
- Averaging time,
- Source characteristics, and
- Transport characteristics.



Note: Numbers in the boxes refer to the steps in the comparison procedure as given in Table 2.1.

Figure 2.1. Procedure for the Comparison of Air Quality Simulation Models

The classification is based on an application tree approach as described in Section 3. An Application Classification Form (see Figure 3.2 or Appendix D) is provided for carrying out this classification. Next, the four-digit "application index" is determined. This index identifies the application throughout the remainder of the comparison. The application must be classified with respect to the physical situation being modeled. Some basic background information about the study model is then recorded.

Step 2 - Document Study Model Equations

The element-by-element comparisons are facilitated by listing the major equations used by the study model on the back of the Evaluation Form - Part A. The user must examine the study model documentation carefully to determine the equations which are actually used. In some cases, when the study model documentation is inadequate or inconsistent, it may be necessary to examine the computer code itself to make the determination. The equations used by selected reference models are documented in Appendix B.

Step 3 - Check Model Compatibility

In this step the general compatibility of the study model with the application of interest is checked. Brief guidelines are given in Section 4.2 for determining whether

- Treatments of elements essential to the application of interest are incorporated in the study model and
- Output from the study model meets the user's requirements.

The documentation for the study model should contain the information to make the compatibility determination.

Step 4 - Classify Study Model Type

In this step, the study model is classified according to the general modeling approach adopted. This model classification is useful in identifying the way in which the model treats several application elements. Specific guidelines can be found in Section 4.3.

If the model is classified as a rollback/statistical model, or if it is found to involve both simulation and statistical estimation procedures, the methodology described in this workbook does not apply. A general discussion of some of the considerations involved in the comparison of such models may be

The classification is based on an application tree approach as described in Section 3. An Application Classification Form (see Figure 3.2 or Appendix D) is provided for carrying out this classification. Next, the four-digit "application index" is determined. This index identifies the application throughout the remainder of the comparison. The application must be classified with respect to the physical situation being modeled. Some basic background information about the study model is then recorded.

Step 2 - Document Study Model Equations

The element-by-element comparisons are facilitated by listing the major equations used by the study model on the back of the Evaluation Form - Part A. The user must examine the study model documentation carefully to determine the equations which are actually used. In some cases, when the study model documentation is inadequate or inconsistent, it may be necessary to examine the computer code itself to make the determination. The equations used by selected reference models are documented in Appendix B.

Step 3 - Check Model Compatibility

In this step the general compatibility of the study model with the application of interest is checked. Brief guidelines are given in Section 4.2 for determining whether

- Treatments of elements essential to the application of interest are incorporated in the study model and
- Output from the study model meets the user's requirements.

The documentation for the study model should contain the information to make the compatibility determination.

Step 4 - Classify Study Model Type

In this step, the study model is classified according to the general modeling approach adopted. This model classification is useful in identifying the way in which the model treats several application elements. Specific guidelines can be found in Section 4.3.

If the model is classified as a rollback/statistical model, or if it is found to involve both simulation and statistical estimation procedures, the methodology described in this workbook does not apply. A general discussion of some of the considerations involved in the comparison of such models may be found in Section 7. If the study model incorporates a calibration procedure which empirically adjust the estimates made by a simulation model, the user should consider only the simulation model and simply ignore the presence of the calibration procedure when applying the methodology.

Step 5 - Identify Reference Model

Table 4.1, Section 4.4, identifies suggested reference models for some of the indexed applications. This step only involves looking up the appropriate reference model for the application index determined in Step 1.

At this point, the Evaluation Form - Part A should be completely filled out. This form is shown in Figure 2.2.

Step 6 - Review and Modify Importance Ratings

This is the first step in which the user must consider the twelve application elements. Each element specifies a particular physical aspect of the overall processes by which the emission of pollutants into the atmosphere affects the air quality at some point. Figure 2.3 depicts the relationship between these application elements and the estimation of atmospheric pollutant levels. In order to compare the study model to the reference model, the user needs to know

- The importance of each element to the application of interest and
- How the treatment used by the study model compares to that used by the reference model.

An estimate of the importance of each element to each application can be found from Tables 4.2-4.13 in Section 4.5. Each element has been rated as being of HIGH, MEDIUM, or LOW importance to each application. The user should review these importance ratings. In light of the specific application, a particular rating may either be changed to another of the ratings given above or be designated as CRITICAL or IRRELEVANT. Critical elements are those to which it is desired to give extraordinary weight when the two models are compared. Irrelevant elements describe processes that are inoperative in the application of interest. Generally, with the exception of irrelevant elements, the user should expect to make very few modifications to the given ratings and, at most, one CRITICAL designation.

The Evaluation Form - Part B should now be completed by indicating the importance rating for each application element and any changes (see Figure 2.4).

EVALUATION FORM

Part A: Abstract and References

Study Model:

References:

Abstract:

Classification:

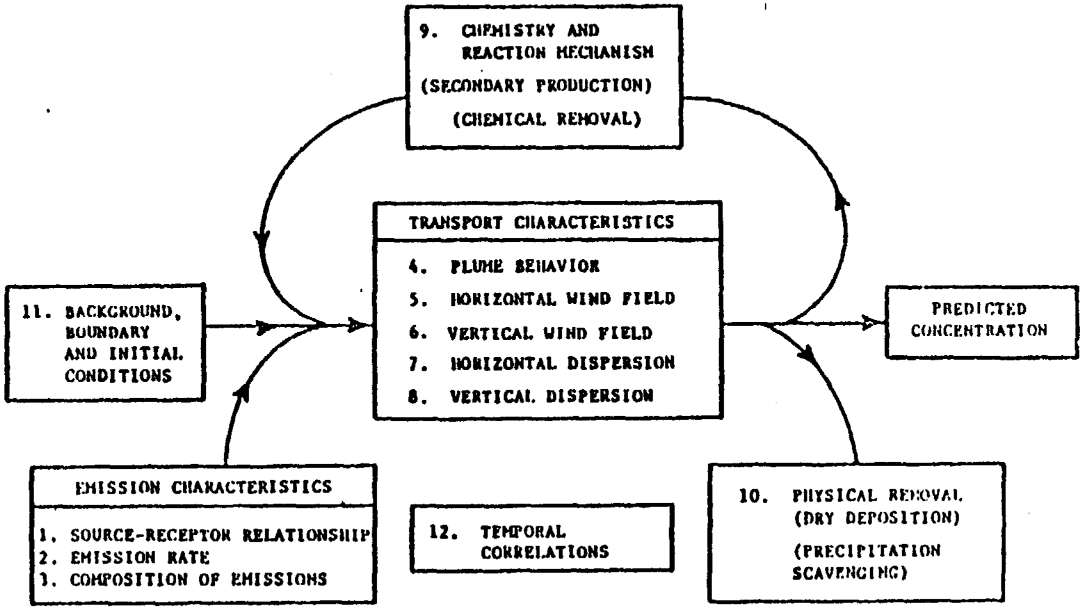
Application Index: **Reference Model:**

Application Description:

Model Applicability: Applicable ☐ Not Applicable ☐

Note: The reverse side of this form for documenting the equations is not shown.

Figure 2.2. Evaluation Form - Part A



Note: Temporal correlations relate the time variations of all other application elements.

Figure 2.3. Application Elements as Major Factors Affecting Pollutant Concentrations

EVALUATION FORM

Part B: Importance Ratings

Application Index:

Application Element	Importance Rating Initial	Importance Rating Modified[a]
Source-Receptor Relationship		
Emission Rate		
Composition of Emissions		
Plume Behavior		
Horizontal Wind Field		
Vertical Wind Speed		
Horizontal Dispersion		
Vertical Dispersion		
Chemistry and Reaction Mechanism		
Physical Removal Processes		
Background, Boundary, Initial Conditions		
Temporal Correlations		

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[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

Figure 2.4. Evaluation Form - Part B

Step 7 - Determine Treatments of Application Elements

In this step the treatments of the application elements by both the study model and the reference model are determined. The treatments for each element should be described on the Evaluation Form - Part C. The user should consult that part of Section 5 that corresponds to each element. Section 5 gives guidelines, questions, and tables to aid the user in determining the study model's treatment of each element. If additional guidance is needed, Appendix A provides detailed discussions of various common treatments of the application elements.

The treatment of each element by selected reference models can be found in Tables B.2-B.13 in Appendix B.

It is strongly recommended that the sections of Appendix A appropriate to each element be read. The general discussion in each section provides information on the physical processes which are involved and hence builds a foundation for making the comparisons required in Step 8.

Step 8 - Compare the Two Treatments of Each Element

Once the treatment of a particular element has been determined, the next step is to determine whether the study model's treatment of that element is

- BETTER than,
- COMPARABLE to, or
- WORSE than

that of the reference model. Detailed guidance on making this comparison is given in Section 6.2.1. The required comparison is qualitative. Occasionally, the user may have some difficulty in deciding whether, for instance, the study model's treatment is better than or comparable to the reference model's. In such cases, it is suggested that the user enter the best estimate and note the other rating in parentheses for later consideration. In general, the user is urged to make a unique comparison whenever possible.

The Evaluation Form - Part C should be completed at this point (see Figure 2.5). Note that the form in Figure 2.5 contains room for describing the treatments of two elements only. Additional copies of this form up to a maximum total of six will be required in order to handle all relevant elements.

EVALUATION FORM

Part C: Treatment of Elements

Application Index:_________

Application Element: Reference Model: Treatment:	Application Element: Reference Model: Treatment:
Study Model: Importance Rating: Comparative Evaluation: Treatment:	Study Model: Importance Rating: Comparative Evaluation: Treatment:

Figure 2.5. Evaluation Form - Part C

Step 9 - Synthesize the Final Technical Comparison

The information required for the final technical comparison can be organized on the Evaluation Form - Part D (see Figure 2.6). As discussed in Section 6.2.2, the user first summarizes the results of the element-by-element comparisons. An initial evaluation is made by considering the relative treatments of the most important elements, and this initial evaluation is then modified or not according to the relative treatments of the elements of lesser importance. Elements of low importance are considered only in ambiguous cases. The final evaluation obtained in this way represents the final result of applying the methodology and at this point the comparison is complete.

EVALUATION FORM

Part D: Technical Comparison

Application Index:________________ Reference Model:________________ Study Model________________

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL					__________
HIGH					__________
MEDIUM					__________
LOW					
IRRELEVANT	____	XXX	XXX	XXX	
Total	(Should equal 12)				

TECHNICAL EVALUATION __________

Figure 2.6. Evaluation Form - Part D

3 APPLICATION CLASSIFICATION

3.1 INTRODUCTION

The first step in the methodology is to suitably define the application as discussed in Sections 3.2-3.6. This workbook cannot treat all possible factors in detail. Thus, the user needs to consider the situation of interest and to exercise judgment at all stages of the evaluation. It is necessary, however, to classify the application in as much detail as practicable.

Four general aspects of air pollution simulation have been identified as being suitable for this purpose. In this section, the user classifies the application with respect to these four aspects. In the process, a four digit number is generated. This number serves to identify the class of applications to be considered in the comparison. This number, the application index, is used throughout the workbook for various purposes. The user should not consider in any way the details of the operation of either the reference or the study model in classifying the application. The classification should reflect only the characteristics of the problem at hand without regard to possible simulation techniques.

Note that meteorological concepts are not used in the classification scheme. Relevant aspects of meteorology comprise several of the application elements discussed in Section 5.

3.2 INSTRUCTIONS

The following procedure enables the user to classify the application of interest and to construct the application index. Figure 3.1 shows the classification process schematically. Decision trees and the accompanying guidelines are used to classify the application in the following four categories:

- Pollutant characteristics
- Averaging time,
- Source characteristics, and
- Transport characteristics.

The trees require definite decisions at each branch point. In cases of uncertainty, the user may follow multiple branches and refer to the application

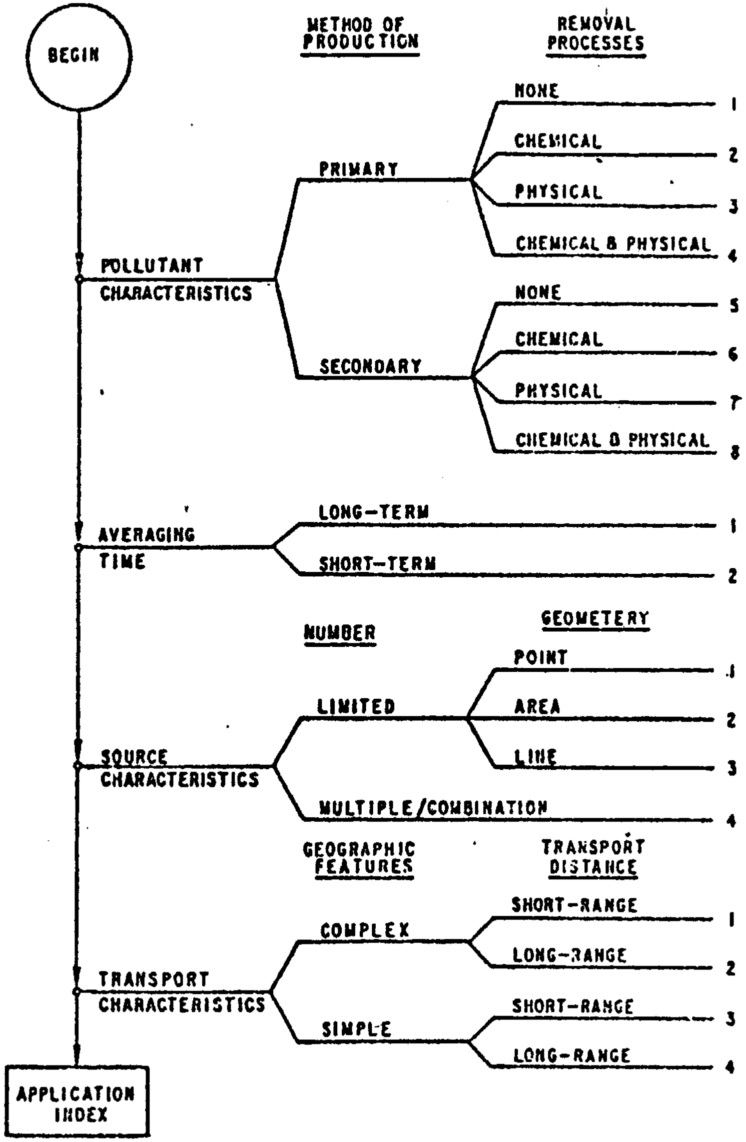

Figure 3.1. Scheme for Classifying Model Applications

element descriptions in Appendix A. The information in these detailed descriptions may facilitate the identification of the most pertinent classification. Each branch of each decision tree ends in a one-digit number that classifies the given application within the category being considered. After classifying the application in all four categories, the index numbers are combined into the four-digit composite application index.

The steps in classifying the application are listed below:

1. Classify the application within each of the four categories shown in Figure 3.1.
2. Determine the one-digit numbers corresponding to the specific classification chosen within each of the four categories.
3. Form the composite application index from these four one-digit numbers.

In classifying the application, the user should consult the guidelines for each descriptive category contained in Sections 3.3-3.6.

As an example, consider an application that involves estimating the short-term concentrations of total suspended particulate (a primary pollutant) due to a power plant (single point source) when (1) the interest is in the area close to the plant; (2) particulate removal by fallout, deposition, etc. can be ignored; and (3) the local geographic features are simple. The application index would be 1213, corresponding to the index numbers of 1, 2, 1 and 3 for the categories "pollutant characteristics," "averaging time," "source characteristics," and "transport characteristics" respectively. Figure 3.2 shows a completed sample Application Classification Form for this specific example.

3.3 CLASSIFICATION OF POLLUTANT CHARACTERISTICS

The decision tree for classifying pollutant characteristics is shown in Figure 3.3. The tree indicates processes by which pollutants are produced and/or removed from the atmosphere. The first step is to classify the pollutant as either primary or secondary. Primary pollutants are defined as those emitted directly into the atmosphere and secondary pollutants are defined as those produced in the atmosphere by chemical reactions. For example, if the application involves estimating the additional CO concentration caused

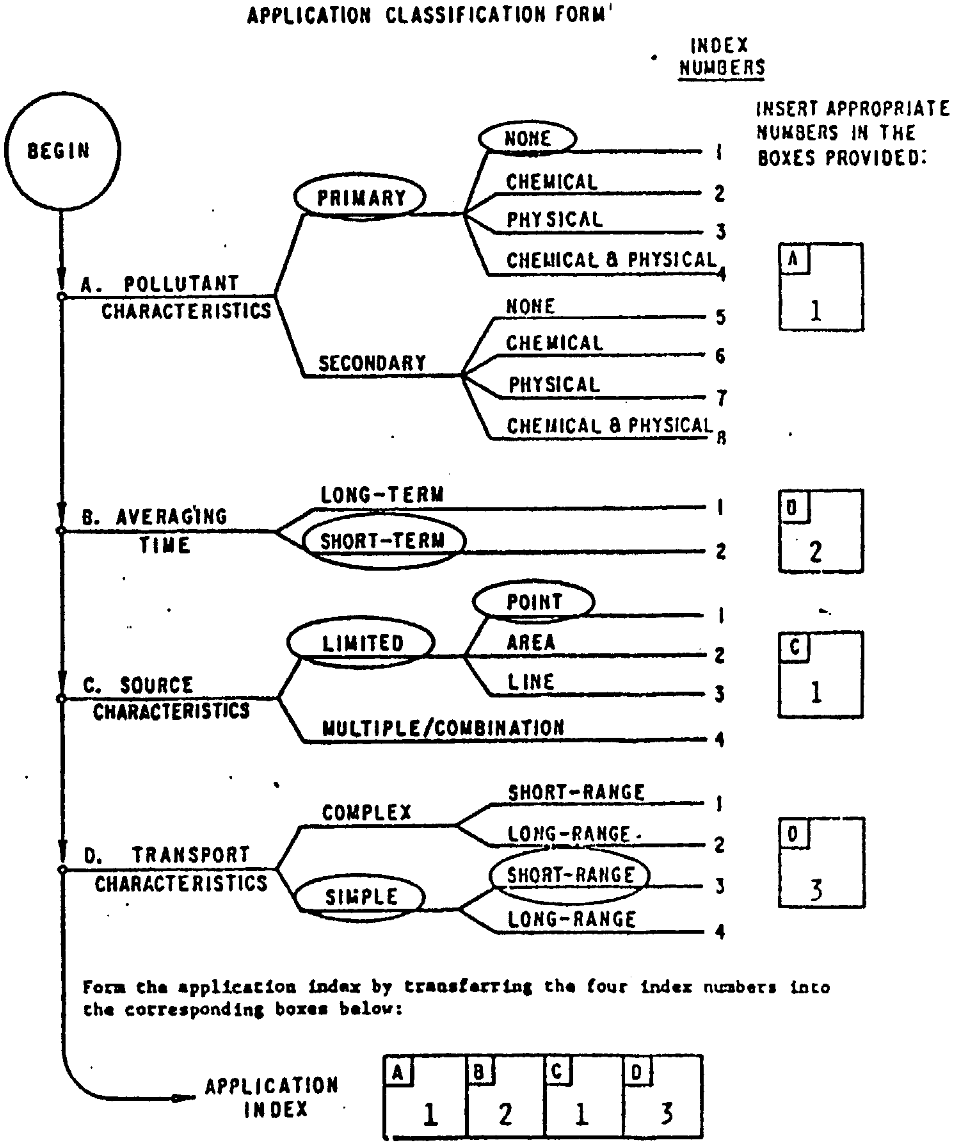

Figure 3.2. Sample Completed Application Classification Form

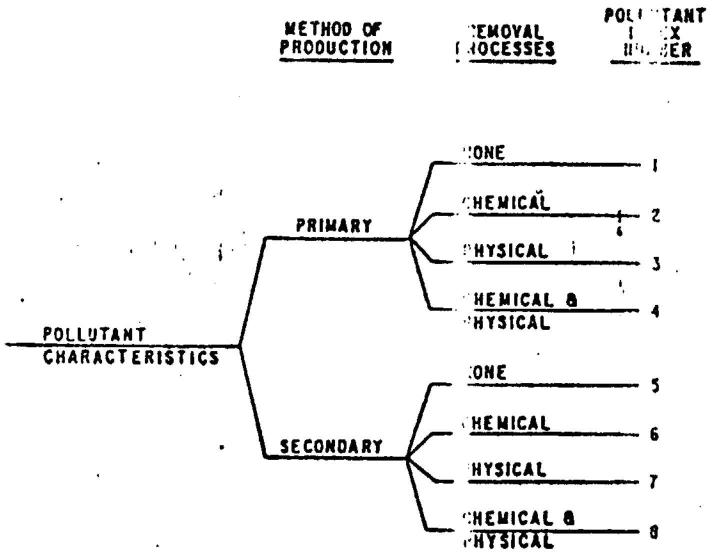

Figure 3.3. Decision Tree for Classifying Pollutant Characteristics

by a new highway link, CO is classified as a primary pollutant because it comes directly from the vehicular sources using the link. The most common example of a secondary pollutant is ozone, which is produced by photochemically initiated reactions involving reactive hydrocarbons and nitrogen oxides.

When the application involves a secondary pollutant, it eventually becomes necessary to determine the chemical identity of the primary precursors of that pollutant. Knowledge of the nature of the precursors and their sources is required by the nature of the modeling process; namely, to relate emissions from sources to atmospheric concentrations. Primary precursors are defined here as those substances that are emitted directly into the atmosphere, undergo chemical reaction, and whose ultimate reaction products include the pollutant of interest. Determination of the precursors often requires expert advice but is not required at this point in the classification. Knowledge of sources of the precursors is necessary when the source characteristics are classified.

A particular pollutant can be both emitted directly into the atmosphere and produced by atmospheric chemical reactions; hence it can be both primary and secondary. For example, particulate sulfates are emitted directly from catalytic converters on automobiles and result as well from atmospheric reactions involving SO_2. In applications involving the total concentration of such a pollutant, it may be possible to choose a single classification. For example, if primary sources are known to be dominant, the pollutant should be classified primary. On the other hand, if secondary generation dominates, the secondary classification should be used. In situations where neither prevails, both branches should be explored. The model used must be able to handle both primary and secondary production. In such cases, the comparison will involve going through the evaluation process twice: identifying two applications, two reference models, two sets of importance ratings and making two independent evaluations. These evaluations can then be weighted by the relative importance of primary and secondary production and combined to arrive at the desired overall comparison.

In applications involving a specific source, the classification should be made based upon whether the pollutant emitted from that source is the pollutant of interest or a precursor.

After the method of production has been classified, the processes by which the pollutant is removed from the atmosphere must be classified. This second classification should be made by considering removal processes that are important over the range of time and distance involved in the application. In some situations, removal of the pollutant may be negligible and the branch labeled "None" is chosen. The determining factor is the relationship between the pollutant's removal rate under the conditions being studied and its residence time within the study area. Estimation of the appropriate removal rates may require expert advice. If roughly more than one-quarter to one-third of the pollutant could be removed within the study area, removal processes should be accounted for within a simulation model.

If removal is important, a decision is required as to the type of removal processes involved. Chemical removal processes are those in which the pollutant reacts chemically in the atmosphere as, for example, when SO_2 reacts to form sulfates and ceases to exist as the chemical species of interest. Physical removal processes produce a change in the amount of pollutant in the air without causing an immediate change in the chemical species of the material removed. They include such processes as gravitational settling, impaction, precipitation scavenging, and dry deposition. In cases where both chemical and physical removal processes are significant, the branch labeled "Chemical and Physical" should be chosen, even if the user is interested primarily in only one type. Of course, if one type of removal process is clearly predominant, that branch should be chosen.

Other terminology is frequently employed in discussing pollutant characteristics. *Reactive* pollutants are those that react chemically in the atmosphere. They thus belong on one of the four branches labelled "chemical" or "chemical and physical" removal. Pollutants that are not reactive are called *stable* even if physical processes remove them from the atmosphere. *Conservative* pollutants are those for which no rem process is significant enough to be considered.

Common characteristics of the criteria pollutants are given in Table 3.1. The indicated classifications are illustrative only and are not intended as an exhaustive list of all possibilities. In other circumstances, the classification might be different from those shown in the table.

3.4 CLASSIFICATION OF AVERAGING TIMES

The decision tree for classifying averaging times is shown in Figure 3.4. The time of interest is that over which the estimated concentrations are to be averaged. For a particular pollutant, averaging times from several minutes to a year may be of interest. Applications involving concentrations averaged for 24 hours or less should be considered as distinct from those in which seasonal or annual averages are estimated. The former are classified as short-term. Longer averaging times like a month, season, or year are classified as long-term. Table 3.2 classifies the averaging times specified in the NAAQS.

3.5 CLASSIFICATION OF SOURCE CHARACTERISTICS

In order to classify source characteristics, the number and the geometry of the sources involved in the application must be determined. The decision tree for classifying source characteristics is shown in Figure 3.5. The proper branch of the tree is chosen by considering both the number and the geometry together. The user should choose the branch appropriate to the physical characteristics of the sources as inventoried for use in the model.

Whenever the dimensions of a stationary source are small compared to the distance at which concentrations are to be estimated, the source can be treated as a geometric point. Generally, sources are treated as points if they emit a substantial amount of any criteria pollutant, e.g. 100 tons per year. Some control agencies treat sources with as little as 1 ton per year of emissions as points.

Sources that emit small amounts of pollutant are usually aggregated and treated as uniform area sources. Their large number and highly variable emission rates preclude treating them as individual sources. In addition, some sources, such as open quarries or windblown fields, are "true" area sources due to their geometry. They are not aggregates of many point or line sources.

The line source designation is usually reserved for special problems involving aircraft or microscale analyses of vehicular impacts. As is the case with multiple point sources, closely packed line sources such as streets in downtown areas are frequently treated as uniform area sources. If individual source data exists, the more appropriate line classification should be made; if the data base aggregates the lines to areas, the area classification should be made.

A small number of sources (generally less than 10-20) having the same geometry should be classified "limited" in number. Thus, if the impact of a power plant with five stacks were being estimated, the "limited" branch should be chosen. The same choice should also be made if five spatially separated sources are involved. However, in the latter case, the user should be aware that some models for treating a limited number of sources assume that these sources are coincident in space or equivalently that the separations between sources are small compared to the transport distances. The choice between the "limited" or the "multiple" branch should be based on the number of sources to be modeled, not the number of actual sources. Thus, if several hundred small incinerators have been inventoried as six area sources, the sources would be characterized as limited in number (six area sources), not multiple.

Table 3.1 Classification of Criteria Pollutants[a]

Pollutant	Conditions	Method of Production	Removal Processes	Pollutant Index Number
TSP	Particles smaller than about 30µm.	Primary	None	1
	Particles larger than about 30µm.	Primary	Physical (gravitational settling)	3
SO_2	Residence time[b] under 5-8 hrs.	Primary	None	1
	Residence time[b] over 5-8 hrs.	Primary	Chemical and Physical	4
CO	Most conditions.	Primary	None	1
NO_2	Most sources emit mainly NO which reacts to form NO_2.	Secondary	Chemical	6
Oxidants	Primary sources are generally negligible.	Secondary	Chemical	6
Non-methane Hydrocarbons	-	Primary	Chemical	2

[a] These characteristics are for short-range urban situations without precipitation and could change under other circumstances.

[b] "Residence time" is approximated by the time taken to traverse the region of interest at a characteristic wind speed.

If either multiple sources or several source geometries are to be modeled, the "Multiple/Combination" branch is chosen. If a limited number of sources of a single geometry are to be modeled, the appropriate branch along the "Limited" path is chosen.

The source characteristics of some common source categories are given in Table 3.3. In particular applications, these general guidelines may be modified. For example, if the impact of a small number of industrial process sources is being investigated, the source characteristics should be classified as a limited number of point sources and not as part of an aggregated area source.

Geographic features should be classified as complex if their presence requires the consideration of point-to-point variations in the speed or direction of transport winds. Applications involving areas with rough terrain, areas containing or close to a large body of water, or areas in valleys or street canyons should generally be classified as having "complex" geographic features. Areas with level or gently rolling terrain should generally be classified as having "simple" geographic features. Determining the appropriate classification may require the advice of an expert air pollution meteorologist. The determination may also depend upon other features of the specific application. For example, variations in terrain that are significant when short-range transport is being considered might be insignificant when long-range transport is of interest. In coastal areas or near the Great Lakes, the potential effects of sea or lake breezes may require the complex classification. The precise distance inland over which the complex classification must be maintained cannot be specified without knowing the details of the application. If in doubt, the user should consult the technical material in Appendices A.3 and A.4 or obtain expert advice on the particular situation.

A different set of applications arises when the affects of sources are estimated over long rather than short distances. As a general rule-of-thumb, distances between sources and receptors that exceed 60-100 km (40-60 mi) should be classified long-range. The transport distance is also related to the residence time considered when the pollutant characteristics were classified. Care should be taken to see that the two choices are made on a consistent basis.

Table 3.2 Classification of NAAQS Averaging Times

Pollutant	Averaging Time	Classification	Averaging Time Index No.
TSP[a]	Annual	Long-term	1
	24-hour	Short-term	2
SO_2[a]	Annual	Long-term	1
	24-hour	Short-term	2
	3-hour	Short-term	2
CO	8-hour	Short-term	2
	1-hour	Short-term	2
Oxidants	1-hour	Short-term	2
Hydrocarbons	3-hour	Short-term	2
NO_2	Annual	Long-term	1

[a] These averaging times are also specified for the Prevention of Significant Deterioration (PSD) increments.

Table 3.3. Classification of Common Source Categories

Source Category	Number	Source Size[a]	Geometric Description	Source Characteristics Index Number
Industrial Process	Limited	Large	Point	1
	Multiple	Small	Area	4
Fuel Combustion (Internal and External)	Limited	Large	Point	1
	Multiple	Small	Area	4
Transportation	Limited		Line	3
	Multiple		Line or Area	4
Electricity Generation	Limited		Point	1
	Multiple		Point	4
Incineration	Limited		Point	1
	Multiple		Area	4
Urban Area	Multiple	Various	Combination	4

[a] Source size is measured relative to the point source size specified in the emission inventory. For example, major (large) sources are generally considered to be those that emit more than 100 tons per year.

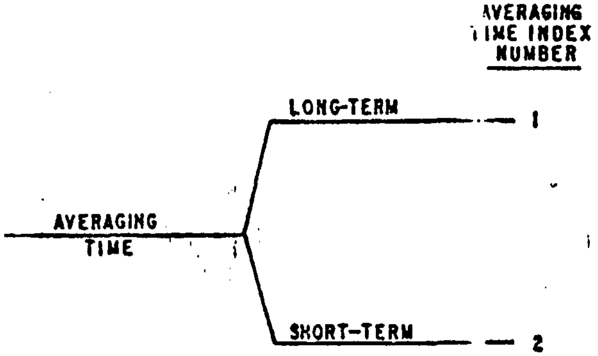

Figure 3.4. Decision Tree for Classifying Averaging Times

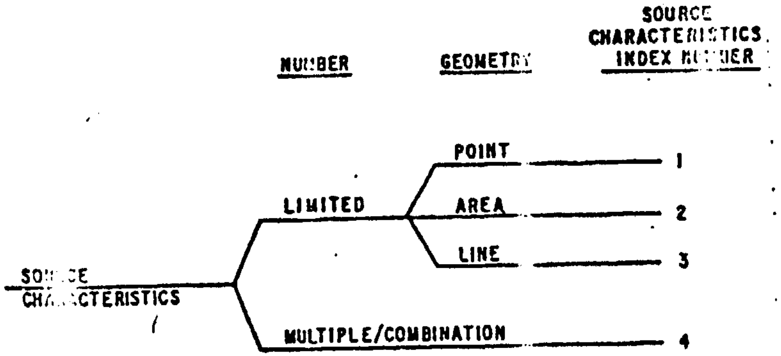

Figure 3.5. Decision Tree for Classifying Source Characteristics

3.6 CLASSIFICATION OF TRANSPORT CHARACTERISTICS

The decision tree for classifying transport characteristics is shown in Figure 3.6. This tree classifies the application with respect to geographic features and the transport distance from sources to receptors. One important general factor affecting transport has been omitted from the tree: meteorology. Meteorology has been omitted so that the application can be defined by relatively fixed or invariant characteristics of the application rather than by the variable factors which affect transport and dispersion.

The application is defined by specific pollutant characteristics, specific averaging times, well-defined source characteristics, well-defined geography, and a specific region. However, a wide range of meteorological conditions frequently must be analyzed. The relevant meteorological considerations and transport under certain specific adverse meteorological conditions are discussed in Appendices A.2 and A.4.

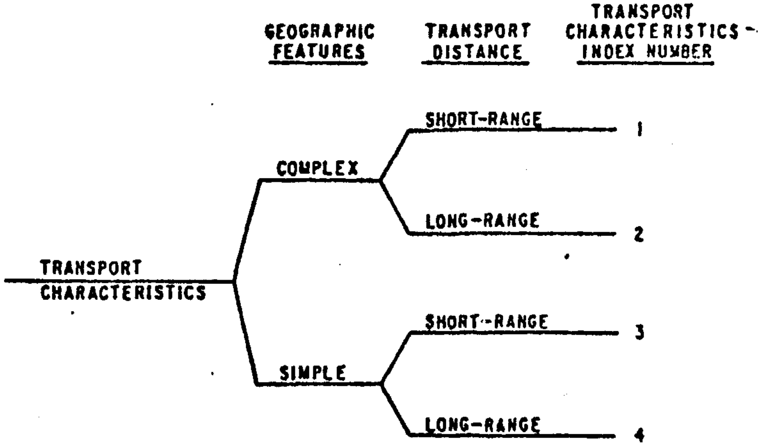

Figure 3.6. Decision Tree for Classifying Transport Characteristics

4 PRELIMINARY ANALYSIS

4.1 INTRODUCTION

In this section, guidelines and instructions are provided to enable the user to carry out steps 3-6 as given in Table 2.1 and shown in Figure 2.1. These steps involve a check to see that the study model is compatible with the application in certain essential respects, the classification of the study model, the identification of the reference model to be used in the comparison, and the review and possible modification of the importance ratings. These steps are considered in Sections 4.2-4.5, respectively. Sufficient guidelines for carrying out Step 2, the documentation of the study model equations, may be found in Section 2.3.

4.2 CHECK COMPATIBILITY OF STUDY MODEL WITH APPLICATION

It is desirable, before proceeding further, to determine that the study model meets two specific requirements of the application of interest and is therefore compatible with it. Generally, reference models can be used as standards for comparison even when they are not strictly compatible with the application of interest.

The first requirement is that the study model should contain treatments of all elements in which the user has a specific interest or which are required by the nature of the application. For example, if the user has determined that some specific physical removal process is important for the application of interest, and has as a result chosen the appropriate branch in the Application Tree, the study model should incorporate a treatment, however simplified, of that process. If the pollutant of interest is subject to chemical removal processes, and/or if it is a secondary pollutant, the study model should incorporate a treatment of the effects of the relevant chemical reactions. This may be extended to processes not covered in this workbook. If the user is interested in the effects of any process whatever, the study model must incorporate a treatment of that process.

The second requirement is that the study model should provide the user with the desired results. No attempt is made to list the various possibilities here. It is assumed that the user knows what estimates are desired and can determine whether or not the study model provides them. For example, the application might involve calculating the frequency distribution of twenty-four hour averages at some location. In this case, a model which gives only the maximum twenty-four hour average is not compatible with the user's application, because the desired information is not available as an output from the model.

4.3 CLASSIFICATION OF STUDY MODEL

The possible treatments of several application elements depend upon the general type of model being considered. It is, therefore, useful to classify the study model with regard to certain general characteristics. Guidelines are provided in this section to enable the user to carry out this classification; further discussion may be found in Appendix A.4.2.

The study model should first be categorized as either a simulation model or as a rollback/statistical model. The distinctions between these two broad categories are based upon

- The extent to which the model in question attempts to simulate the relevant physical and chemical processes which significantly affect atmospheric pollution levels and

- The degree to which locally measured air quality data are required for model usage or for the adjustment of model parameters.

A simulation model should attempt to describe mathematically the effects of all relevant physical phenomena expected to have a significant effect on air quality in the application of interest. It should not absolutely require the existence and use of locally measured air quality data except possibly to fix initial and boundary conditions. For example, a model which incorporates a model calibration procedure involving a statistical adjustment of concentration estimates should still be classified as a simulation model.

Rollback/statistical models are also formulated mathematically and may require many of the same input variables, such as wind speed or mixing height, as do simulation models. They do not, however, attempt to describe the physical processes involved in the transport and dispersion of pollutants from source to receptor in order to estimate pollutant concentrations. Instead, the relationship between concentrations and the model input variables is determined empirically. This is usually done by assuming some simple functional relationship containing one or more adjustable parameters and then determining the values of those parameters that produce the best agreement with air quality data.

If the study model is classified as a rollback/statistical model, or if statistical conversion of averaging times is used by the model, the methodology described in this workbook does not apply. General guidelines regarding the comparison of rollback/statistical models may be found in Section 7 but the user should consult with an expert to determine the proper way to perform the evaluation in such cases.

If the study model is a simulation model, it may be categorized according to the following two additional features:

1. General modeling approach adopted
    - Numerical, involving the solution by numerical procedures of equations based upon the conservation of mass (K-theory), or
    - Semiempirical, involving the assumption of a particular functional form for the pollutant distribution; and
2. Treatment of the time dependence of pollutant concentrations
    - Steady-state, involving no time dependence; only a single constant set of conditions is used,
    - Dynamic, involving the estimation of pollutant concentrations as functions of time or as functions of position along a dynamic trajectory; evolution of the system in time is described in a causal manner,
    - Sequential, in which a sequence of conditions is considered; a separate independent calculation is done for each, or
    - Climatological, in which a number of different conditions are considered, each weighted by its frequency of occurrence; a separate calculation is done for each.

The user should be able to categorize the study model according to the general modeling approach from the definitions given and the study model documentation. If further discussion is needed, Appendix A.4.2 may be consulted. It should be pointed out that the first categorization relates to the treatment of dispersion by the study model and that different classifications may be needed for the treatments of horizontal and vertical dispersion.

The treatment of the time dependence of pollutant concentrations must be determined in order to carry out the second classification, and the user should be able to make this determination from the definitions provided together with the study model documentation. Again, further discussion is given in Appendix A.4.2.

Two points need to be made here regarding the classification of time dependence. The first relates to the difference between a dynamic model and a sequential model. Dynamic models often divide the total simulated time interval into a series of time steps and treat the pollutant distribution at the end of one step as the initial distribution for the next, thereby handling the time dependence in a causal manner. Sequential models also consider a series of time periods, but ignore the causal relation between pollutant distributions at each time step and do independent calculations for each.

The second point is that for sequential and climatological models, the individual calculations made for each of the conditions considered may be carried out using either dynamic or steady-state methods; a steady-state model is almost always used. This classification should also be indicated. Thus combinations like "climatological (steady-state)" or "sequential (steady-state)" arise.

Table B.1 in Appendix B gives the classification for selected reference models suggested for use in this workbook.

4.4 IDENTIFICATION OF REFERENCE MODEL

Table 4.1 suggests reference models that may be associated with some of the indexed applications. Each suggested reference model is briefly described in Appendix B. In the table, many applications do not have an associated reference model. In these cases, the user is encouraged to compare his model with some other applicable simulation model. If no such model is available, there is no reference model and no comparison can be made. Since not all aspects of an application have been classified by the foregoing procedure, footnotes have been provided where additional information is required in determining the appropriate reference model.

Table 4.1. Suggested Reference Models for Indexed Applications[a]

Index Number	Reference Model	Index Number	Reference Model	Index Number	Reference Model
1111	Valley, CRSTER (b,c)	2211	Valley	4111	Valley
1112		2212		4112	
1113	CDM, CRSTER (c,h)	2213	STRAM	4113	CDM
1114		2214	STRAM	4114	
1121	Valley	2221		4121	Valley
1122		2222		4122	
1123	CDM	2223	RAM	4123	CDM
1124		2224		4124	
1131		2231		4131	
1132		2232		4132	
1133		2233		4133	
1134		2234		4134	
1141	Valley	2241		4141	Valley
1142		2242		4142	
1143	CDM	2243	RAM	4143	CDM
1144		2244		4144	
1211	Valley, CRSTER (b,c)	3111	Valley	4211	Valley
1212		3112		4212	
1213	RAM, CRSTER (c,i)	3113	ATM	4213	STRAM
1214		3114		4214	STRAM
1221		3121	Valley	4221	
1222		3122		4222	
1223	RAM	3123		4223	RAM
1224		3124		4224	
1231		3131		4231	
1232		3132		4232	
1233	HIWAY, APRAC (d)	3133		4233	
1234		3134		4234	
1241		3141	Valley	4241	
1242		3142		4242	
1243	RAM, APRAC (e)	3143	CDM	4243	RAM
1244		3144		4244	
2111	Valley	3211	Valley	5111	
2112		3212		5112	
2113	CDM	3213	STRAM	5113	
2114		3214	STRAM	5114	
2121	Valley	3221		5121	
2122		3222		5122	
2123	CDM	3223	RAM	5123	
2124		3224		5124	
2131		3231		5131	
2132		3232		5132	
2133		3233		5133	
2134		3234		5134	
2141	Valley	3241		5141	
2142		3242		5142	
2143	CDM	3243	RAM	5143	
2144		3244		5144	
5211	SAI, DIFKIN (f)	6223	SAI, DIFKIN (f)	7234	
5212		6224		7241	
5213	SAI, DIFKIN (f)	6231		7242	
5214		6232		7243	
5221	SAI, DIFKIN (f)	6233		7244	
5222		6234		8111	
5223	SAI, DIFKIN (f)	6241	SAI, DIFKIN (f)	8112	
5224		6242		8113	
5231		6243	SAI, DIFKIN (f)	8114	
5232		6244		8121	

Table 4.1. (Contd.)

Index Number	Reference Model	Index Number	Reference Model	Index Number	Reference Model
5233		7111		8122	
5234		7112		8123	
5241	SAI, DIFKIN (f)	7113		8124	
5242		7114		8131	
5243	SAI, DIFKIN (f)	7121		8132	
5244		7122		8133	
6111		7123		8134	
6112		7124		8141	
6113		7131		8142	
6114		7132		8143	
6121		7133		8144	
6122		7134		8211	
6123		7141		8212	
6124		7142		8213	STRAM
6131		7143		8214	STRAM
6132		7144		8221	
6133		7211		8222	
6134		7212		8223	
6141		7213	STRAM	8224	
6142		7214	STRAM	8231	
6143		7221		8232	
6144		7222		8233	
6211	SAI, DIFKIN (f)	7223		8234	
6212		7224		8241	
6213	STRAM,SAI,DIFKIN(f,g)	7231		8242	
6214	STRAM	7232		8243	
6221	SAI, DIFKIN (f)	7233		8244	
6222					

Note: References to users' guides for each suggested reference model can be found in Appendix B.

[a] For applications for which no reference is listed, the user should compare his model with another applicable simulation model.

[b] Valley should be used when the receptor height exceeds the stack height (plume impaction case).

[c] CRSTER should be used only when receptor is below stack height.

[d] HIWAY is used for analysis of single highway link, APRAC for urban highway systems.

[e] Choose RAM for a combination of source types, APRAC for multiple line sources (highway systems).

[f] SAI is a regional grid model; DIFKIN is a trajectory model. Which to choose as a reference model depends upon aspects of the user's application not classified in the tree. SAI treats only photochemical smog. DIFKIN is also designed to treat photochemical smog, but provision is made for user-specification of an arbitrary chemical mechanism involving arbitrary, user-defined chemical species. Area sources may require other than emission data for pre-processor or preprocessing by user in both models.

[g] STRAM allows treatments of other than photochemical reactions. If the interest is in photochemistry choose SAI or DIFKIN.

[h] CRSTER assumes all sources are located at the same point. For a single source with multiple stacks, where this is a reasonable approximation, choose CRSTER rather than CDM as the reference model.

[i] CRSTER assumes all sources are located at the same point. For a single source with multiple stacks, where this is a reasonable approximation, choose CRSTER rather than RAM as the reference model.

4.5 REVIEW AND MODIFICATION OF IMPORTANCE RATINGS

As indicated in Section 2.1, the importance rating of an element is a measure of the importance of that element as a factor in determining atmospheric pollutant concentrations in the application of interest. The importance ratings are used as weighting factors in combining the individual element-by-element comparisons of the study and reference models into a final comparative evaluation.

Tables 4.2–4.13 at the end of this section give the importance rating of each element in each of the indexed applications. Brief discussions of these ratings may be found in Appendix A.9. At this point in the methodology, the user should review the importance ratings corresponding to the application index previously constructed and determine the need for modification of these ratings in the specific situation of interest.

Three types of situations arise that may justify modifying the importance ratings given in the tables at the end of this section:

- When the particular circumstances being modeled, or the particular interests of the user indicate that an element is either more or less important than the tabulated entry,
- When a particular element is of such overwhelming interest or importance that its treatment is critical to the application, and
- When a particular element has no bearing on the application and hence is irrelevant.

In the first situation, the decision to change a rating depends very much on the particular situation involved and the particular interests of the user. The user should review these ratings considering those aspects of the specific application not considered in the Application Tree. If necessary, the user should modify these ratings. Such changes should be made only after thoughtful reflection and consultation with an expert. For example, the user may be interested in estimating the amount of SO_2 removed by deposition in a region where deposition would usually be small and hence rated as of LOW importance. Given this particular interest, the importance rating for physical removal might be changed from LOW to MEDIUM or HIGH with the concurrence of an expert. The choice between MEDIUM and HIGH must be left to the user's discretion and depends upon how much weight it is felt that deposition deserves relative to the other application elements.

It may also be desirable to give one element exceptional weight in the technical evaluation. In this case, the element is designated CRITICAL to the overall technical evaluation. The comparison of the way that element is treated is weighted even more heavily than that of an element of HIGH importance. The CRITICAL designation should be used sparingly and then only when the user has a very strong interest in an effect associated specifically with that element. As an example, if it is desired to pick one of several alternative sites for a new source so as to give the "best" resulting air pollution estimates, source-receptor relationship might be treated as a CRITICAL element. In this example, the user needs to determine the differences in pollutant concentrations as the horizontal location of the source changes, perhaps by only relatively small amounts. Only models that handle horizontal location in a detailed manner would be acceptable. However, horizontal location is only one aspect of the application element "source-receptor relationship." In such situations, the user must identify clearly which aspect is critical in making the comparison between two models.

Lastly, some elements may be IRRELEVANT in the application of interest and should be so designated. These elements are not considered at all in the technical comparison. Examples of irrelevant elements include chemistry and reaction mechanism for primary conservative pollutants and physical removal in situations for which dry deposition and precipitation scavenging are unimportant. Although it may appear a rather simple matter to decide whether a given element is irrelevant, the user must be cautioned against the indiscriminate designation of irrelevant elements. Except in clear-cut instances such as the examples given above, most elements will have at least some LOW importance to the application and may need to be considered in cases where ambiguity exists. Irrelevant elements, however, are never considered in the comparison under any circumstances.

It bears repeating that changes in the importance ratings and especially the designation of an application element as CRITICAL should be undertaken only with expert advice and a firm conviction that the specific situation to be simulated clearly dictates such changes. Otherwise, the uniformity of evaluation that this workbook can provide is nullified. At most, no more than one or two changes in the tabulated importance ratings or a single critical designation, if any, should be made.

TABLES 4.2–4.13 – IMPORTANCE RATINGS

These ratings are based on the relative importance of each element to each class of applications as defined by the branches of the Application Tree.

For an interpretation of the Application Index as it applies to each table, see Fig. 3.1.

Brief discussions of these ratings are contained in Appendix A.9.

Table 4.2. Importance Ratings for Source-Receptor Relationships

1111	HIGH	3113	HIGH	5121	HIGH	7123	HIGH
1112	MEDIUM	3114	MEDIUM	5122	MEDIUM	7124	MEDIUM
1113	HIGH	3121	HIGH	5123	HIGH	7131	HIGH
1114	MEDIUM	3122	MEDIUM	5124	MEDIUM	7132	HIGH
1121	HIGH	3123	HIGH	5131	HIGH	7133	HIGH
1122	MEDIUM	3124	MEDIUM	5132	MEDIUM	7134	MEDIUM
1123	MEDIUM	3131	HIGH	5133	HIGH	7141	HIGH
1124	MEDIUM	3132	MEDIUM	5134	MEDIUM	7142	MEDIUM
1131	HIGH	3133	HIGH	5141	HIGH	7143	HIGH
1132	MEDIUM	3134	MEDIUM	5142	MEDIUM	7144	MEDIUM
1133	HIGH	3141	HIGH	5143	MEDIUM	7211	HIGH
1134	MEDIUM	3142	MEDIUM	5144	MEDIUM	7212	HIGH
1141	MEDIUM	3143	MEDIUM	5211	HIGH	7213	HIGH
1142	MEDIUM	3144	MEDIUM	5212	HIGH	7214	HIGH
1143	MEDIUM	3211	HIGH	5213	HIGH	7221	HIGH
1144	MEDIUM	3212	HIGH	5214	MEDIUM	7222	HIGH
1211	HIGH	3213	HIGH	5221	HIGH	7223	HIGH
1212	MEDIUM	3214	MEDIUM	5222	MEDIUM	7224	MEDIUM
1213	HIGH	3221	HIGH	5223	HIGH	7231	HIGH
1214	MEDIUM	3222	MEDIUM	5224	MEDIUM	7232	HIGH
1221	HIGH	3223	HIGH	5231	HIGH	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	HIGH	7234	HIGH
1223	HIGH	3231	HIGH	5233	HIGH	7241	HIGH
1224	MEDIUM	3232	HIGH	5234	MEDIUM	7242	MEDIUM
1231	HIGH	3233	HIGH	5241	HIGH	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	MEDIUM	7244	MEDIUM
1233	HIGH	3241	HIGH	5243	HIGH	8111	HIGH
1234	MEDIUM	3242	MEDIUM	5244	MEDIUM	8112	HIGH
1241	HIGH	3243	HIGH	6111	HIGH	8113	HIGH
1242	MEDIUM	3244	MEDIUM	6112	HIGH	8114	HIGH
1243	MEDIUM	4111	HIGH	6113	HIGH	8121	HIGH
1244	MEDIUM	4112	HIGH	6114	HIGH	8122	HIGH
2111	HIGH	4113	HIGH	6121	HIGH	8123	HIGH
2112	HIGH	4114	MEDIUM	6122	HIGH	8124	MEDIUM
2113	HIGH	4121	HIGH	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	MEDIUM	8132	HIGH
2121	HIGH	4123	HIGH	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	HIGH	4131	HIGH	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	HIGH	6134	HIGH	8142	MEDIUM
2131	HIGH	4133	HIGH	6141	HIGH	8143	HIGH
2132	HIGH	4134	MEDIUM	6142	MEDIUM	8144	MEDIUM
2133	HIGH	4141	HIGH	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	MEDIUM	8212	HIGH
2141	HIGH	4143	HIGH	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	HIGH	4211	HIGH	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	HIGH	6214	HIGH	8222	HIGH
2211	HIGH	4213	HIGH	6221	HIGH	8223	HIGH
2212	HIGH	4214	HIGH	6222	HIGH	8224	HIGH
2213	HIGH	4221	HIGH	6223	HIGH	8231	HIGH
2214	HIGH	4222	HIGH	6224	HIGH	8232	HIGH
2221	HIGH	4223	HIGH	6231	HIGH	8233	HIGH
2222	HIGH	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	HIGH	4231	HIGH	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	HIGH	6234	HIGH	8242	HIGH
2231	HIGH	4233	HIGH	6241	HIGH	8243	HIGH
2232	HIGH	4234	HIGH	6242	HIGH	8244	MEDIUM
2233	HIGH	4241	HIGH	6243	HIGH		
2234	HIGH	4242	MEDIUM	6244	MEDIUM		
2241	HIGH	4243	HIGH	7111	HIGH		
2242	MEDIUM	4244	MEDIUM	7112	HIGH		
2243	HIGH	5111	HIGH	7113	HIGH		
2244	MEDIUM	5112	MEDIUM	7114	MEDIUM		
3111	HIGH	5113	HIGH	7121	HIGH		
3112	MEDIUM	5114	MEDIUM	7122	MEDIUM		

Table 4.3. Importance Ratings for Emission Rate

1111	MEDIUM	3113	MEDIUM	5121	HIGH	7123	HIGH
1112	MEDIUM	3114	MEDIUM	5122	MEDIUM	7124	MEDIUM
1113	MEDIUM	3121	MEDIUM	5123	HIGH	7131	HIGH
1114	MEDIUM	3122	MEDIUM	5124	MEDIUM	7132	MEDIUM
1121	MEDIUM	3123	MEDIUM	5131	HIGH	7133	HIGH
1122	MEDIUM	3124	MEDIUM	5132	MEDIUM	7134	MEDIUM
1123	MEDIUM	3131	MEDIUM	5133	HIGH	7141	MEDIUM
1124	MEDIUM	3132	MEDIUM	5134	MEDIUM	7142	MEDIUM
1131	MEDIUM	3133	MEDIUM	5141	MEDIUM	7143	MEDIUM
1132	MEDIUM	3134	MEDIUM	5142	MEDIUM	7144	MEDIUM
1133	MEDIUM	3141	MEDIUM	5143	MEDIUM	7211	HIGH
1134	MEDIUM	3142	MEDIUM	5144	MEDIUM	7212	HIGH
1141	MEDIUM	3143	MEDIUM	5211	HIGH	7213	HIGH
1142	MEDIUM	3144	MEDIUM	5212	HIGH	7214	HIGH
1143	MEDIUM	3211	HIGH	5213	HIGH	7221	HIGH
1144	MEDIUM	3212	MEDIUM	5214	HIGH	7222	HIGH
1211	HIGH	3213	HIGH	5221	HIGH	7223	HIGH
1212	MEDIUM	3214	MEDIUM	5222	HIGH	7224	HIGH
1213	HIGH	3221	HIGH	5223	HIGH	7231	HIGH
1214	MEDIUM	3222	MEDIUM	5224	HIGH	7232	HIGH
1221	HIGH	3223	HIGH	5231	HIGH	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	HIGH	7234	HIGH
1223	HIGH	3231	HIGH	5233	HIGH	7241	HIGH
1224	MEDIUM	3232	MEDIUM	5234	HIGH	7242	MEDIUM
1231	HIGH	3233	HIGH	5241	HIGH	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	MEDIUM	7244	MEDIUM
1233	HIGH	3241	MEDIUM	5243	HIGH	8111	HIGH
1234	MEDIUM	3242	MEDIUM	5244	MEDIUM	8112	HIGH
1241	MEDIUM	3243	MEDIUM	6111	HIGH	8113	HIGH
1242	MEDIUM	3244	MEDIUM	6112	HIGH	8114	HIGH
1243	MEDIUM	4111	HIGH	6113	HIGH	8121	HIGH
1244	MEDIUM	4112	MEDIUM	6114	HIGH	8122	HIGH
2111	HIGH	4113	HIGH	6121	HIGH	8123	HIGH
2112	MEDIUM	4114	MEDIUM	6122	HIGH	8124	HIGH
2113	HIGH	4121	HIGH	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	HIGH	8132	HIGH
2121	HIGH	4123	HIGH	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	HIGH	4131	HIGH	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	MEDIUM	6134	HIGH	8142	MEDIUM
2131	HIGH	4133	HIGH	6141	HIGH	8143	HIGH
2132	MEDIUM	4134	MEDIUM	6142	MEDIUM	8144	MEDIUM
2133	HIGH	4141	MEDIUM	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	MEDIUM	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	MEDIUM	4211	HIGH	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	HIGH	6214	HIGH	8222	HIGH
2211	HIGH	4213	HIGH	6221	HIGH	8223	HIGH
2212	HIGH	4214	HIGH	6222	HIGH	8224	HIGH
2213	HIGH	4221	HIGH	6223	HIGH	8231	HIGH
2214	HIGH	4222	HIGH	6224	HIGH	8232	HIGH
2221	HIGH	4223	HIGH	6231	HIGH	8233	HIGH
2222	HIGH	4224	HIGH	6232	HIGH	8234	HIGH
2223	HIGH	4231	HIGH	6233	HIGH	8241	HIGH
2224	HIGH	4232	HIGH	6234	HIGH	8242	HIGH
2231	HIGH	4233	HIGH	6241	HIGH	8243	HIGH
2232	HIGH	4234	HIGH	6242	HIGH	8244	HIGH
2233	HIGH	4241	HIGH	6243	HIGH		
2234	HIGH	4242	MEDIUM	6244	HIGH		
2241	HIGH	4243	HIGH	7111	HIGH		
2242	MEDIUM	4244	MEDIUM	7112	MEDIUM		
2243	HIGH	5111	HIGH	7113	HIGH		
2244	MEDIUM	5112	MEDIUM	7114	MEDIUM		
3111	MEDIUM	5113	HIGH	7121	HIGH		
3112	MEDIUM	5114	MEDIUM	7122	MEDIUM		

Table 4.4. Importance Ratings for Chemical Composition of Emissions[a]

1111	LOW	3113	LOW	5121	MEDIUM	7123	MEDIUM
1112	LOW	3114	LOW	5122	MEDIUM	7124	MEDIUM
1113	LOW	3121	LOW	5123	MEDIUM	7131	MEDIUM
1114	LOW	3122	LOW	5124	MEDIUM	7132	MEDIUM
1121	LOW	3123	LOW	5131	MEDIUM	7133	MEDIUM
1122	LOW	3124	LOW	5132	MEDIUM	7134	MEDIUM
1123	LOW	3131	LOW	5133	MEDIUM	7141	MEDIUM
1124	LOW	3132	LOW	5134	MEDIUM	7142	MEDIUM
1131	LOW	3133	LOW	5141	MEDIUM	7143	MEDIUM
1132	LOW	3134	LOW	5142	MEDIUM	7144	MEDIUM
1133	LOW	3141	LOW	5143	MEDIUM	7211	MEDIUM
1134	LOW	3142	LOW	5144	MEDIUM	7212	MEDIUM
1141	LOW	3143	LOW	5211	MEDIUM	7213	MEDIUM
1142	LOW	3144	LOW	5212	MEDIUM	7214	MEDIUM
1143	LOW	3211	LOW	5213	MEDIUM	7221	MEDIUM
1144	LOW	3212	LOW	5214	MEDIUM	7222	MEDIUM
1211	LOW	3213	LOW	5221	MEDIUM	7223	MEDIUM
1212	LOW	3214	LOW	5222	MEDIUM	7224	MEDIUM
1213	LOW	3221	LOW	5223	MEDIUM	7231	MEDIUM
1214	LOW	3222	LOW	5224	MEDIUM	7232	MEDIUM
1221	LOW	3223	LOW	5231	MEDIUM	7233	MEDIUM
1222	LOW	3224	LOW	5232	MEDIUM	7234	MEDIUM
1223	LOW	3231	LOW	5233	MEDIUM	7241	MEDIUM
1224	LOW	3232	LOW	5234	MEDIUM	7242	MEDIUM
1231	LOW	3233	LOW	5241	MEDIUM	7243	MEDIUM
1232	LOW	3234	LOW	5242	MEDIUM	7244	MEDIUM
1233	LOW	3241	LOW	5243	MEDIUM	8111	HIGH
1234	LOW	3242	LOW	5244	MEDIUM	8112	HIGH
1241	LOW	3243	LOW	6111	HIGH	8113	HIGH
1242	LOW	3244	LOW	6112	HIGH	8114	HIGH
1243	LOW	4111	MEDIUM	6113	HIGH	8121	HIGH
1244	LOW	4112	MEDIUM	6114	HIGH	8122	HIGH
2111	MEDIUM	4113	MEDIUM	6121	HIGH	8123	HIGH
2112	MEDIUM	4114	MEDIUM	6122	HIGH	8124	HIGH
2113	MEDIUM	4121	MEDIUM	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	HIGH	8132	HIGH
2121	MEDIUM	4123	MEDIUM	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	MEDIUM	4131	MEDIUM	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	MEDIUM	6134	HIGH	8142	HIGH
2131	MEDIUM	4133	MEDIUM	6141	HIGH	8143	HIGH
2132	MEDIUM	4134	MEDIUM	6142	HIGH	8144	HIGH
2133	MEDIUM	4141	MEDIUM	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	HIGH	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	MEDIUM	4211	MEDIUM	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	MEDIUM	6214	HIGH	8222	HIGH
2211	MEDIUM	4213	MEDIUM	6221	HIGH	8223	HIGH
2212	MEDIUM	4214	MEDIUM	6222	HIGH	8224	HIGH
2213	MEDIUM	4221	MEDIUM	6223	HIGH	8231	HIGH
2214	MEDIUM	4222	MEDIUM	6224	HIGH	8232	HIGH
2221	MEDIUM	4223	MEDIUM	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	MEDIUM	4231	MEDIUM	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	MEDIUM	6234	HIGH	8242	HIGH
2231	MEDIUM	4233	MEDIUM	6241	HIGH	8243	HIGH
2232	MEDIUM	4234	MEDIUM	6242	HIGH	8244	HIGH
2233	MEDIUM	4241	MEDIUM	6243	HIGH		
2234	MEDIUM	4242	MEDIUM	6244	HIGH		
2241	MEDIUM	4243	MEDIUM	7111	MEDIUM		
2242	MEDIUM	4244	MEDIUM	7112	MEDIUM		
2243	MEDIUM	5111	MEDIUM	7113	MEDIUM		
2244	MEDIUM	5112	MEDIUM	7114	MEDIUM		
3111	LOW	5113	MEDIUM	7121	MEDIUM		
3112	LOW	5114	MEDIUM	7122	MEDIUM		

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[a] When a particulate size distribution is required, consult an expert to determine the importance of this application element.

Table 4.5. Importance Ratings for Plume Behavior

1111	HIGH	3113	HIGH	5121	MEDIUM	7123	MEDIUM
1112	MEDIUM	3114	MEDIUM	5122	LOW	7124	LOW
1113	MEDIUM	3121	MEDIUM	5123	MEDIUM	7131	HIGH
1114	LOW	3122	LOW	5124	LOW	7132	MEDIUM
1121	MEDIUM	3123	MEDIUM	5131	MEDIUM	7133	MEDIUM
1122	LOW	3124	LOW	5132	LOW	7134	LOW
1123	MEDIUM	3131	HIGH	5133	MEDIUM	7141	HIGH
1124	LOW	3132	MEDIUM	5134	LOW	7142	MEDIUM
1131	MEDIUM	3133	MEDIUM	5141	MEDIUM	7143	MEDIUM
1132	LOW	3134	LOW	5142	LOW	7144	LOW
1133	MEDIUM	3141	HIGH	5143	MEDIUM	7211	HIGH
1134	LOW	3142	MEDIUM	5144	LOW	7212	MEDIUM
1141	MEDIUM	3143	MEDIUM	5211	HIGH	7213	HIGH
1142	LOW	3144	LOW	5212	MEDIUM	7214	MEDIUM
1143	MEDIUM	3211	HIGH	5213	HIGH	7221	HIGH
1144	LOW	3212	MEDIUM	5214	MEDIUM	7222	MEDIUM
1211	HIGH	3213	HIGH	5221	HIGH	7223	HIGH
1212	MEDIUM	3214	MEDIUM	5222	MEDIUM	7224	MEDIUM
1213	HIGH	3221	HIGH	5223	MEDIUM	7231	HIGH
1214	MEDIUM	3222	MEDIUM	5224	LOW	7232	MEDIUM
1221	HIGH	3223	HIGH	5231	HIGH	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	MEDIUM	7234	MEDIUM
1223	MEDIUM	3231	HIGH	5233	HIGH	7241	HIGH
1224	LOW	3232	MEDIUM	5234	MEDIUM	7242	MEDIUM
1231	HIGH	3233	HIGH	5241	HIGH	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	MEDIUM	7244	MEDIUM
1233	HIGH	3241	HIGH	5243	HIGH	8111	HIGH
1234	MEDIUM	3242	MEDIUM	5244	MEDIUM	8112	MEDIUM
1241	HIGH	3243	HIGH	6111	HIGH	8113	HIGH
1242	MEDIUM	3244	MEDIUM	6112	MEDIUM	8114	MEDIUM
1243	HIGH	4111	HIGH	6113	MEDIUM	8121	MEDIUM
1244	MEDIUM	4112	MEDIUM	6114	LOW	8122	LOW
2111	HIGH	4113	HIGH	6121	MEDIUM	8123	MEDIUM
2112	MEDIUM	4114	MEDIUM	6122	LOW	8124	LOW
2113	MEDIUM	4121	MEDIUM	6123	MEDIUM	8131	HIGH
2114	LOW	4122	LOW	6124	LOW	8132	MEDIUM
2121	MEDIUM	4123	MEDIUM	6131	MEDIUM	8133	MEDIUM
2122	LOW	4124	LOW	6132	LOW	8134	LOW
2123	MEDIUM	4131	HIGH	6133	MEDIUM	8141	HIGH
2124	LOW	4132	MEDIUM	6134	LOW	8142	MEDIUM
2131	MEDIUM	4133	MEDIUM	6141	MEDIUM	8143	MEDIUM
2132	LOW	4134	LOW	6142	LOW	8144	LOW
2133	MEDIUM	4141	HIGH	6143	MEDIUM	8211	HIGH
2134	LOW	4142	MEDIUM	6144	LOW	8212	MEDIUM
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	LOW	4144	LOW	6212	MEDIUM	8214	MEDIUM
2143	MEDIUM	4211	HIGH	6213	HIGH	8221	HIGH
2144	LOW	4212	MEDIUM	6214	MEDIUM	8222	MEDIUM
2211	HIGH	4213	HIGH	6221	HIGH	8223	HIGH
2212	MEDIUM	4214	MEDIUM	6222	MEDIUM	8224	MEDIUM
2213	HIGH	4221	HIGH	6223	MEDIUM	8231	HIGH
2214	MEDIUM	4222	MEDIUM	6224	LOW	8232	MEDIUM
2221	HIGH	4223	HIGH	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	MEDIUM	8234	MEDIUM
2223	MEDIUM	4231	HIGH	6233	HIGH	8241	HIGH
2224	LOW	4232	MEDIUM	6234	MEDIUM	8242	MEDIUM
2231	HIGH	4233	HIGH	6241	HIGH	8243	HIGH
2232	MEDIUM	4234	MEDIUM	6242	MEDIUM	8244	MEDIUM
2233	HIGH	4241	HIGH	6243	HIGH		
2234	MEDIUM	4242	MEDIUM	6244	MEDIUM		
2241	HIGH	4243	HIGH	7111	HIGH		
2242	MEDIUM	4244	MEDIUM	7112	MEDIUM		
2243	HIGH	5111	HIGH	7113	HIGH		
2244	MEDIUM	5112	MEDIUM	7114	MEDIUM		
3111	HIGH	5113	MEDIUM	7121	MEDIUM		
3112	MEDIUM	5114	LOW	7122	LOW		

Table 4.6. Importance Ratings for Horizontal Wind Field

1111	MEDIUM	3113	MEDIUM	5121	MEDIUM	7123	MEDIUM
1112	HIGH	3114	HIGH	5122	HIGH	7124	HIGH
1113	MEDIUM	3121	MEDIUM	5123	MEDIUM	7131	HIGH
1114	HIGH	3122	HIGH	5124	HIGH	7132	HIGH
1121	MEDIUM	3123	MEDIUM	5131	HIGH	7133	MEDIUM
1122	HIGH	3124	HIGH	5132	HIGH	7134	HIGH
1123	MEDIUM	3131	MEDIUM	5133	MEDIUM	7141	MEDIUM
1124	HIGH	3132	HIGH	5134	HIGH	7142	HIGH
1131	MEDIUM	3133	MEDIUM	5141	MEDIUM	7143	MEDIUM
1132	HIGH	3134	HIGH	5142	HIGH	7144	HIGH
1133	MEDIUM	3141	MEDIUM	5143	MEDIUM	7211	HIGH
1134	HIGH	3142	HIGH	5144	HIGH	7212	HIGH
1141	MEDIUM	3143	MEDIUM	5211	HIGH	7213	HIGH
1142	HIGH	3144	HIGH	5212	HIGH	7214	HIGH
1143	MEDIUM	3211	HIGH	5213	HIGH	7221	HIGH
1144	HIGH	3212	HIGH	5214	HIGH	7222	HIGH
1211	HIGH	3213	HIGH	5221	HIGH	7223	MEDIUM
1212	HIGH	3214	HIGH	5222	HIGH	7224	HIGH
1213	HIGH	3221	HIGH	5223	MEDIUM	7231	HIGH
1214	HIGH	3222	HIGH	5224	HIGH	7232	HIGH
1221	HIGH	3223	MEDIUM	5231	HIGH	7233	HIGH
1222	HIGH	3224	HIGH	5232	HIGH	7234	HIGH
1223	MEDIUM	3231	HIGH	5233	HIGH	7241	HIGH
1224	HIGH	3232	HIGH	5234	HIGH	7242	HIGH
1231	HIGH	3233	MEDIUM	5241	HIGH	7243	MEDIUM
1232	HIGH	3234	HIGH	5242	HIGH	7244	HIGH
1233	MEDIUM	3241	HIGH	5243	MEDIUM	8111	HIGH
1234	HIGH	3242	HIGH	5244	HIGH	8112	HIGH
1241	HIGH	3243	MEDIUM	6111	HIGH	8113	MEDIUM
1242	HIGH	3244	HIGH	6112	HIGH	8114	HIGH
1243	MEDIUM	4111	HIGH	6113	MEDIUM	8121	HIGH
1244	HIGH	4112	HIGH	6114	HIGH	8122	HIGH
2111	HIGH	4113	MEDIUM	6121	HIGH	8123	MEDIUM
2112	HIGH	4114	HIGH	6122	HIGH	8124	HIGH
2113	MEDIUM	4121	MEDIUM	6123	MEDIUM	8131	HIGH
2114	HIGH	4122	HIGH	6124	HIGH	8132	HIGH
2121	MEDIUM	4123	MEDIUM	6131	HIGH	8133	MEDIUM
2122	HIGH	4124	HIGH	6132	HIGH	8134	HIGH
2123	MEDIUM	4131	HIGH	6133	MEDIUM	8141	HIGH
2124	HIGH	4132	HIGH	6134	HIGH	8142	HIGH
2131	HIGH	4133	MEDIUM	6141	HIGH	8143	MEDIUM
2132	HIGH	4134	HIGH	6142	HIGH	8144	HIGH
2133	MEDIUM	4141	MEDIUM	6143	MEDIUM	8211	HIGH
2134	HIGH	4142	HIGH	6144	HIGH	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	HIGH	4144	HIGH	6212	HIGH	8214	HIGH
2143	MEDIUM	4211	HIGH	6213	HIGH	8221	HIGH
2144	HIGH	4212	HIGH	6214	HIGH	8222	HIGH
2211	HIGH	4213	HIGH	6221	HIGH	8223	HIGH
2212	HIGH	4214	HIGH	6222	HIGH	8224	HIGH
2213	HIGH	4221	HIGH	6223	HIGH	8231	HIGH
2214	HIGH	4222	HIGH	6224	HIGH	8232	HIGH
2221	HIGH	4223	MEDIUM	6231	HIGH	8233	HIGH
2222	HIGH	4224	HIGH	6232	HIGH	8234	HIGH
2223	MEDIUM	4231	HIGH	6233	HIGH	8241	HIGH
2224	HIGH	4232	HIGH	6234	HIGH	8242	HIGH
2231	HIGH	4233	HIGH	6241	HIGH	8243	HIGH
2232	HIGH	4234	HIGH	6242	HIGH	8244	HIGH
2233	HIGH	4241	HIGH	6243	HIGH		
2234	HIGH	4242	HIGH	6244	HIGH		
2241	HIGH	4243	MEDIUM	7111	HIGH		
2242	HIGH	4244	HIGH	7112	HIGH		
2243	MEDIUM	5111	HIGH	7113	MEDIUM		
2244	HIGH	5112	HIGH	7114	HIGH		
3111	MEDIUM	5113	MEDIUM	7121	MEDIUM		
3112	HIGH	5114	HIGH	7122	HIGH		

Table 4.7. Importance Ratings for Vertical Wind Field

1111	HIGH	3113	LOW	5121	HIGH	7123	LOW
1112	MEDIUM	3114	LOW	5122	MEDIUM	7124	LOW
1113	LOW	3121	HIGH	5123	LOW	7131	HIGH
1114	LOW	3122	MEDIUM	5124	LOW	7132	MEDIUM
1121	HIGH	3123	LOW	5131	HIGH	7133	LOW
1122	MEDIUM	3124	LOW	5132	MEDIUM	7134	LOW
1123	LOW	3131	HIGH	5133	LOW	7141	HIGH
1124	LOW	3132	MEDIUM	5134	LOW	7142	MEDIUM
1131	HIGH	3133	LOW	5141	HIGH	7143	LOW
1132	MEDIUM	3134	LOW	5142	MEDIUM	7144	LOW
1133	LOW	3141	HIGH	5143	LOW	7211	HIGH
1134	LOW	3142	MEDIUM	5144	LOW	7212	HIGH
1141	HIGH	3143	LOW	5211	HIGH	7213	LOW
1142	MEDIUM	3144	LOW	5212	HIGH	7214	LOW
1143	LOW	3211	HIGH	5213	LOW	7221	HIGH
1144	LOW	3212	MEDIUM	5214	LOW	7222	HIGH
1211	HIGH	3213	LOW	5221	HIGH	7223	LOW
1212	MEDIUM	3214	LOW	5222	HIGH	7224	LOW
1213	LOW	3221	HIGH	5223	LOW	7231	HIGH
1214	LOW	3222	MEDIUM	5224	LOW	7232	HIGH
1221	HIGH	3223	LOW	5231	HIGH	7233	LOW
1222	MEDIUM	3224	LOW	5232	HIGH	7234	LOW
1223	LOW	3231	HIGH	5233	LOW	7241	HIGH
1224	LOW	3232	MEDIUM	5234	LOW	7242	HIGH
1231	HIGH	3233	LOW	5241	HIGH	7243	LOW
1232	MEDIUM	3234	LOW	5242	HIGH	7244	LOW
1233	LOW	3241	HIGH	5243	LOW	8111	HIGH
1234	LOW	3242	MEDIUM	5244	LOW	8112	HIGH
1241	HIGH	3243	LOW	6111	HIGH	8113	LOW
1242	MEDIUM	3244	LOW	6112	HIGH	8114	LOW
1243	LOW	4111	HIGH	6113	LOW	8121	HIGH
1244	LOW	4112	MEDIUM	6114	LOW	8122	HIGH
2111	HIGH	4113	LOW	6121	HIGH	8123	LOW
2112	MEDIUM	4114	LOW	6122	HIGH	8124	LOW
2113	LOW	4121	HIGH	6123	LOW	8131	HIGH
2114	LOW	4122	MEDIUM	6124	LOW	8132	HIGH
2121	HIGH	4123	LOW	6131	HIGH	8133	LOW
2122	MEDIUM	4124	LOW	6132	HIGH	8134	LOW
2123	LOW	4131	HIGH	6133	LOW	8141	HIGH
2124	LOW	4132	MEDIUM	6134	LOW	8142	HIGH
2131	HIGH	4133	LOW	6141	HIGH	8143	LOW
2132	MEDIUM	4134	LOW	6142	HIGH	8144	LOW
2133	LOW	4141	HIGH	6143	LOW	8211	HIGH
2134	LOW	4142	MEDIUM	6144	LOW	8212	HIGH
2141	HIGH	4143	LOW	6211	HIGH	8213	LOW
2142	MEDIUM	4144	LOW	6212	HIGH	8214	LOW
2143	LOW	4211	HIGH	6213	LOW	8221	HIGH
2144	LOW	4212	HIGH	6214	LOW	8222	HIGH
2211	HIGH	4213	LOW	6221	HIGH	8223	LOW
2212	HIGH	4214	LOW	6222	HIGH	8224	LOW
2213	LOW	4221	HIGH	6223	LOW	8231	HIGH
2214	LOW	4222	HIGH	6224	LOW	8232	HIGH
2221	HIGH	4223	LOW	6231	HIGH	8233	LOW
2222	HIGH	4224	LOW	6232	HIGH	8234	LOW
2223	LOW	4231	HIGH	6233	LOW	8241	HIGH
2224	LOW	4232	HIGH	6234	LOW	8242	HIGH
2231	HIGH	4233	LOW	6241	HIGH	8243	LOW
2232	HIGH	4234	LOW	6242	HIGH	8244	LOW
2233	LOW	4241	HIGH	6243	LOW		
2234	LOW	4242	HIGH	6244	LOW		
2241	HIGH	4243	LOW	7111	HIGH		
2242	HIGH	4244	LOW	7112	MEDIUM		
2243	LOW	5111	HIGH	7113	LOW		
2244	LOW	5112	MEDIUM	7114	LOW		
3111	HIGH	5113	LOW	7121	HIGH		
3112	MEDIUM	5114	LOW	7122	MEDIUM		

Table 4.8. Importance Ratings for Horizontal Dispersion

1111	MEDIUM	3113	HIGH	5121	MEDIUM	7123	HIGH
1112	MEDIUM	3114	MEDIUM	5122	MEDIUM	7124	MEDIUM
1113	MEDIUM	3121	MEDIUM	5123	MEDIUM	7131	HIGH
1114	MEDIUM	3122	MEDIUM	5124	MEDIUM	7132	MEDIUM
1121	MEDIUM	3123	MEDIUM	5131	HIGH	7133	HIGH
1122	MEDIUM	3124	MEDIUM	5132	MEDIUM	7134	MEDIUM
1123	MEDIUM	3131	MEDIUM	5133	HIGH	7141	HIGH
1124	MEDIUM	3132	MEDIUM	5134	MEDIUM	7142	MEDIUM
1131	MEDIUM	3133	MEDIUM	5141	HIGH	7143	HIGH
1132	MEDIUM	3134	MEDIUM	5142	MEDIUM	7144	MEDIUM
1133	MEDIUM	3141	MEDIUM	5143	HIGH	7211	HIGH
1134	MEDIUM	3142	MEDIUM	5144	MEDIUM	7212	HIGH
1141	MEDIUM	3143	MEDIUM	5211	HIGH	7213	HIGH
1142	MEDIUM	3144	MEDIUM	5212	HIGH	7214	HIGH
1143	MEDIUM	3211	HIGH	5213	HIGH	7221	HIGH
1144	MEDIUM	3212	HIGH	5214	HIGH	7222	HIGH
1211	HIGH	3213	HIGH	5221	HIGH	7223	HIGH
1212	MEDIUM	3214	HIGH	5222	MEDIUM	7224	HIGH
1213	HIGH	3221	HIGH	5223	HIGH	7231	HIGH
1214	MEDIUM	3222	MEDIUM	5224	MEDIUM	7232	HIGH
1221	MEDIUM	3223	HIGH	5231	HIGH	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	HIGH	7234	HIGH
1223	MEDIUM	3231	HIGH	5233	HIGH	7241	HIGH
1224	MEDIUM	3232	MEDIUM	5234	HIGH	7242	HIGH
1231	HIGH	3233	HIGH	5241	HIGH	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	HIGH	7244	HIGH
1233	HIGH	3241	HIGH	5243	HIGH	8111	HIGH
1234	MEDIUM	3242	MEDIUM	5244	HIGH	8112	HIGH
1241	HIGH	3243	HIGH	6111	HIGH	8113	HIGH
1242	MEDIUM	3244	MEDIUM	6112	HIGH	8114	HIGH
1243	HIGH	4111	HIGH	6113	HIGH	8121	HIGH
1244	MEDIUM	4112	MEDIUM	6114	HIGH	8122	MEDIUM
2111	HIGH	4113	HIGH	6121	HIGH	8123	HIGH
2112	MEDIUM	4114	MEDIUM	6122	MEDIUM	8124	MEDIUM
2113	HIGH	4121	MEDIUM	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	MEDIUM	8132	HIGH
2121	MEDIUM	4123	MEDIUM	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	MEDIUM	4131	HIGH	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	MEDIUM	6134	HIGH	8142	HIGH
2131	HIGH	4133	HIGH	6141	HIGH	8143	HIGH
2132	MEDIUM	4134	MEDIUM	6142	HIGH	8144	HIGH
2133	HIGH	4141	HIGH	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	HIGH	8212	HIGH
2141	HIGH	4143	HIGH	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	HIGH	4211	HIGH	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	HIGH	6214	HIGH	8222	HIGH
2211	HIGH	4213	HIGH	6221	HIGH	8223	HIGH
2212	HIGH	4214	HIGH	6222	HIGH	8224	HIGH
2213	HIGH	4221	HIGH	6223	HIGH	8231	HIGH
2214	HIGH	4222	MEDIUM	6224	HIGH	8232	HIGH
2221	HIGH	4223	HIGH	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	HIGH	4231	HIGH	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	HIGH	6234	HIGH	8242	HIGH
2231	HIGH	4233	HIGH	6241	HIGH	8243	HIGH
2232	HIGH	4234	HIGH	6242	HIGH	8244	HIGH
2233	HIGH	4241	HIGH	6243	HIGH		
2234	HIGH	4242	HIGH	6244	HIGH		
2241	HIGH	4243	HIGH	7111	HIGH		
2242	HIGH	4244	HIGH	7112	HIGH		
2243	HIGH	5111	HIGH	7113	HIGH		
2244	HIGH	5112	MEDIUM	7114	HIGH		
3111	HIGH	5113	HIGH	7121	HIGH		
3112	MEDIUM	5114	MEDIUM	7122	MEDIUM		

Table 4.9. Importance Ratings for Vertical Dispersion

1111	HIGH	3113	HIGH	5121	HIGH	7123	HIGH
1112	MEDIUM	3114	MEDIUM	5122	MEDIUM	7124	HIGH
1113	HIGH	3121	HIGH	5123	HIGH	7131	HIGH
1114	MEDIUM	3122	MEDIUM	5124	MEDIUM	7132	HIGH
1121	HIGH	3123	HIGH	5131	HIGH	7133	HIGH
1122	MEDIUM	3124	MEDIUM	5132	MEDIUM	7134	HIGH
1123	HIGH	3131	HIGH	5133	HIGH	7141	HIGH
1124	MEDIUM	3132	MEDIUM	5134	MEDIUM	7142	HIGH
1131	HIGH	3133	HIGH	5141	HIGH	7143	HIGH
1132	MEDIUM	3134	MEDIUM	5142	MEDIUM	7144	HIGH
1133	HIGH	3141	HIGH	5143	HIGH	7211	HIGH
1134	MEDIUM	3142	MEDIUM	5144	MEDIUM	7212	HIGH
1141	HIGH	3143	HIGH	5211	HIGH	7213	HIGH
1142	MEDIUM	3144	MEDIUM	5212	MEDIUM	7214	HIGH
1143	HIGH	3211	HIGH	5213	HIGH	7221	HIGH
1144	MEDIUM	3212	MEDIUM	5214	MEDIUM	7222	HIGH
1211	HIGH	3213	HIGH	5221	HIGH	7223	HIGH
1212	MEDIUM	3214	MEDIUM	5222	MEDIUM	7224	HIGH
1213	HIGH	3221	HIGH	5223	HIGH	7231	HIGH
1214	MEDIUM	3222	MEDIUM	5224	MEDIUM	7232	HIGH
1221	HIGH	3223	HIGH	5231	HIGH	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	MEDIUM	7234	HIGH
1223	HIGH	3231	HIGH	5233	HIGH	7241	HIGH
1224	MEDIUM	3232	MEDIUM	5234	MEDIUM	7242	HIGH
1231	HIGH	3233	HIGH	5241	HIGH	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	MEDIUM	7244	HIGH
1233	HIGH	3241	HIGH	5243	HIGH	8111	HIGH
1234	MEDIUM	3242	MEDIUM	5244	MEDIUM	8112	HIGH
1241	HIGH	3243	HIGH	6111	HIGH	8113	HIGH
1242	MEDIUM	3244	MEDIUM	6112	HIGH	8114	HIGH
1243	HIGH	4111	HIGH	6113	HIGH	8121	HIGH
1244	MEDIUM	4112	MEDIUM	6114	HIGH	8122	HIGH
2111	HIGH	4113	HIGH	6121	HIGH	8123	HIGH
2112	MEDIUM	4114	MEDIUM	6122	HIGH	8124	HIGH
2113	HIGH	4121	HIGH	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	HIGH	8132	HIGH
2121	HIGH	4123	HIGH	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	HIGH	4131	HIGH	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	MEDIUM	6134	HIGH	8142	HIGH
2131	HIGH	4133	HIGH	6141	HIGH	8143	HIGH
2132	MEDIUM	4134	MEDIUM	6142	HIGH	8144	HIGH
2133	HIGH	4141	HIGH	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	HIGH	8212	HIGH
2141	HIGH	4143	HIGH	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	HIGH	4211	HIGH	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	MEDIUM	6214	HIGH	8222	HIGH
2211	HIGH	4213	HIGH	6221	HIGH	8223	HIGH
2212	MEDIUM	4214	MEDIUM	6222	HIGH	8224	HIGH
2213	HIGH	4221	HIGH	6223	HIGH	8231	HIGH
2214	MEDIUM	4222	MEDIUM	6224	HIGH	8232	HIGH
2221	HIGH	4223	HIGH	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	HIGH	4231	HIGH	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	MEDIUM	6234	HIGH	8242	HIGH
2231	HIGH	4233	HIGH	6241	HIGH	8243	HIGH
2232	MEDIUM	4234	MEDIUM	6242	HIGH	8244	HIGH
2233	HIGH	4241	HIGH	6243	HIGH		
2234	MEDIUM	4242	MEDIUM	6244	HIGH		
2241	HIGH	4243	HIGH	7111	HIGH		
2242	MEDIUM	4244	MEDIUM	7112	HIGH		
2243	HIGH	5111	HIGH	7113	HIGH		
2244	MEDIUM	5112	MEDIUM	7114	HIGH		
3111	HIGH	5113	HIGH	7121	HIGH		
3112	MEDIUM	5114	MEDIUM	7122	HIGH		

Table 4.10. Importance Ratings for Chemistry and Reaction Mechanism

1111	LOW	3113	LOW	5121	MEDIUM	7123	MEDIUM
1112	LOW	3114	LOW	5122	MEDIUM	7124	MEDIUM
1113	LOW	3121	LOW	5123	MEDIUM	7131	MEDIUM
1114	LOW	3122	LOW	5124	MEDIUM	7132	MEDIUM
1121	LOW	3123	LOW	5131	MEDIUM	7133	MEDIUM
1122	LOW	3124	LOW	5132	MEDIUM	7134	MEDIUM
1123	LOW	3131	LOW	5133	MEDIUM	7141	MEDIUM
1124	LOW	3132	LOW	5134	MEDIUM	7142	MEDIUM
1131	LOW	3133	LOW	5141	MEDIUM	7143	MEDIUM
1132	LOW	3134	LOW	5142	MEDIUM	7144	MEDIUM
1133	LOW	3141	LOW	5143	MEDIUM	7211	MEDIUM
1134	LOW	3142	LOW	5144	MEDIUM	7212	MEDIUM
1141	LOW	3143	LOW	5211	MEDIUM	7213	MEDIUM
1142	LOW	3144	LOW	5212	MEDIUM	7214	MEDIUM
1143	LOW	3211	LOW	5213	MEDIUM	7221	MEDIUM
1144	LOW	3212	LOW	5214	MEDIUM	7222	MEDIUM
1211	LOW	3213	LOW	5221	MEDIUM	7223	MEDIUM
1212	LOW	3214	LOW	5222	MEDIUM	7224	MEDIUM
1213	LOW	3221	LOW	5223	MEDIUM	7231	MEDIUM
1214	LOW	3222	LOW	5224	MEDIUM	7232	MEDIUM
1221	LOW	3223	LOW	5231	MEDIUM	7233	MEDIUM
1222	LOW	3224	LOW	5232	MEDIUM	7234	MEDIUM
1223	LOW	3231	LOW	5233	MEDIUM	7241	MEDIUM
1224	LOW	3232	LOW	5234	MEDIUM	7242	MEDIUM
1231	LOW	3233	LOW	5241	MEDIUM	7243	MEDIUM
1232	LOW	3234	LOW	5242	MEDIUM	7244	MEDIUM
1233	LOW	3241	LOW	5243	MEDIUM	8111	HIGH
1234	LOW	3242	LOW	5244	MEDIUM	8112	HIGH
1241	LOW	3243	LOW	6111	HIGH	8113	HIGH
1242	LOW	3244	LOW	6112	HIGH	8114	HIGH
1243	LOW	4111	MEDIUM	6113	HIGH	8121	HIGH
1244	LOW	4112	MEDIUM	6114	HIGH	8122	HIGH
2111	MEDIUM	4113	MEDIUM	6121	HIGH	8123	HIGH
2112	MEDIUM	4114	MEDIUM	6122	HIGH	8124	HIGH
2113	MEDIUM	4121	MEDIUM	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	HIGH	8132	HIGH
2121	MEDIUM	4123	MEDIUM	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	MEDIUM	4131	MEDIUM	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	MEDIUM	6134	HIGH	8142	HIGH
2131	MEDIUM	4133	MEDIUM	6141	HIGH	8143	HIGH
2132	MEDIUM	4134	MEDIUM	6142	HIGH	8144	HIGH
2133	MEDIUM	4141	MEDIUM	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	HIGH	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	MEDIUM	4211	MEDIUM	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	MEDIUM	6214	HIGH	8222	HIGH
2211	MEDIUM	4213	MEDIUM	6221	HIGH	8223	HIGH
2212	MEDIUM	4214	MEDIUM	6222	HIGH	8224	HIGH
2213	MEDIUM	4221	MEDIUM	6223	HIGH	8231	HIGH
2214	MEDIUM	4222	MEDIUM	6224	HIGH	8232	HIGH
2221	MEDIUM	4223	MEDIUM	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	MEDIUM	4231	MEDIUM	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	MEDIUM	6234	HIGH	8242	HIGH
2231	MEDIUM	4233	MEDIUM	6241	HIGH	8243	HIGH
2232	MEDIUM	4234	MEDIUM	6242	HIGH	8244	HIGH
2233	MEDIUM	4241	MEDIUM	6243	HIGH		
2234	MEDIUM	4242	MEDIUM	6244	HIGH		
2241	MEDIUM	4243	MEDIUM	7111	MEDIUM		
2242	MEDIUM	4244	MEDIUM	7112	MEDIUM		
2243	MEDIUM	5111	MEDIUM	7113	MEDIUM		
2244	MEDIUM	5112	MEDIUM	7114	MEDIUM		
3111	LOW	5113	MEDIUM	7121	MEDIUM		
3112	LOW	5114	MEDIUM	7122	MEDIUM		

Table 4.11. Importance Ratings for Physical Removal Processes

1111	LOW	3113	MEDIUM	5121	LOW	7123	MEDIUM
1112	MEDIUM	3114	HIGH	5122	MEDIUM	7124	HIGH
1113	LOW	3121	HIGH	5123	LOW	7131	HIGH
1114	MEDIUM	3122	HIGH	5124	MEDIUM	7132	HIGH
1121	LOW	3123	MEDIUM	5131	LOW	7133	MEDIUM
1122	MEDIUM	3124	HIGH	5132	MEDIUM	7134	HIGH
1123	LOW	3131	HIGH	5133	LOW	7141	HIGH
1124	MEDIUM	3132	HIGH	5134	MEDIUM	7142	HIGH
1131	LOW	3133	MEDIUM	5141	LOW	7143	MEDIUM
1132	MEDIUM	3134	HIGH	5142	MEDIUM	7144	HIGH
1133	LOW	3141	HIGH	5143	LOW	7211	MEDIUM
1134	MEDIUM	3142	HIGH	5144	MEDIUM	7212	HIGH
1141	LOW	3143	MEDIUM	5211	LOW	7213	MEDIUM
1142	MEDIUM	3144	HIGH	5212	MEDIUM	7214	HIGH
1143	LOW	3211	MEDIUM	5213	LOW	7221	MEDIUM
1144	MEDIUM	3212	HIGH	5214	LOW	7222	HIGH
1211	LOW	3213	MEDIUM	5221	LOW	7223	MEDIUM
1212	MEDIUM	3214	HIGH	5222	MEDIUM	7224	HIGH
1213	LOW	3221	MEDIUM	5223	LOW	7231	MEDIUM
1214	LOW	3222	HIGH	5224	LOW	7232	HIGH
1221	LOW	3223	MEDIUM	5231	LOW	7233	MEDIUM
1222	MEDIUM	3224	HIGH	5232	MEDIUM	7234	HIGH
1223	LOW	3231	MEDIUM	5233	LOW	7241	MEDIUM
1224	LOW	3232	HIGH	5234	LOW	7242	HIGH
1231	LOW	3233	MEDIUM	5241	LOW	7243	MEDIUM
1232	MEDIUM	3234	HIGH	5242	MEDIUM	7244	HIGH
1233	LOW	3241	MEDIUM	5243	LOW	8111	HIGH
1234	LOW	3242	HIGH	5244	LOW	8112	HIGH
1241	LOW	3243	MEDIUM	6111	MEDIUM	8113	MEDIUM
1242	MEDIUM	3244	HIGH	6112	HIGH	8114	HIGH
1243	LOW	4111	HIGH	6113	MEDIUM	8121	HIGH
1244	LOW	4112	HIGH	6114	MEDIUM	8122	HIGH
2111	MEDIUM	4113	MEDIUM	6121	MEDIUM	8123	MEDIUM
2112	HIGH	4114	HIGH	6122	HIGH	8124	HIGH
2113	MEDIUM	4121	HIGH	6123	MEDIUM	8131	HIGH
2114	MEDIUM	4122	HIGH	6124	MEDIUM	8132	HIGH
2121	MEDIUM	4123	MEDIUM	6131	MEDIUM	8133	MEDIUM
2122	HIGH	4124	HIGH	6132	HIGH	8134	HIGH
2123	MEDIUM	4131	HIGH	6133	MEDIUM	8141	HIGH
2124	MEDIUM	4132	HIGH	6134	MEDIUM	8142	HIGH
2131	MEDIUM	4133	MEDIUM	6141	MEDIUM	8143	MEDIUM
2132	HIGH	4134	HIGH	6142	HIGH	8144	HIGH
2133	MEDIUM	4141	HIGH	6143	MEDIUM	8211	MEDIUM
2134	MEDIUM	4142	HIGH	6144	MEDIUM	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	MEDIUM	8213	MEDIUM
2142	HIGH	4144	HIGH	6212	MEDIUM	8214	HIGH
2143	MEDIUM	4211	MEDIUM	6213	LOW	8221	MEDIUM
2144	MEDIUM	4212	HIGH	6214	MEDIUM	8222	HIGH
2211	MEDIUM	4213	MEDIUM	6221	MEDIUM	8223	MEDIUM
2212	MEDIUM	4214	HIGH	6222	MEDIUM	8224	HIGH
2213	LOW	4221	MEDIUM	6223	LOW	8231	MEDIUM
2214	MEDIUM	4222	HIGH	6224	MEDIUM	8232	HIGH
2221	MEDIUM	4223	MEDIUM	6231	MEDIUM	8233	MEDIUM
2222	MEDIUM	4224	HIGH	6232	MEDIUM	8234	HIGH
2223	LOW	4231	MEDIUM	6233	LOW	8241	MEDIUM
2224	MEDIUM	4232	HIGH	6234	MEDIUM	8242	HIGH
2231	MEDIUM	4233	MEDIUM	6241	MEDIUM	8243	MEDIUM
2232	MEDIUM	4234	HIGH	6242	MEDIUM	8244	HIGH
2233	LOW	4241	MEDIUM	6243	LOW		
2234	MEDIUM	4242	HIGH	6244	MEDIUM		
2241	MEDIUM	4243	MEDIUM	7111	HIGH		
2242	MEDIUM	4244	HIGH	7112	HIGH		
2243	LOW	5111	LOW	7113	MEDIUM		
2244	MEDIUM	5112	MEDIUM	7114	HIGH		
3111	HIGH	5113	LOW	7121	HIGH		
3112	HIGH	5114	MEDIUM	7122	HIGH		

Table 4.12. Importance Ratings for Background, Boundary and Initial Conditions

1111	MEDIUM	3113	MEDIUM	5121	MEDIUM	7123	HIGH
1112	MEDIUM	3114	MEDIUM	5122	MEDIUM	7124	HIGH
1113	MEDIUM	3121	MEDIUM	5123	MEDIUM	7131	HIGH
1114	MEDIUM	3122	MEDIUM	5124	MEDIUM	7132	HIGH
1121	MEDIUM	3123	MEDIUM	5131	MEDIUM	7133	HIGH
1122	MEDIUM	3124	MEDIUM	5132	MEDIUM	7134	HIGH
1123	MEDIUM	3131	MEDIUM	5133	MEDIUM	7141	HIGH
1124	MEDIUM	3132	MEDIUM	5134	MEDIUM	7142	HIGH
1131	MEDIUM	3133	MEDIUM	5141	MEDIUM	7143	HIGH
1132	MEDIUM	3134	MEDIUM	5142	MEDIUM	7144	HIGH
1133	MEDIUM	3141	MEDIUM	5143	MEDIUM	7211	HIGH
1134	MEDIUM	3142	MEDIUM	5144	MEDIUM	7212	HIGH
1141	MEDIUM	3143	MEDIUM	5211	MEDIUM	7213	HIGH
1142	MEDIUM	3144	MEDIUM	5212	MEDIUM	7214	HIGH
1143	MEDIUM	3211	MEDIUM	5213	MEDIUM	7221	HIGH
1144	MEDIUM	3212	MEDIUM	5214	MEDIUM	7222	HIGH
1211	MEDIUM	3213	MEDIUM	5221	MEDIUM	7223	HIGH
1212	MEDIUM	3214	MEDIUM	5222	MEDIUM	7224	HIGH
1213	MEDIUM	3221	MEDIUM	5223	MEDIUM	7231	HIGH
1214	MEDIUM	3222	MEDIUM	5224	MEDIUM	7232	HIGH
1221	MEDIUM	3223	MEDIUM	5231	MEDIUM	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	MEDIUM	7234	HIGH
1223	MEDIUM	3231	MEDIUM	5233	MEDIUM	7241	HIGH
1224	MEDIUM	3232	MEDIUM	5234	MEDIUM	7242	HIGH
1231	MEDIUM	3233	MEDIUM	5241	MEDIUM	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	MEDIUM	7244	HIGH
1233	MEDIUM	3241	MEDIUM	5243	MEDIUM	8111	HIGH
1234	MEDIUM	3242	MEDIUM	5244	MEDIUM	8112	HIGH
1241	MEDIUM	3243	MEDIUM	6111	HIGH	8113	HIGH
1242	MEDIUM	3244	MEDIUM	6112	HIGH	8114	HIGH
1243	MEDIUM	4111	MEDIUM	6113	HIGH	8121	HIGH
1244	MEDIUM	4112	MEDIUM	6114	HIGH	8122	HIGH
2111	MEDIUM	4113	MEDIUM	6121	HIGH	8123	HIGH
2112	MEDIUM	4114	MEDIUM	6122	HIGH	8124	HIGH
2113	MEDIUM	4121	MEDIUM	6123	HIGH	8131	HIGH
2114	MEDIUM	4122	MEDIUM	6124	HIGH	8132	HIGH
2121	MEDIUM	4123	MEDIUM	6131	HIGH	8133	HIGH
2122	MEDIUM	4124	MEDIUM	6132	HIGH	8134	HIGH
2123	MEDIUM	4131	MEDIUM	6133	HIGH	8141	HIGH
2124	MEDIUM	4132	MEDIUM	6134	HIGH	8142	HIGH
2131	MEDIUM	4133	MEDIUM	6141	HIGH	8143	HIGH
2132	MEDIUM	4134	MEDIUM	6142	HIGH	8144	HIGH
2133	MEDIUM	4141	MEDIUM	6143	HIGH	8211	HIGH
2134	MEDIUM	4142	MEDIUM	6144	HIGH	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	MEDIUM	6212	HIGH	8214	HIGH
2143	MEDIUM	4211	MEDIUM	6213	HIGH	8221	HIGH
2144	MEDIUM	4212	MEDIUM	6214	HIGH	8222	HIGH
2211	MEDIUM	4213	MEDIUM	6221	HIGH	8223	HIGH
2212	MEDIUM	4214	MEDIUM	6222	HIGH	8224	HIGH
2213	MEDIUM	4221	MEDIUM	6223	HIGH	8231	HIGH
2214	MEDIUM	4222	MEDIUM	6224	HIGH	8232	HIGH
2221	MEDIUM	4223	MEDIUM	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	MEDIUM	4231	MEDIUM	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	MEDIUM	6234	HIGH	8242	HIGH
2231	MEDIUM	4233	MEDIUM	6241	HIGH	8243	HIGH
2232	MEDIUM	4234	MEDIUM	6242	HIGH	8244	HIGH
2233	MEDIUM	4241	MEDIUM	6243	HIGH		
2234	MEDIUM	4242	MEDIUM	6244	HIGH		
2241	MEDIUM	4243	MEDIUM	7111	HIGH		
2242	MEDIUM	4244	MEDIUM	7112	HIGH		
2243	MEDIUM	5111	MEDIUM	7113	HIGH		
2244	MEDIUM	5112	MEDIUM	7114	HIGH		
3111	MEDIUM	5113	MEDIUM	7121	HIGH		
3112	MEDIUM	5114	MEDIUM	7122	HIGH		

Table 4.13. Importance Ratings for Temporal Correlations

1111	LOW	3113	MEDIUM	5121	MEDIUM	7123	MEDIUM
1112	LOW	3114	LOW	5122	MEDIUM	7124	MEDIUM
1113	LOW	3121	MEDIUM	5123	MEDIUM	7131	HIGH
1114	LOW	3122	MEDIUM	5124	LOW	7132	MEDIUM
1121	LOW	3123	MEDIUM	5131	MEDIUM	7133	MEDIUM
1122	LOW	3124	LOW	5132	MEDIUM	7134	MEDIUM
1123	LOW	3131	MEDIUM	5133	MEDIUM	7141	HIGH
1124	LOW	3132	MEDIUM	5134	LOW	7142	MEDIUM
1131	LOW	3133	MEDIUM	5141	MEDIUM	7143	MEDIUM
1132	LOW	3134	LOW	5142	MEDIUM	7144	MEDIUM
1133	LOW	3141	MEDIUM	5143	MEDIUM	7211	HIGH
1134	LOW	3142	MEDIUM	5144	LOW	7212	HIGH
1141	LOW	3143	MEDIUM	5211	HIGH	7213	HIGH
1142	LOW	3144	LOW	5212	MEDIUM	7214	HIGH
1143	LOW	3211	HIGH	5213	MEDIUM	7221	HIGH
1144	LOW	3212	MEDIUM	5214	MEDIUM	7222	HIGH
1211	MEDIUM	3213	MEDIUM	5221	HIGH	7223	HIGH
1212	MEDIUM	3214	MEDIUM	5222	MEDIUM	7224	HIGH
1213	MEDIUM	3221	HIGH	5223	MEDIUM	7231	HIGH
1214	LOW	3222	MEDIUM	5224	MEDIUM	7232	HIGH
1221	MEDIUM	3223	MEDIUM	5231	HIGH	7233	HIGH
1222	MEDIUM	3224	MEDIUM	5232	MEDIUM	7234	HIGH
1223	MEDIUM	3231	HIGH	5233	MEDIUM	7241	HIGH
1224	LOW	3232	MEDIUM	5234	MEDIUM	7242	HIGH
1231	MEDIUM	3233	MEDIUM	5241	HIGH	7243	HIGH
1232	MEDIUM	3234	MEDIUM	5242	MEDIUM	7244	HIGH
1233	MEDIUM	3241	HIGH	5243	MEDIUM	8111	HIGH
1234	LOW	3242	MEDIUM	5244	MEDIUM	8112	MEDIUM
1241	MEDIUM	3243	MEDIUM	6111	HIGH	8113	MEDIUM
1242	MEDIUM	3244	MEDIUM	6112	MEDIUM	8114	MEDIUM
1243	MEDIUM	4111	MEDIUM	6113	MEDIUM	8121	HIGH
1244	LOW	4112	MEDIUM	6114	MEDIUM	8122	MEDIUM
2111	MEDIUM	4113	MEDIUM	6121	HIGH	8123	MEDIUM
2112	MEDIUM	4114	LOW	6122	MEDIUM	8124	MEDIUM
2113	MEDIUM	4121	MEDIUM	6123	MEDIUM	8131	HIGH
2114	LOW	4122	MEDIUM	6124	MEDIUM	8132	MEDIUM
2121	MEDIUM	4123	MEDIUM	6131	HIGH	8133	MEDIUM
2122	MEDIUM	4124	LOW	6132	MEDIUM	8134	MEDIUM
2123	MEDIUM	4131	MEDIUM	6133	MEDIUM	8141	HIGH
2124	LOW	4132	MEDIUM	6134	MEDIUM	8142	MEDIUM
2131	MEDIUM	4133	MEDIUM	6141	HIGH	8143	MEDIUM
2132	MEDIUM	4134	LOW	6142	MEDIUM	8144	MEDIUM
2133	MEDIUM	4141	MEDIUM	6143	MEDIUM	8211	HIGH
2134	LOW	4142	MEDIUM	6144	MEDIUM	8212	HIGH
2141	MEDIUM	4143	MEDIUM	6211	HIGH	8213	HIGH
2142	MEDIUM	4144	LOW	6212	HIGH	8214	HIGH
2143	MEDIUM	4211	HIGH	6213	HIGH	8221	HIGH
2144	LOW	4212	MEDIUM	6214	HIGH	8222	HIGH
2211	HIGH	4213	MEDIUM	6221	HIGH	8223	HIGH
2212	MEDIUM	4214	MEDIUM	6222	HIGH	8224	HIGH
2213	MEDIUM	4221	HIGH	6223	HIGH	8231	HIGH
2214	MEDIUM	4222	MEDIUM	6224	HIGH	8232	HIGH
2221	HIGH	4223	MEDIUM	6231	HIGH	8233	HIGH
2222	MEDIUM	4224	MEDIUM	6232	HIGH	8234	HIGH
2223	MEDIUM	4231	HIGH	6233	HIGH	8241	HIGH
2224	MEDIUM	4232	MEDIUM	6234	HIGH	8242	HIGH
2231	HIGH	4233	MEDIUM	6241	HIGH	8243	HIGH
2232	MEDIUM	4234	MEDIUM	6242	HIGH	8244	HIGH
2233	MEDIUM	4241	HIGH	6243	HIGH		
2234	MEDIUM	4242	MEDIUM	6244	HIGH		
2241	HIGH	4243	MEDIUM	7111	HIGH		
2242	MEDIUM	4244	MEDIUM	7112	MEDIUM		
2243	MEDIUM	5111	MEDIUM	7113	MEDIUM		
2244	MEDIUM	5112	MEDIUM	7114	MEDIUM		
3111	MEDIUM	5113	MEDIUM	7121	HIGH		
3112	MEDIUM	5114	LOW	7122	MEDIUM		

5 TREATMENT OF APPLICATION ELEMENTS

5.1 INTRODUCTION

This section gives specific guidelines for determining, for each application element, the treatment used by a given model. In making these determinations, reference to the dispersion equation and the other working equations documented on Evaluation Form-Part A is useful. The user must be careful in determining the treatments used by the study model. Model documentation is often inadequate and occasionally inconsistent, and in some cases it may be necessary to examine the computer code itself to determine what the real treatment of some element is. The list of input variables should be examined and checked for consistency with the working equations and general formulation to insure that sufficient information is input and that no seemingly irrelevant data are required. If these general guidelines are followed, the effort involved in determining the treatments of the application elements will be minimized.

5.2 TREATMENT OF SOURCE-RECEPTOR RELATIONSHIP

There are six factors to be considered:

- Horizontal location of sources,
- Release heights,
- Downwind and crosswind distances,
- Orientation of area and line sources,
- Horizontal location of receptors, and
- Height of receptors.

Guidance to aid the user in determining the treatment of these factors is given below.* This guidance and Table 5.1 listing the various treatments assume a multiple source application. In the context of source location, receptor location, release height, and receptor height, the user should not compare treatments solely on their respective levels of detail. Consideration should also be given to whether the level of detail employed is required for the application of interest. For example, if a single source-receptor pair is of interest, a model need not be able to locate many sources and receptors as long as a single pair can be treated in its true relationship.

Horizontal Location

The treatment of the horizontal location of point sources can be found by determining:

- Whether each source can be located arbitrarily at its true location.
- If not, the level of aggregation imposed by the model as distinct from that imposed by the emission inventory.
- The basis for this aggregation.

The key consideration is the level or degree of aggregation required. Little or none implies a relatively detailed treatment in contrast to treatments that require a lot. Some treatments aggregate on the basis of a parameter such as source type and hence convey little information on source location.

For area sources, the considerations are similar:

- Whether each source can be located arbitrarily or must be blocks in a fixed grid network.
- Whether the user can change the scale of the grid to suit the detail available in the inventory.
- Whether the model imposes aggregation in addition to any imposed by the inventory in developing the area sources.
- The basis for the model's aggregation.

The major difference between the point and area sources comes from the two-dimensional nature of the area sources. They must be located as blocks rather than as points; otherwise the progression from the most to the least detailed treatments is the same for both types.

For line sources, the situation is similar except that the line may be treated as an elongated volume source having length, width, and height. For the location of a line the user should determine:

- Whether the line can have width and/or height or is truly considered a one-dimensional source.
- If the receptor height is arbitrary or if only one height (usually ground level) is assumed.
- Whether the line can be uniquely located, usually by the location of its endpoints.
- If not, the degree of aggregation imposed by the model.
- The basis for that aggregation.

Release Height

As used here, release height means the height above ground level at which emissions are physically released into the atmosphere and does not include any considerations of plume rise or other types of plume beh [illegible] which

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*Refer to Appendix A.1.2 for detailed discussion of the treatment of the source-receptor relationship.

are dealt with in Section 5.5. The user should be aware, however, that some effective plume rise may frequently be included in the user-specified release height supplied as input to models that do not treat plume rise explicitly. This approach is discussed in Section 5.5; the comparison of treatments of release height should proceed as if the release heights were the heights at which emissions actually enter the atmosphere. There are three considerations in determining the level of detail with which release height is treated for point, area, and line sources:

- Whether the model treats elevation differences due to terrain.
- Whether the model allows the physical stack height (or height of release above ground level for area and line sources) to vary between different sources or source categories.
- Whether release heights can be specified arbitrarily by the user or whether specific values or sets of values are imposed by the model.

Receptor Location and Receptor Height

Since receptors are generally taken to be points, the user should be able to describe the treatment of receptor location and height by making the same considerations as outlined above. Specifically, the user should determine:

- Whether the receptors can be located arbitrarily or are limited to specific points within the given area.
- If the receptor height is arbitrary or if only one height (usually ground level) is assumed.

With these considerations and the entries in Table 5.1, the user should be able to describe and compare treatments of receptor location and receptor height.

Downwind/Crosswind Distances

Some models contain parameters whose values depend explicitly on downwind or crosswind distances between source-receptor pairs. In such cases, these treatments must be described and compared. In other cases, it should simply be noted on the technical evaluation form that this aspect of the source-receptor relationship is "not applicable." The key consideration for all source types is whether the treatment causes a loss in the precision with which the downwind and crosswind distances can be specified. Aspects for the user to consider are:

- Whether precise downwind/crosswind distances are calculated for each point source-receptor pair or for various points within area sources or along line sources.
- Whether, for area and line sources, single representative or average distances are used.

It should be noted that when the model aggregates sources, the values of downwind/crosswind distance are representative of the grid blocks used in the aggregation and not of the sources themselves.

Orientation

Orientation does not apply to point sources. For area sources, the user needs to consider:

- Whether the sides of the area sources can be arbitrarily oriented, or
- Whether they are restricted to lie along specific directions specified by a grid.

For line sources, the situation is slightly more complex, because a line presents a significantly different appearance depending upon the angle from which it is viewed. The considerations are:

- Whether the line can be inclined or must be horizontal.
- Whether the line can be arbitrarily oriented with respect to the wind direction; some models can treat only a restricted range of orientations.

When these considerations have been made, the user should have little trouble in locating the study model's treatment of each aspect of the source-receptor relationship in Table 5.1 and in briefly describing that treatment on the Evaluation Form-Part C. In applications involving several source types, an overall evaluation must be reached based upon the comparative treatment of each source type individually. Each treatment must be weighted by the expected importance of that source type in the application of interest.

Table 5.1 gives the treatment of the source-receptor relationship by models in general. Table B.2 gives the treatment of the source-receptor relationship by selected reference models.

5.3 TREATMENT OF EMISSION RATE

The degree of spatial and temporal resolution must both be assessed in determining the treatment of emission rate.* Regardless of the aspect or type of source, the user is basically interested in determining:

- Whether an emission rate and emission pattern unique to each source can be specified, or
- Whether average emission rates and general patterns must be used.

For the spatial aspect of point sources, the user need only determine whether each source can have an arbitrary emission rate or whether all sources must have identical rates.

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*Refer to Appendix A.1.3 for detailed discussion of the treatment of emission rate.

Table 5.1. Treatment of Source-Receptor Relationship[a]

a. Horizontal Source Location

Source Type	Method of Treatment
Point	1. Sources located at specific, arbitrary points.
	2. Sources aggregated onto many subareas.
	3. Sources aggregated onto only a few subareas.
	4. Sources aggregated on a basis other than location. No information on location.
	5. Not treated explicitly; all sources treated alike regardless of location.
Area	1. Sources located at arbitrary locations; not located as blocks on a grid network.
	2. Sources located as blocks on grid network. User can change scale of grid.
	3. Sources located as blocks on a grid network. User cannot change scale of grid.
	4. Sources aggregated on a basis other than location. No information on location.
	5. Not treated explicitly.
Line	1. Line located at any desired position; line treated as volume source with width and height as well as length.
	2. Lines treated as one-dimensional (i.e., no width or height) with arbitrary location.
	3. Sources aggregated onto many subareas.
	4. Sources aggregated onto only a few subareas.
	5. Sources aggregated on a basis other than location. No information on location.
	6. Not treated explicitly.

b. Release Height

Table 5.1. (Contd.)

Source Type	Method of Treatment
Point	1. Accounts for both elevation of stack base and physical stack height.
	2. Assumes flat terrain; no elevation corrections. Release at any physical stack height.
	3. Several representative release heights can be specified for each grid cell or category when sources have been aggregated.
	4. Model assumes all releases take place at same user-defined height.
	5. Model assumes all releases take place at same height which user cannot change.
	6. Not treated explicitly.
Area	1. Accounts for both average elevation of area and allows several arbitrary release heights.
	2. Assumes flat terrain; no elevation corrections. Several arbitrary release heights for each area.
	3. Assumes flat terrain. Only one release height for each area.
	4. Only one release height may be specified for all areas.
	5. Model assumes all releases take place at same height which user cannot change.
	6. Not treated explicitly.
Line	1. Release height and elevation may both be specified.
	2. Flat terrain assumed, arbitrary release height for each source.
	3. Several representative release heights can be specified for each grid square when sources have been aggregated.
	4. Assumes all releases at same height which user cannot change.
	5. Not treated explicitly.

c. Downwind/Crosswind Distances

Source Type	Method of Treatment
Point	1. Precise downwind and crosswind distances calculated for each source-receptor pair.
	2. Single representative or average value used for aggregate of several point sources.
	3. Not treated explicitly.
Area	1. Calculated for various points within each area source.
	2. Single representative or average value used for each area source.
	3. Not treated explicitly.

Table 5.1. (Contd.)

Line	1. Single value calculated for each segment along line. 2. Single representative or average value used for entire line. 3. Single representative or average value used for aggregate of several line sources. 4. Not treated explicitly.

d. Source Orientation

Source Type	Method of Treatment
Point	1. Not applicable.
Area	1. Areas can assume any orientation; sides not restricted to lie along specific directions. 2. Sides of areas restricted to be along specific grid directions. 3. Not treated explicitly.
Line	1. Line can assume any orientation with respect to receptor and may be inclined. 2. Line assumed to be horizontal; orientation arbitrary. 3. Applies to only a restricted range of orientations. 4. Not treated explicitly.

e. Receptor Location

Method of Treatment

1. Receptor located at specific, arbitrary location.
2. Receptor located at specific, arbitrary location within some specific area, commonly an area source emission grid.
3. Receptors located at points on a separate user-defined grid.
4. Receptors located only at points defined within the model.
5. Receptor locations defined only as being within certain boundaries smaller than the entire region of interest, e.g., within a given grid cell.
6. Receptor location not treated explicitly. Concentration estimate independent of receptor location within region of interest.

Table 5.1. (Contd.)

f. Receptor Height

Method of Treatment

1. Receptor located at specific, arbitrary height above ground.
2. Receptor located at specific, arbitrary height above ground subject to upper limit constraint, e.g., effective stack height.
3. Receptor located at one of several discrete user-defined heights.
4. Receptor located at one of several model-defined heights.
5. Receptor heights defined only as being within certain ranges.
6. Receptors constrained to be all at the same height.
7. Receptors constrained to be all at gound level.
8. Not treated explicitly.

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[a] Within each source type, treatments are listed in order of decreasing level of detail. Various combinations of the treatments for each aspect of the source-receptor may be used; the user can arrive at an overall comparison by determining how the models compare in their treatment of each aspect.

For area sources, there are several methods for treating the emission rate, depending on how the concentration estimates are made. The user must determine:

- Whether variation in the emission rate is allowed within a single source or whether each area is assumed to emit uniformly.
- If the areas must be uniform, whether the emission rates are arbitrary or whether they must be the same or selected from a specific set of values.
- Whether concentration estimates are obtained by numerical integration over the area or by replacing the area by a small number of effective point sources.
- Whether contributions from all individual area sources are estimated.
- Whether a single estimate of the total area source contribution is made.

Similarly, for line sources the considerations are:

- Whether the emission rate can vary along the line or whether the line is assumed to be a uniform source.
- If the line must be uniform, whether the emission rate is arbitrary.
- Whether concentration estimates are obtained by integration or by replacing the line by a small number of effective point sources.

For the temporal aspect, the considerations are the same for all types of sources:

- Whether the emissions can vary with time, or
- Whether constant emission rates are assumed.
- If the emissions can vary with time, whether the model uses
  - An actual time sequence of emission rates,
  - A sampled set of emission rates, or
  - A set of rates partially arranged in sequence or correlated with other variables.

With these considerations, the user should be able to determine a model's treatment of emission rate and to describe it on the evaluation Form-Part C.

Table 5.2 gives the general treatment of emission rate. Table B.3 gives the treatment of emission rate by the reference models.

5.4 TREATMENT OF COMPOSITION OF EMISSIONS

The user must deal with two aspects of the composition of emissions. For all types of emissions, the chemical composition must be treated except when dealing with primary, stable pollutants. In addition, for particulate matter, the size distribution may need to be considered.[a]

If treatment of chemical composition of emissions is required by the application, the user should consider:

- Whether all relevant compounds are treated individually or whether certain compounds are lumped into classes with each class treated by a representative or hypothetical compound. The specific compounds or classes treated should be listed or described on the Evaluation Form-Part C.
- If lumping is used, the number of classes considered and whether these classes are appropriate to the application of interest.
- Whether the model determines emissions of certain compounds as fixed fractions of input emissions regardless of source type.
- Whether further assumptions are made regarding the composition of user-input emissions.
- Whether the model treats only one of many compounds known to interact.

In making these determinations, expert advice may be required.

When fallout, deposition, or precipitation scavenging (rainout or washout) are involved, the size distribution of particulate matter is important. The treatment used may be found by determining:

- Whether a size distribution is used and if so, whether it is continuous or discrete.
  - If continuous, whether the functional form can be specified or whether parameters are input for a fixed distribution.
  - If discrete, whether there are many narrow size ranges or a few broad ranges.
- If a size distribution is not used, whether some given fraction of the emissions is affected by the size-dependent mechanism.
- If so, whether the fraction is arbitrary.

These considerations should enable the user to determine the treatment of composition of emissions.

Table 5.3 gives the general treatments of the composition of emissions. Table B.4 gives the treatments used by the selected reference models.

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[a] Refer to Appendix A.1.4 for detailed discussion of the treatment of composition of emissions.

Table 5.2. Treatment of Emission Rate

Variation	Source Type		Method of Treatment
Spatial	Point	1.	Allows arbitrary emission rate for each source.
		2.	All sources assumed to have identical emission rates.
	Area	1.	Allows variation over each area source. Total contribution estimated by summing all individual contributions. Individual contributions estimated by integration.
		2.	Assumes uniform area sources with arbitrary emission rates. Total contribution estimated by summing all individual contributions. Individual contributions estimated by integration.
		3.	Assumes uniform area sources with arbitrary emission rates. Total contribution estimated by integration without estimating individual source contributions.
		4.	Assumes uniform area sources with arbitrary emission rates. Total contribution estimated by summing all individual contributions. Individual contributions estimated by replacing each area source by a small number of effective point sources.
		5.	Assumes uniform area sources, all with the same emission rate. Total contribution estimated by replacing entire area source distribution by a small number of effective point sources.
	Line	1.	Allows variation along the line. Integrates to obtain concentration.
		2.	Assumes arbitrary emission rate is uniform along the line. Integrates to obtain concentration.
		3.	Allows variation along the line. Replaces line by a small number of effective point sources with emission rates dependent upon position along line.
		4.	Assumes uniform lines with arbitrary emission rates. Replaces line by small number of effective point sources.
		5.	Assumes all lines have the same uniform emission rate. Replaces line by small number of effective point sources.
Temporal[b]	All	1.	Treats an actual time sequence of emission rates averaged over a short interval (typically one hour).
		2.a.	Treats a sampled set of the possible emission rates appropriate to a short interval.
		b.	Treats time sequence of short-term emission rates derived by model from input emission rates appropriate to longer term.
		3.	Treats a time sequence of emission rates averaged over a long interval (e.g., one day).
		4.	Uses a set of emission rates which are at most partially arranged in sequence.
		5.	Treats only constant emission rates.

[a] Within each source type, the treatments are listed in order of decreasing level of detail.

[b] In addition to the level of detail, the suitability of the technique of treating the variations must be assessed as discussed in Appendix A.1.3 whenever the treatment allows temporal variations to be specified.

Table 5.3. Treatment of Composition of Emissions[a]

Aspect Treated		Method of treatment
Chemical Composition[b]	1.	Emissions of all relevant compounds treated individually.
	2.	Lumps some emissions into a large number of classes appropriate to the application of interest; other emissions treated as individual compounds. All members of each class treated by a representative or hypothetical compound. All relevant emissions treated.
	3.	Uses a gross lumping of some of the emissions into only a few classes. Other emissions treated as individual compounds. All relevant emissions treated.
	4.	Treats emissions of only some of the compounds known to take part in relevant reactions.
	5.	Places fixed fractions of input emissions into a small number of classes. Uses same fractions for all sources.
	6.	Treats only one of many compounds known to interact or one lumped class of emissions.
	7.	Same as No. 6 but the model places a fixed fraction of input emissions into the single class.
Size Distribution[c]	1.	Treats continuous size distribution and allows the functional form to be specified by the user.
	2.	Treats continuous size distribution. Parameters of a fixed distribution specified by the user.
	3.	Treats all particles within various size ranges by a corresponding set of representative sizes; uses a large number of narrow ranges.
	4.	Same as No. 3 but treats a small number of broad ranges.
	5.	Assumes a given user-input fraction of emissions are affected by the size-dependent mechanism of interest.
	6.	Same as 5 but fraction is set by the model.
	7.	Not treated explicitly.

[a] Within each aspect, the treatments are listed in order of decreasing level of detail.

[b] Important only in cases involving secondary or reactive pollutants.

[c] Important only in cases involving fallout, deposition, or precipitation scavenging (washout or rainout) of particulates.

5.5 TREATMENT OF PLUME BEHAVIOR

By considering the following, the user should be able to determine the study model's treatment of plume behavior:*

- Whether a plume rise formula is used by the model.
- If so, whether the formula has been extensively validated for the specific application of interest or for similar applications.
- Whether the formula is one of the common ones: Briggs' 2/3, Holland, CONCAWE, CONCAWE simplified, or the ASME formula.
- If the formula has not been validated and is not one of the four common formulae:
  - To what power of the inverse wind speed the plume rise is proportional.
  - Whether there is a buoyancy term and the power to which it is raised.
  - Whether there is a momentum term.

  - Whether the formula accounts for differences in atmospheric stability.
  - Whether plume rise is a function of downwind distance.
- If no plume rise formula used, whether the product of wind speed and plume rise is assumed constant.
- If so, whether the constant can be changed from source to source.
- Upon what other parameters, like stability, the constant can depend.
- Whether downwash and/or fumigation are treated.

In comparing treatments of plume rise, the main consideration should be validation in either the application of interest or similar applications. A properly validated formula should always be considered better than an unvalidated formula.

As pointed out in Section 5.2, some effective plume rise may be included in the values of the stack or release height specified by the user as input to a model. If this approach is adopted, the treatment of plume rise must be determined from the algorithm or formulae by which the effective plume rise is estimated prior to its inclusion as part of the release height. Otherwise, the treatment implemented in the computer program should be determined.

When the "tilted plume" approximation has been used to treat deposition from particulate plumes, this treatment should be included under dry deposition (Table 5.13).

Table 5.4 gives the general treatments of plume behavior, and Table B.5 gives the treatments used by the selected reference models.

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*Refer to Appendix A.2.2 for detailed discussion of the treatment of plume behavior.

Table 5.4. Treatment of Plume Behavior[a]

Method of Treatment

1. Plume rise formulation validated for the specific application of interest.
2. Plume rise formulation validated for applications similar to the one of interest.
3. Fully detailed treatment with plume rise and dispersion treated simultaneously. Limited validation.[b]
4. Two-step treatments. Plume rise is calculated and then dispersion is calculated from a virtual source at an effective stack height.
   a. Analytical formulas, depending upon meteorology and stack parameters, used to estimate plume rise:
      - Plume rise treated by one of the common formulae: Brigg's 2/3, Holland, CONCAWE, CONCAWE simplified, or ASME.
      - Plume rise treated by unvalidated formula satisfying the general guidelines and comparing favorably with common formulas.[c] (See Appendix A.2 and Table A.1 for these guidelines.)
      - Plume rise treated by unvalidated formula satisfying some of the general guidelines or comparing unfavorably with common formulae.[c] (See Appendix A.2 and Table A.1 for these guidelines.)

   b. Product of plume rise and wind speed assumed constant. User can choose value of constant for each source and use different constants for a small number of meteorological or source parameters, e.g., stability.

   c. Product of plume rise and wind speed assumed constant. User can choose value of constant for each source. Constant is independent of other source and meteorological parameters.

   d. As in 4 (c), but one value of the constant used for all sources.

   e. Single value of plume rise used for all sources. (Could be included in release height.)
5. Not treated explicitly.

[a] Treatments are listed in order of decreasing level of detail.

[b] Not used in most models at this time; used only in special applications.

[c] Special weight should be given to formulas treating plume rise as a function of downwind distance. This consideration is more important for low-level than for elevated releases.

Notes: 1. In addition to comparing the treatments of plume rise, the user should consider whether the models treat downwash or fumigation. Treatment of either or both by a model tends to make that model's treatment of plume behavior better than the treatment by a model that ignores these effects.

2. Where the "tilted plume" approximation has been used for particulate plumes, the user should include this under the treatment of dry deposition. (See Table 5.12.)

5.6 TREATMENT OF HORIZONTAL AND VERTICAL WIND FIELDS

The treatment of the horizontal wind field by the study model may be determined from the following considerations:*

- Whether the horizontal components of the wind velocity may depend on horizontal location.
- If not, whether both wind speed and direction are treated explicitly or whether one or both are not treated explicitly.
- If the horizontal components depend on position, whether the dependence is arbitrary or assumed a priori.
- If arbitrary, whether the components are specified at discrete points or as continuous functions of position.
- Whether both the horizontal components may depend on height above ground.
- If so, whether they are specified at discrete heights or as continuous functions of height.
- If the wind direction is constant with height, whether the wind speed can depend upon height.
- If so, whether the dependence is arbitrary.
- If arbitrary, whether the wind speed is specified at discrete intervals or given as a continuous function of height.
- Whether a specified dependence with height of either or both wind speed and direction is assumed a priori.
- If either or both wind speed and direction are constant with height, whether different values are used for different source heights.
- Whether the horizontal components depend on time.
- If so, whether they are specified continuously or at a sequence of elapsed times.
- If specified at a sequence of times, whether they are assumed constant within each interval or interpolated between times.
- Whether the treatment is climatological.

These considerations should guide the user to an identification of the treatment of the horizontal wind field. In addition, the following specific information should be provided on the Evaluation Form-Part C:

- The model classification as determined in Section 4.3.
- A description of the nature of any constraints on the allowable values of the wind speed and direction, e.g., the number of sectors and wind speed classes used in a climatological model.
- A description of the nature of any parameters, either user-specified or built into the model, that govern the dependence of wind speed and direction on position, height above ground, or time, e.g., power law dependence of wind speed on height with exponents dependent on atmospheric stability.
- A description of any dependence of the horizontal wind components on position, height, or time that explicitly or implicitly is assumed a priori by the study model.
- The source of nature of any non-standard meteorological data required in the model determination of the wind field.
- Any additional information relating to the treatment of the horizontal wind field not covered in this discussion.

The treatment of the vertical component of the wind field may be determined in a similar manner from the following considerations:

- Whether the vertical wind field is treated explicitly; whether an implicit treatment is used; or whether the vertical wind field is not considered in the study model formulation.
- If treated explicitly, whether the vertical component depends arbitrarily upon horizontal position and/or height above ground.
- If arbitrarily dependent on position and/or height, whether the vertical component is a continuous function of those variables or whether it is specified at discrete points.
- Whether there is any assumed a priori dependence of the vertical component on position or height above ground.
- Whether the vertical component depends on time.
- If so, whether it is specified continuously or at a sequence of elapsed times.
- If specified at a sequence of times, whether it is assumed constant within each interval or whether its value is interpolated.

Although these questions will enable the user to identify the study model's treatment of vertical wind field, additional information should be provided. This additional information is the same as required above for the horizontal wind field. If the study model uses an implicit treatment of the vertical wind field, the treatment should be described in sufficient detail to make clear the assumptions involved.

Tables 5.5 and 5.6, respectively, give the treatments of the horizontal wind field and the vertical wind field by models in general. Tables B.6 and B.7 give the treatments used by selected reference models.

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*Refer to Appendix A.3.2 for a discussion of the possible treatments of the horizontal and vertical wind fields.

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Table 5.5. Treatment of Horizontal Wind Field[a]

Dependence on		
Horizontal Location	Height above Ground	Time
1. Arbitrary. Wind speed and direction specified as continuous functions of horizontal position.	1. Arbitrary. Wind speed and direction specified as continuous functions of height.	1. Arbitrary. Wind speed and direction specified as continuous function of time.
2. Arbitrary. Wind speed and direction specified at points of a horizontal grid.	2. Arbitrary. Wind speed and direction specified at heights of a vertical grid.	2. Arbitrary. Wind speed and direction specified at a sequence of elapsed times: a. Values interpolated between times. b. Values constant within each interval.
3. Specific positional dependence built into model, not subject to user modification beyond the specification of parameter values.	3. Wind direction constant with height. Wind speed an arbitrary continuous function of height.	3. Climatological. Wind speed and direction specified as being within well-defined ranges having known joint frequencies of occurrence.
4. Wind speed and direction independent of position (uniform).	4. Wind direction constant with height. Wind speed dependence on height arbitrary, values specified at heights of a vertical grid.	4. Wind speed and direction constant in time (steady-state).
5. Wind speed independent of position. Wind direction not treated explicity.	5. Specific height dependence built into model, not subject to user modification beyond the specification of parameter values.	5. Not treated explicitly.
6. Wind speed and direction not treated explicitly.	6. Both wind speed and wind direction constant with height (uniform). Values used may depend on source height.	
	7. Both wind speed and wind direction constant with height (uniform). Same values used for all source heights.	
	8. Wind speed and direction not treated explicitly.	

Note: Arbitrary here means either that the model will accept any appropriate user-defined wind field which has been independently determined or that the model itself, given appropriate user specification of the problem, will generate the wind field in a manner compatible with mass consistency, the proper boundary conditions for fluid flow, and any assumptions built into the model. No constraints are placed on allowable values.

[a]Treatments arranged in order of decreasing level of detail.

5.7 TREATMENT OF HORIZONTAL AND VERTICAL DISPERSION

The treatment of both horizontal and vertical dispersion by the study model may represent different modeling approaches.* For example, horizontal dispersion may be described with a semiempirical method and vertical dispersion may be described with a numerical method. On the other hand, the two treatments may be closely related. In either case, separate descriptions of the treatments of these two elements are required on the Evaluation Form-Part C. General treatments of dispersion corresponding to the different types of models identified in the classification procedure outlined in Section 4.3 are given in Table 5.7. Certain information is required to adequately specify the particular treatment used by the study model. Regardless of the model type, the following information should be provided:

- The model classification as determined in Section 4.3.
- The treatment or parameterization of atmospheric stability used in estimating the values of eddy diffusivities or standard deviations (see Table 5.8). The name (or names) of any parameter or turbulence classification scheme used to specify the stability of the atmosphere or the level of turbulence should be noted. If a classification scheme is used, the number of classes used should be noted. Limits or other constraints to allowable parameter values should be indicated.
- The treatment or parameterization of surface roughness effects used in estimating the values of eddy diffusivities or standard deviations (see Table 5.9). Information similar to that required for the treatment of atmospheric stability should be provided.

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*Refer to Appendix A.4.2 for a detailed discussion of the treatment of horizontal and vertical dispersion.

Table 5.6. Treatment of Vertical Wind Field[a]

Dependence on		
Horizontal Location	Height above Ground	Time
1. Arbitrary Vertical wind field specified as a continuous function of horizontal position.	1. Arbitrary. Vertical wind field specified as a continuous function of height.	1. Arbitrary. Vertical wind field specified as a continuous function of time.
2. Arbitrary. Vertical wind field specified at points of a horizontal grid.	2. Arbitrary. Vertical wind field specified at heights of a vertical grid.	2. Arbitrary. Vertical wind field specified at a sequence of elapsed times: a. Values interpolated between times. b. Values constant within each interval.
3. Specific explicit positional dependence built into model, not subject to user modification beyond the specification of parameter values.	3. Specific explicit height dependence built into model, not subject to user modification beyond the specification of parameter values	3. Vertical wind field assumed constant in time (steady-state).
4. Vertical wind field treated implicitly. a. Effects of terrain or other factors accounted for by assuming that the center of mass of the pollutant emission follows a prescribed path either with respect to the local topography or as would result from any other factors considered. b. Assumed equal to zero everywhere.	4. Vertical wind field treated implicitly. a. Effects of terrain or other factors accounted for by assuming that the center of mass of the pollutant emission follows a prescribed path either with respect to the local topography or as would result from any other factors considered. b. Assumed equal to zero at all heights.	4. Not treated explicitly. (Effects of vertical wind field not considered in model formulation.)
5. Not treated explicitly. (Effects of vertical wind field not considered in model formulation.)	5. Not treated explicitly. (Effects of vertical wind field not considered in model formulation.)	

Note: Arbitrary here means either that the model will accept any appropriate user-defined wind field which has been independently determined or that the model itself, given appropriate user specification of the problem, will generate the wind field in a manner compatible with mass consistency, the proper boundary conditions for fluid flow, and any assumptions built into the model. No constraints are placed on allowable values.

[a] Treatments arranged in order of decreasing level of detail.

- The origin or basis for choosing the specific model parameter values (see Table 5.10). If the specific parameters are widely used or have been published in the scientific literature, it is sufficient to identify them (for example, the Pasquill-Gifford dispersion coefficients for the Gaussian plume model) and provide an appropriate reference; if they are not widely used and not publicly available, the basis for using them should be noted.

- The averaging time for meteorological variables.

This information may be omitted in certain cases in which dispersion is described implicitly, rather than explicitly. This is the case in the narrow plume or sector averaging approximations for horizontal dispersion or in the uniform mixing approximation for vertical dispersion, for example.

Additional information is also required, depending on the treatment classification.

Semiempirical. The functional form assumed for the pollutant distribution should be identified if commonly used (e.g., Gaussian plume, narrow plume approximation, sector averaging, uniform mixing), or described briefly if not widely used, including some indication of its origin. Dependences of model parameters on position, height, time, meteorological, or other variables should be indicated if not adequately described under the general information above.

Numerical. The dependence of the eddy diffusivity on position, height, time, meteorological, or other variables should be indicated, in addition to the basis for the values or for the specific parameterization that is used by the study model (see Table 5.11). The general name or type of numerical method used to solve the diffusion equation should be mentioned, although comparison based on the details of the numerical techniques is beyond the scope of this methodology.

Table 5.7. General Treatments of Dispersion

Model Classification	Method of Treatment[a,b]
1. Numerical/dynamic	
a. Closure models	Numerical solution of equations giving pollutant concentrations and fluxes as well as several meteorological parameters as functions of position and time.
b. Gradient-transfer	Numerical solution of diffusion equation giving pollutant concentrations as a function of position and time. Eddy diffusivities estimated as functions of height, time and/or meteorological variables.
2. Numerical/steady-state Gradient-transfer or "K-theory" models only	As in 1b. except that eddy diffusivities are independent of time.
3. Semiempirical/dynamic	Dispersion described by an assumed shape function, depending on position and time. Assumed function contains parameters which are adjust to reflect the effects of meteorology and surface roughness. Examples[a]: a. Gaussian puff model. b. Gaussian plume about trajectory. c. Narrow plume approximation (horizontal dispersion only). d. Box model (uniform vertical distribution).
4. Semiempirical/steady-state	Dispersion described by an assumed shape function, a function of position only. Assumed function contains parameters which are adjusted to reflect the effects of meteorology and surface roughness. Examples[a]: a. Gaussian plume. b. Narrow plume approximation (horizontal dispersion only). c. Box model (uniform vertical distribution).
5. Climatological	Treatment depends on nature of model used for basic calculations, but normally steady-state. Examples[a]: a. K-theory models (numerical). b. Gaussian models (semiempirical). c. Sector averaging (narrow plume approximation; horizontal dispersion only; semiempirical).

[a] Treatments and examples are listed approximately in order of decreasing level of detail.

[b] Models can be compared on their relative level of detail only after it has been determined that they use approaches equally applicable to the application of interest.

Steady-State. The averaging time, or the period of time over which a steady-state condition is assumed to hold, should be indicated.

Sequential or Climatological. No specific additional information is required if the study model has been classified as sequential or climatological.

Dynamic. The time dependence should be described to a sufficient extent to indicate its general nature. For example, a model that has been classified dynamic because it involves the determination of a trajectory, but in which the time dependence of the pollutant concentration is not explicit, should be disginguished from a model in which it is. In cases involving explicit time dependence, the method of describing the temporal variation, either continuously or in a sequence of time steps, should be indicated along with the size of the time step used.

Finally, any additional information relevant to the treatment of dispersion that may affect the evaluation or clarify the operation of the study model should be given. This information may include:

- Different modes of operation under different meteorological circumstances,
- Different treatments for different source geometries, and
- Any additional or different assumptions made in the formulation of the study model not covered in the discussion in this workbook.

Table 5.7 gives the general treatments of dispersion. Tables 5.8 and 5.9, respectively, give the treatments of atmospheric stability and surface roughness used in estimating the values of the dispersion parameters (the eddy diffusivities or standard deviations). Table 5.10 gives possible bases for comparing different choices of dispersion parameter values. Table 5.11 gives possible treatments of the spatial and temporal dependence of eddy diffusivities. Treatments of horizontal and vertical dispersion by selected reference models are given in Tables B.8 and B.9.

5.6 TREATMENT OF CHEMISTRY AND REACTION MECHANISM[a]

The treatment of chemistry and reaction mechanism used by the study model may be determined from the following considerations (expert advice may be required in some cases):

- Whether all relevant reactions and chemical species are handled.
- Whether similar compounds are treated together in one or more classes (lumping approximation) or whether only some of the relevant compounds are treated.
- Whether the equilibrium approximation is applied to the system of reactions.
- Whether all reactions are truly first order (linear).
- Whether the appearance and disappearance of pollutants of interest are approximated by one or more first-order processes.

In addition to these considerations, the user must also determine:

- Whether any adjustment is made for the effects of incomplete turbulent mixing.

Finally, the following additional information should also be provided:

- A two-or three-word description of the general chemical system being treated (e.g., photochemical smog system).
- The number of distinct chemical reactions considered.
- The number and an explicit list of the chemical species, real or "lumped," treated in the mechanism.
- If the lumping approximation is used, a list of those species treated in the mechanism that are representative compounds for the classes being used.
- If the steady-state approximation is used, a list of those species to which it is applied.
- A description, including the extent of any user input, of any spatial or temporal variation attributed to any chemical reaction rate constant.
- A description of any optional modes of operation, such as user-specification of an arbitrary reaction mechanism.

Table 5.12 gives the general treatments of chemistry and reaction mechanism. The treatments used by selected reference models are given in Table B.10.

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[a] Refer to Appendix A.5.2 for a discussion of the possible treatments of chemistry and reaction mechanism.

Table 5.8. Treatment of Atmospheric Stability[a]

1. Atmospheric stability characterized by the numerical value of a stability parameter (see for example Table A.3) that may take on any value within the range for which the model is designed.
2. Atmospheric stability divided into discrete classes within which no variation is recognized.
   a. Many classes, including time of day or other parameters.
   b. Many classes, not including other factors, or Few classes, but including additional factors.
   c. Few classes, no additional factors included.
3. Atmospheric stability not explicitly treated.

[a] Treatments given in order of decreasing level of detail.

Table 5.9. Treatment of Surface Roughness[a]

1. Surface roughness characterized by the numerical value of a roughness parameter (such as the roughness length) which can take on any value within some appropriate range.
2. Surface roughness characterized in terms of discrete classes or types of surface.
   a. Many classes.
   b. Few classes.
3. Surface roughness not treated explicitly.

[a] Treatments given in order of decreasing level of detail.

5.9 TREATMENT OF PHYSICAL REMOVAL PROCESSES

Two physical removal processes are considered in this workbook: dry deposition and precipitation scavenging. The guidelines in this section enable the user to identify the treatment of each used by the study model.*

Dry Deposition

The treatment of dry deposition may be determined from the following considerations:

- Whether both the effect on the vertical concentration profile and the effect of pollutant removal are treated.
- If so, whether the deposition velocity is assumed constant and/or independent of position.
- Whether only the effect of pollutant removal is treated. (Effective source-strength treatment.)
- If so, how the effective source strength is determined.
  - Integration of mass removal rate proportional to ground level concentration, or
  - Assumed exponential decay.
- Whether the deposition velocity is a function of meteorological variables.
- Whether the tilted plume approximation is used to treat gravitational settling.

Additional information relating to assumed deposition velocity values or assumed dependences on meteorological or other parameters should be included in the description on the Evaluation Form-Part C.

Precipitation Scavenging

The treatment of precipitation scavenging may be determined from the following considerations:

- Whether the study model allows the washout coefficient to be an arbitrary function of time.
- Whether the washout coefficient is obtained from a user-supplied time-dependent rainfall rate.
- Whether the washout coefficient is assumed to be constant over the period during which precipitation occurs.
- Whether each occurrence of rainfall is assumed to remove the same fraction of pollutant.
- Whether the user may specify the frequency of rainfall.

As before, additional information relating to any model assumptions such as washout coefficient values, rainfall frequencies, etc. should be provided. Precipitation scavenging should be assumed to occur only during precipitation. If a study model always applies an exponential decay factor, that treatment should not be considered as a treatment of precipitation scavenging.

Table 5.13 gives the general treatments of these two removal processes and Table B.11 gives the treatments of physical removal processes by selected reference models.

5.10 TREATMENT OF BACKGROUND, BOUNDARY AND INITIAL CONDITIONS

There are five aspects of the element to be considered:

- Background,
- Upper boundary condition at the mixing height,
- Lower boundary condition at the earth's surface,
- Boundary condition at the vertical sides of the region of interest, and
- Initial conditions in the region of interest.

The treatments of each of these aspects depends upon the classification of the study model as numerical/dynamic, numerical/steady-state, semiempirical/dynamic, or semiempirical/steady-state.* The treatment used by a climatological model depends upon the treatment employed by the model used to do the basic dispersion calculations. Sequential steady-state treatments may account for variations by using different values for each time interval involved and hence provide more detail than treatments that treat only a single steady-state.

Background

Numerical models treat upwind pollutant levels in terms of the boundary condition at the upwind vertical side; hence background does not need to be considered for them.

For semiempirical/dynamic models the user must determine whether spatial and temporal variations in background are treated:

- Whether the background is time-dependent or constant.
- Whether the background can change arbitrarily from receptor to receptor, or whether it must be uniform across the region of interest.

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*Refer to Appendix A.6.2 and A.6.3 for discussions of possible treatments of dry deposition and precipitation scavenging.

*Refer to Appendix A.7.2 for a detailed discussion of treatments of background, boundary and initial conditions.

For semiempirical/steady-state models, only the second consideration need be made, because there can be no time dependence.

Upper Boundary Condition

The upper boundary condition refers to the way in which dispersion is treated at the mixing height. The user should focus on the variations in mixing height which can be accommodated by the model and whether the top of the mixing layer is treated as an absolute or partial barrier to pollutants.

For numerical/dynamic models, the user should determine:

- Whether pollutants dispersing upward are allowed to be only partially reflected at the mixing height, or whether perfect reflection is specified.
- Whether pollutants can be entrained into the region of interest from above as the mixing height increases.
- Whether the mixing height can vary with location.

For a numerical/steady-state model only the first three considerations apply.

For semiempirical/dynamic models, the user must determine:

- Whether the mixing height can be a function of time.
- Which method of treatment is used:
  - Perfect reflection simulated by multiple image sources and evaluation of the resulting infinite sum, or
  - Perfect reflection with interpolation used between the region where the mixing height has no effect and the region of uniform mixing.
- Whether a functional form has been chosen that implicity assumes the mixing height is large enough so as not to affect pollutant concentrations.
- Whether an implicit treatment has been used.

Implicit treatments simulate the effect of the mixing height by limiting the appropriate parameters of the semiempirical dispersion function. For example, the vertical dispersion coefficient in a Gaussian plume formulation may be limited to simulate the limited upward spread of a plume.

Only the last three considerations apply to a semiempirical/steady-state model.

Lower Boundary Condition

The lower boundary condition refers to the way in which dispersion is treated at the earth's surface.

For a numerical/dynamic model the following considerations should be made:

- Whether partial reflection treated, or whether perfect reflection must be used.
- If partial reflection is treated, a numerical model will generally do so in terms of a dry <u>deposition velocity</u>. In this case the user must determine:
  - Whether the dry deposition velocity can vary with location within the region of interest.
  - Whether the dry deposition velocity can vary with time.

For numerical/steady-state models, the consideration of time dependence is irrelevant.

The considerations (and treatments) are the same for both semiempirical/dynamic and semiempirical/steady-state models. The user should consider:

- Whether partial reflection is treated, or whether only perfect reflection is treated.
- If only perfect reflection is treated:
  - Whether multiple image sources or a single image source is used.
  - Whether the infinite sum giving the concentration estimate is evaluated or whether interpolation is used between the region where the mixing height has no effect and the region of uniform mixing.

Note also that some semiempirical models use only a single image source to treat perfect reflection at the earth's surface. In this case, no multiple reflections can occur and the upper boundary is implicitly assumed to have no effect on pollutant concentrations. If partial reflection is treated by a semiempirical model, the functional form used is normally a solution to the diffusion equation appropriate to the partial reflection boundary condition.

Vertical Sides

For a numerical/dynamic model, the following considerations should enable the user to determine the model's treatment of the boundary conditions at the vertical sides. The considerations are almost the same for numerical/steady-state models, except that time dependence need not be considered. The user should determine:

- Whether the flux into the region can vary from point to point.
- Whether the flux can differ at different elevations.
- Whether the flux can vary with time, or whether it must be constant.

The user should recall that numerical models treat background pollutant concentrations as a boundary condition at the vertical sides.

Semiempirical models treat this boundary condition at the vertical sides as background. Hence, this condition need not be considered for such models.

Initial Conditions

Initial conditions need only be considered for dynamic models. For both numerical/dynamic and semiempirical/dynamic models, the user should determine:

- Whether the initial concentrations can vary from point to point, or whether they must be uniform throughout the region.

In making this determination, both the dependence on horizontal location and elevation should be considered.

After taking these considerations into account, the user should be able to determine the study model's treatment of each relevant aspect of background, boundary and initial conditions.

Any additional information which would clarify the study model's treatment of a particular element should also be included with the description of the treatment on the Evaluation Form-Part C. Examples of such information include:

- How background levels are determined at different locations or times. For example, whether they are user-specified at each time interval or are interpolated between one initial value and one final value.
- How mixing height is determined and upon what parameters it depends.
- The parameters limited and the limiting values or the method used in an implicit treatment of an upper or lower boundary condition should be noted.
- How the flux through the vertical sides of the region of interest is determined for different locations and times.
- Any additional assumptions made in the study model's treatment that are not covered by this workbook.

General treatments of background, boundary and initial conditions are given in Table 5.14 and the treatments used by selected reference models are given in Table 8.12.

5.11 TREATMENT OF TEMPORAL CORRELATIONS

In dealing with temporal correlations, the quantities of primary interest are emissions, meteorological variables, removal processes, background, and the various boundary conditions.*

If the study model is dynamic or sequential, the temporal correlations between these various quantities are usually accounted for automatically; in other cases, the degree or correlation between the various time-dependent quantities must be assessed by the user. For both sequential and non-sequential treatments the user must determine:

- The degree of temporal resolution available to describe the temporal variations. The degree may be different for different parameters.
- Whether these quantities are correlated to a high degree. In other words, whether a concentration estimate for a particular time is made on the basis of values of the varying parameters that are appropriate to that particular time.

These considerations should enable the user to determine the study model's treatment of temporal correlations.

In addition, when comparing treatments by two different models, the user should consider:

- Whether the magnitude of the variations in the specific application of interest are sufficiently large to require detailed correlation.
- Whether the quantities correlated by the model are important to the specific application.

For example, if emission rates are truly constant, it is unnecessary to correlate them with changes in meteorology. Or, it may be more important to correlate two highly critical quantities than to correlate four quantities of lesser importance to the application of interest.

When describing the treatment on Evaluation Form-Part C, the user should list:

- The quantities correlated,
- The degree of temporal resolution; for example, day-night differences or hourly differences in emission rates,
- The method used to accomplish the correlations; for example, via a stability wind rose or by hourly values input by the user,
- Any scheme used to correlate variables; for example, adjusting input mixing height by stability class,
- Any correlations particularly important in the application of interest, and
- Any correlations that are unimportant because certain variables are constant in the particular application of interest.

General treatments of temporal correlations are given in Table 5.15 and treatments by selected reference models are given in Table 8.13.

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*Detailed discussions of treatments of temporal correlations can be found in Appendix A.8.2.

Table 5.10. Possible Bases for Estimating Dispersion Parameter Values[a]

Model Type	Parameters	Bases for Evaluation
Numerical	Horizontal or vertical eddy diffusivity	1. Diffusivity values determined from special meteorological data acquired for the specific application of interest.
		2. Diffusivity values estimated from routinely measured meteorological quantities using either theoretical or empirical formulae.
		3. Diffusivity values assumed known; specified within model.
Semiempirical[b]	Parameters depend on model formulation (in Gaussian plume case, horizontal and vertical standard deviations).	1. Standard deviations determined from special meteorological data acquired for the application of interest.
		2. Standard deviations specified within model, values based on prior field studies; correction factors based on user-supplied information applied to correct for different meteorological or surface conditions.
		3. Same as No. 2 but without correction factors.
		4. Standard deviations estimated within model from analytic solutions to the advection-diffusion equation (necessarily involving simplified meteorology) and user-supplied information.
		5. Simple theoretical estimates of standard deviations used, specified within model.

[a] Bases in approximate order of decreasing applicability.

[b] Descriptions of bases written in terms of a Gaussian model.

Table 5.11. Spatial and/or Temporal Dependence of Eddy Diffusivities[a]

Dependence of Horizontal or Vertical Eddy Diffusivity on		
Horizontal Location	**Height above Ground**	**Time**
1. Arbitrary. Diffusivity specified as a continuous function of horizontal position.	1. Arbitrary. Diffusivity specified as a continuous function of height.	1. Arbitrary. Diffusivity specified as a continuous function of time.
2. Arbitrary. Diffusivity specified at points on a horizontal grid.	2. Arbitrary. Diffusivity specified at heights of a vertical grid.	2. Arbitrary. Diffusivity specified at a sequence of elapsed times:
3. Specific positional dependence built into model, not subject to user modification beyond specification of parameter values.	3. Specific dependence on height built into model, not subject to user modification beyond specification of parameter values.	a. Values interpolated between times. b. Values constant within each interval.
		3. Diffusivity constant in time (steady-state).
4. Diffusivity independent of position: horizontal uniformity assumed.	4. Diffusivity independent of height: vertical uniformity assumed.	

Note: Arbitrary here means that the model will accept any appropriate user-defined eddy diffusivity dependence on horizontal and vertical position and time or that the model itself, given appropriate user-supplied input, will estimate this dependence. No constraints are placed on the allowed values.

[a] Treatments arranged in order of decreasing level of detail.

Table 5.12. Treatment of Chemistry and Reaction Mechanism[a]

1. Complete mechanism used:
   a. System of truly first-order reactions - exact treatment possible independent of dispersion.
   b. More general system of reactions -
      - Includes all known relevant reactions except those definitely known to be insignificant and
      - Treats all chemical species explicitly.
2. Simplified mechanism used, incorporating the steady-state approximation for highly reactive intermediates but not the lumping approximation for similar species.
3. Simplified mechanism used, involving the lumping of similar chemical species into classes and/or treatment of only some of the relevant compounds but not the steady-state approximation.
4. Simplified mechanism used, involving both steady-state and either the lumping approximation and/or the treatment of only some of the relevant compounds.
5. Equilibrium approximation used, with or without the lumping approximation.
6. Approximates the disappearance and/or appearance of a pollutant of interest and/or the appearance of its reaction products as first-order reactions and uses exact treatment for the first-order (exponential) processes.
7. Not treated explicitly.

[a] Treatments given in order [illegible]creasing level of detail.

Table 5.13. Treatment of Physical Removal Processes[a]

Dry Deposition	Precipitation Scavenging
1. Both pollutant removal and effect on vertical concentration profile treated by imposition of appropriate boundary condition at ground surface. a. Deposition velocity a function of position (and time for dynamic models), surface roughness, and atmospheric stability. b. Deposition velocity a constant.	1. Integrated exponential decay with time-dependent rainout or washout coefficient appropriate for specific variation in cloud density or rainfall rate.
2. Pollutant removal simulated by time or downwind-distance dependent factor (effective source-strength treatment). Effect on vertical concentration profile not treated explicitly. a. Factor determined by: • Ground level pollutant concentration and/or • Dependence of deposition velocity on time, position, surface roughness, atmospheric stability. b. Factor equal to simple exponential decay term.	2. Exponential decay with constant rainout or washout coefficient. Removal process operates only for the fraction of time during which it rains; rainfall frequency input by user.
3. Tilted plume approximation (gravitational settling of large particulate matter only).	3. Each occurence of precipitation scavenging assumed to reduce pollutant concentration by a constant factor.
4. Not treated explicitly.	4. As in No. 2 but rainfall frequency fixed internally and not subject to user specification.
	5. Not treated explicitly.

[a] Treatments given in order of decreasing level of detail.

Table 5.14. Treatment of Background, Boundary and Initial Conditions[a]

a. Background

Type of Model	Method of Treatment[a]
Numerical/dynamic	(Treated as a boundary condition at vertical boundaries.)
Numerical/steady-state[c]	(Treated as a boundary condition at vertical boundaries.)
Semiempirical/dynamic	1. Time-dependent level added to calculated concentrations; value can change at each receptor. 2. As in No. 1, but value is uniform throughout region of interest at all times. 3. Single uniform, constant level added to calculated concentrations. 4. No treated explicitly.
Semiempirical/steady-state[c]	1. Background level can vary with location within region. 2. Single uniform level for entire region added to calculated concentrations. 3. Not treated explicitly.
Climatological	Level of detail depends upon treatment employed by model used to do basic dispersion calculations.

b. Upper Boundary Condition (at Mixing Height)

Type of Model	Method of Treatment[a]
Numerical/dynamic	1. Treats both partial reflection and entrainment of pollutants from above mixing layer.[b] Mixing height depends upon location and time. 2. Treats either partial reflection or entrainment, but not both. 3. Treats only perfect reflection. Mixing height depends upon location and time. 4. Treats only perfect reflection. Mixing height is a constant and uniform over region of interest.
Numerical/steady-state[c]	1. Treats both partial reflection and entrainment of pollutants from above mixing layer.[b] Mixing height depends upon location only. 2. Treats either partial reflection or entrainment. 3. Treats only perfect reflection. Mixing height depends upon location only. 4. Treats only perfect reflection. Mixing height uniform over region of interest.
Semiempirical/dynamic	1. Uses perfect reflection boundary condition. Mixing height is a function of time. Uses method of multiple images and evaluates infinite sum. 2. Same as No. 1, but with constant mixing height. 3. Uses perfect reflection with interpolation between region where mixing height has no effect and region of uniform mixing. 4. Functional form implicitly assumes mixing height large enough to have no effect. 5. Implicit treatment limits appropriate parameters, such as vertical dispersion coefficient.
Semiempirical/steady-state[c]	1. Uses perfect reflection with constant mixing height. Uses method of multiple images and evaluates infinite sum. 2. Uses perfect reflection with interpolation between region where mixing height has no effect and region of uniform mixing. 3. Functional form implicitly assumes mixing height large enough to have no effect. 4. Implicit treatment limits appropriate parameters, such as vertical dispersion coefficient.
Climatological	Level of detail depends upon treatment employed by model used to do basic dispersion calculations.

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Table 5.14 (Contd.)

c. Lower Boundary Condition (at Earth's Surface)

Type of Model	Method of Treatment[a]
Numerical/ dynamic	1. Allows for partial reflection in terms of a dry deposition velocity, which can depend on location and time.
	2. Treats partial reflection using constant dry deposition velocity.
	3. Treats perfect reflection only.
Numerical/ steady-state[c]	1. Allows for partial reflection in terms of a dry deposition velocity, which can depend on location.
	2. Treats partial reflection using constant dry deposition velocity.
	3. Treats perfect reflection only.
Semiempirical/ dynamic	1. Assumed form of vertical concentration profile based on solution to diffusion equation which includes boundary condition describing partial reflection.
	2. Treats only perfect reflection by method of multiple images; evaluates infinite sum.
	3. Treats only perfect reflection; uses single image source treatment and interpolates between region where mixing height has no effect and region of uniform mixing.
	4. Treats only perfect reflection; uses single image source treatment with an implicit treatment of upper boundary condition (hence no multiple reflections).
Semiempirical/ steady-state	1. Assumed form of vertical concentration profile based on solution to diffusion equation which includes boundary condition describing partial reflection.
	2. Treats only perfect reflection by method of multipe images; evaluates infinite sum.
	3. Treats only perfect reflection; uses single image source treatment and interpolates between region where mixing height has no effect and region of uniform mixing.
	4. Treats only perfect reflection; uses single image source treatment with an implicit treatment of upper boundary condition (hence no multiple reflections).
Climatological	Level of detail depends upon treatment employed by model used to do basic dispersion calculations.

Table 5.14 (Contd.)

d. Vertical Sides

Type of Model	Method of Treatment[a]
Numerical/ dynamic	1. Treats flux into region as function of location (including elevation) and time.
	2. a. Treats flux into region as function of horizontal location (no elevation dependence) and time, or
	b. Treats flux as a function of either location (including elevation) or time, but not both.
	3. Treats flux as a function of horizontal location only (no elevation or time dependence).
	4. Treats flux as a constant.
	5. Not treated explicitly; assumes horizontal uniformity.
Numerical/ steady-state[c]	1. Treats flux into region as function of location (including elevation).
	2. Treats flux as a function of horizontal location only.
	3. Treats flux as a constant.
	4. Not treated explicitly; assumes horizontal uniformity.
Semiempirical/ dynamic	(Treated as background.)
Semiempirical/ steady-state	(Treated as background.)
Climatological	Level of detail depends upon treatment employed by model used to do basic dispersion calculations.

Table 5.14 (Contd.)

e. Initial Conditions

Type of Model	Method of Treatment[a]
Numerical/dynamic	1. Treated as a function of position (including elevation). 2. Specified as uniform, independent of position.
Numerical/steady-state	Not applicable.
Semiempirical/dynamic	1. Treated as a function of position (including elevation). 2. Treated as uniform, independent of position.
Semiempirical/steady-state	Not applicable.
Climatological	Level of detail depends upon treatment employed by model used to do basic dispersion calculations.

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[a] Treatments are listed in order of decreasing level of detail within each type of model.

[b] Fumigation may also be treated by numerical models through an appropriate choice of the upper boundary condition during the time of the fumigation.

[c] Sequential steady-state treatments can account for variations in parameters like background and mixing height by assigning a different value to each of the time intervals involved. Models providing this capability give more detailed treatments of this element than those which do not.

Table 5.15. Treatment of Temporal Correlations[a]

Method of Treatment[b]
1. Sequential treatments (correlations automatic).[c]
a. High degree of temporal resolution (usually one hour) of all quantities.
b. High degree of temporal resolution of time-dependent quantities most important to the application.
c. Either low degree of temporal resolution or failure to correlate some important quantities.
2. Non-sequential treatments with limited correlation.
a. High degree of temporal resolution and correlation of time-dependent quantities important to application.
b. Either low degree of temporal resolution or failure to correlate some important quantities.
3. Correlations not treated explicitly.

---

[a] The quantities of interest here are those used to determine emissions, meteorology, removal processes, background, and boundary conditions.

[b] Treatments are listed in order of decreasing level of detail.

[c] Found in dynamic and sequential models.

: : :

: : :

6 COMPARATIVE EVALUATION

6.1 INTRODUCTION

This section provides detailed guidance on comparing two simulation models. The comparison is made after the importance rating of each element has been reviewed and the treatment of each element has been determined. The comparative evaluation is technical in nature and consists of two steps described in Sections 6.2.1 and 6.2.2, respectively. In the first step, the models are compared on an element-by-element basis; in the second, these individual comparisons and the importance ratings are combined into the <u>technical evaluation</u>.

6.2 TECHNICAL COMPARISON

Before initially attempting to compare the treatments of an element by two models, it is strongly recommended that the user be familiar with the technical material presented in the appropriate section of Appendix A. Experienced users may have a lesser need for such reference material.

6.2.1 <u>Comparing Treatments of Individual Elements</u>

The study model's treatment of a particular element should be rated as BETTER than, COMPARABLE to, or WORSE that the reference model's treatment. This rating depends on the <u>relative level of detail</u> with which the two models treat the element and the <u>need</u> for a detailed treatment. If the study model's treatment is significantly more detailed than that used by the reference model <u>and</u> considerable detail is needed in the application, the study model's treatment is rated BETTER. If both treatments are essentially the same, the study model is rated COMPARABLE. Finally, if the study model incorporates substantially less of the detail needed in the application, it is rated WORSE. Guidance on determining the relative level of detail is available from three sources:

- The general tables in Section 5,
- The discussions in Appendix A, and
- The degree of flexibility the user has in defining input to the model.

The tables in Section 5 list various treatments of each element in order of decreasing level of detail. These tables are the basic tools to be used in determining the relative level of detail used in a given treatment. Some elements have been further subdivided into several aspects, each of which must be considered in making the comparison for those elements.

When there is only a single aspect, the user should locate the treatment used by the study model and the treatment used by the reference model on the appropriate table in Section 5. Tables B.2-B.13 in Appendix B give the treatments used by selected reference models. Since not all possible treatments are listed in the tables, the user may need to infer at what level a given treatment would be located if it were explicitly included in the table. On the basis of the relative level at which the two treatments occur, the user should decide upon a <u>comparative rating</u> of the study model with respect to the reference model. Judgment must be exercised at this stage; a treatment occurring at a slightly higher level in the table than another is not necessarily a BETTER treatment. COMPARABLE should be interpreted as meaning "near" or "approximately the same" and should <u>not</u> be interpreted as meaning exact equality. A significant or substantial difference makes the comparative rating BETTER or WORSE.

When the relative level of detail of two treatments is determined, the relevance of that detail to the particular situation should also be considered. The tables of treatments in Section 6 are general in nature and may indicate a difference in the level of detail that is irrelevant in the application of interest. For example, assume that the application involves level terrain, that the study model accounts for physical stack height, and that the reference model accounts for both the topographic elevation of the source as well as the physical stack height. In this case, the study model would not be rated as WORSE than the reference model, since elevation corrections are not required in the specific situation being modeled.

The situation becomes more complicated for those elements for which several aspects are discussed. The comparison is made for each aspect separately and the results combined to give a comparative rating for the element as a whole. The user should be guided by two things:

- The likely importance of the various aspects in the particular situation to be simulated, and
- The expected sensitivity of model estimates to changes in each aspect separately.

The actual situation can be examined to determine which aspects might require more detailed treatment. These would then weigh more heavily in the evaluation of the element as a whole. Treatments of aspects to which the concentration estimates are most sensitive would weigh more heavily than treatments of aspects to which the estimates are least sensitive. A <u>qualitative judgement</u> on these matters is being sought; quantitative information is not required. It may become necessary to consult an expert if questions regarding sensitivity arise.

In difficult situations, the discussions in Appendix A may help resolve the problem.

Specific guidance for all possible situations is clearly not feasible, but the general principles discussed above should enable the user to compare the treatments in most situations. If this guidance does not allow the user to reach a decision, an expert should be consulted.

One final point needs to be made regarding the comparative rating of treatments. For elements like dispersion for which the model itself must be classified, the user must consider the appropriateness of the type of model to the application at hand. Many factors could go into determing whether a particular type of model is appropriate and no specific guidance can be given. The user must make a decision based on specific needs of the problem. For example, the tables for dispersion in Section 5 list numerical/dynamic treatments above the semiempirical/steady-state treatments. However, as discussed in Appendix A, if certain conditions are satisfied, a semiempirical/steady-state treatment may be just as good as a numerical/dynamic treatment. In fact, if a high degree of spatial resolution is required, the semiempirical approach may be more applicable. Thus, the user should be warned that a highly detailed approach may be inapplicable given the user's specific needs. This example illustrates the need for the user to be familiar with the material in Appendix A.

6.2.2 Overall Technical Comparison

This section describes the procedure for synthesizing the comparisons of the individual elements into the TECHNICAL EVALUATION.

When there have been no designations of CRITICAL elements, the user should proceed as follows:

1. Examine the distribution of the treatments of the HIGH-rated elements among the categories BETTER, COMPARABLE, and WORSE. Based on the type of distribution and the guidance below, formulate a tentative evaluation.
2. Based on the distribution and number of the MEDIUM-rated elements, determine the need to modify the tentative rating assigned in step 1. Modify as required.
3. The modified rating obtained in Step 2 will normally be the TECHNICAL EVALUATION. In ambiguous situations, the LOW-rated elements may need to be considered.

If the user is unable to complete the TECHNICAL EVALUATION given the following guidelines, an expert should be consulted.

It is also strongly suggested that the user document the reasons for the decisions made, particularly in ambiguous cases.

6.2.2.1 Comparison Based on HIGH-Rated Elements (Step 1)

In step 1, only the high-rated elements are considered. The user should take the following points into consideration:

- The relative numbers of treatments in each category (the distribution),
- The specific application elements in each category,
- The relative importance of these elements in the application of interest,
- Factors unique to the application of interest, and
- Possible ambiguous ratings in parentheses.

Five types of distributions can arise. Each is described below along with the manner in which the other considerations affect the evaluation. It is not always necessary for the user to identify the particular distribution as long as the application of the general ideas is understood.

Case 1 - All Treatments of High-Rated Elements in Same Category (BETTER, COMPARABLE, WORSE)

In this case, the comparison is obvious. For example, if there are three highly important elements and the treatment of each by the study model is rated better, BETTER is the unambiguous entry in the "Comparative Rating" column.

Case - 2 Equal Numbers of Treatments in Each Category

With equal numbers of treatments in each category, the user cannot simply assume that one better treatment balances out one worse treatment. Rather, the user should identify those elements whose treatments are being considered in the three categories. The importance of these elements to the specific situation to be modeled should then be reassessed and any factors unique to that situation should be considered. This process should not be interpreted as a reassignment of the importance ratings but rather as a means to "fine tune" the HIGH ratings in order to resolve an otherwise ambiguous situation. Although all these elements are of generally high importance in the application, the HIGH category itself covers a rather broad range and some of these elements may be more important than others. If such a determination can be made, a basis may exist for making a comparison other then COMPARABLE.

Other information may be gained by looking at any ambiguous element-by-element comparisons. For example, if one of the COMPARABLE ratings is ambiguous and is indicated as perhaps belonging in the BETTER category, the judgement would lean toward BETTER as the Comparative Rating. This judgment is made only after the relative importances of the elements rated as better and worse have been considered.

Case 3 - A Large Number of Treatments in One Category and a Smaller Number in the Other Two

The considerations here are similar to those described above. The comparative rating is that category with the largest number of elements. The confidence in this rating increases as the relative number of treatments in this category increases. For example, a rating of COMPARABLE based on three comparable treatments and two worse ones is much more tenuous than a COMPARABLE rating based on four comparable treatments and one worse one. Some additional insight may also be gained by examining any ambiguous ratings. Since these ratings are second guesses, their major use should be in cases where they tend to remove ambiguity from the situation, that is. if they support the initial comparison. In any case, no final assignment of the Comparative Rating should be made until the elements whose treatments are listed in each column are identified and their relative importance reevaluated. It may be possible, for instance, for a single WORSE treatment of a highly rated element to justify a Comparative Rating of WORSE even if the treatments of several other high-rated elements are COMPARABLE.

Case 4 - Large Numbers of Treatments in COMPARABLE and One Other Category and a Small Number in the Third

The same considerations apply here as enumerated in Case 3. Here, however, any change in rating from the category with the largest number of treatments would generally be to that associated with the next larger number of elements.

Case 5 - A Large Number of Treatments in the BETTER and WORSE Categories and a Small Number in COMPARABLE

This type of distribution should be considered anomalous and the user should review the individual comparisons and importance ratings before proceeding. If the anomaly cannot be resolved, an expert should be consulted for aid in the comparison.

6.2.2.2. Comparison Based on MEDIUM- and LOW-RATED ELEMENTS (Steps 2 and 3)

In step 2, the MEDIUM-rated elements are considered and the user must decide whether or not to change the Comparative Evaluation reached at the end of step 1. Keeping in mind that the MEDIUM-rated elements are by definition less important individually than the HIGH-rated elements, the user should consider the following:

- The same considerations as involved in step 1, and
- The relative numbers of HIGH- and MEDIUM-rated elements.

The consideration of the distribution of the MEDIUM-rated elements and factors unique to the application follow lines parallel to those discussed in Section 6.2.2.1. If the distribution of high and medium elements are similar, no change is made in the rating. If the distributions are different, the desirability of a change becomes stronger as the relative number of medium elements increases. When the numbers of high and medium elements are considered, the user must think about which elements are involved and their relative importance in the specific situation of interest. For example, consider the two cases outlined in Table 6.1. In case A, the user would be much more likely to change the initial Comparative Rating from BETTER to COMPARABLE than in case B, because of the relatively larger number of MEDIUM-rated elements in case A.

Table 6.1. Effect of Numbers of Elements on Ratings

Case	Importance Rating	Better	Comparable	Worse	Comparative Rating
A	HIGH	1	1	0	BETTER
	MEDIUM	0	6	0	COMPARABLE
B	HIGH	3	1	0	BETTER
	MEDIUM	0	4	0	BETTER

In most cases, step 3 simply involves writing down the Comparative Rating reached at the end of step 2 as the TECHNICAL EVALUATION. The LOW-rated elements are usually not considered. In cases in which the user considers that a contemplated change based on the MEDIUM-rated elements is ambiguous, it may be necessary to look at the LOW-rated elements in an attempt to resolve the ambiguity. The rules for the comparison are essentially the same as in step 2, except that in this case the user is examining the distribution, number of elements, and importance to the application to see if the indicated direction of change is the same as that being contemplated. If it is, the ambiguity may be removed. If not, the change should probably not be made. If problems still remain, an expert should be consulted.

At this point, the TECHNICAL EVALUATION is complete.

6.2.2.3 Comparison with a CRITICAL Element

If a CRITICAL element has been designated, the procedure is almost the same, except that the initial rating is based upon consideration of that element alone. Possible subsequent modifications are then based first upon consideration of the treatments of the HIGH-rated elements and then upon those of the MEDIUM-rated elements. However, if a critical element is treated worse, the user may consider making this single comparison the basis of the entire TECHNICAL EVALUATION. For comparable and better treatments of the critical element, the entire procedure should be applied. Since there will generally be only a single critical element and several HIGH-rated elements, the user must decide how many high elements would be required to override an initial Comparative Rating based on the critical element alone. Again, the user must reach a qualitative judgment based on the considerations discussed above and must not base an entire comparison on a single critical element.

7 ROLLBACK/STATISTICAL MODELS

7.1 GENERAL

The emphasis in this workbook is on the comparison of simulation models. By definition, these models simulate mathematically the effects of physical and chemical processes that affect air quality. Furthermore, the relevant phenomena are considered and described in terms of fundamental physical principles of general applicability. As a result, a simulation model has the property of being transferable from one location to another as long as the limitations imposed by assumptions made in the basic formulation of the model are not violated. Air quality data taken within the region of interest is not required except to fix boundary and/or initial conditions.

Models which do not satisfy these criteria may be encountered by the user. This section provides general guidelines for their evaluation and comparison. Such models are termed rollback/statistical models throughout this workbook and are characterized by one or both of the following properties:

- Only a very few of the factors relating to emissions, meteorological, transformation, and removal processes are explicitly considered in the formulation of the model.
- Locally measured air quality data is required in order to determine empirically the values of various coefficients or parameters in the model.

Included in this classification is the simple rollback model and various extensions of it. The simple rollback model assumes a linear relation between total pollutant emissions within some region and pollutant concentrations within that region. It does not explicitly consider the spatial distribution of emissions, the location of the receptors of interest, nor any meteorological factors.

Also included in the rollback/statistical category are those models that require the use of actual atmospheric monitoring data, including both air quality and meteorological variables, for the empirical adjustment of model parameters. The relationship between air quality and selected meteorological parameters is determined empirically in these models, commonly through the use of regression or other statistical techniques.

7.2 ADVANTAGES AND DISADVANTAGES

The major technical advantage enjoyed by statistical models is the close relationship between concentration estimates and values actually measured under more or less similar circumstances. The effects of all those factors that determine atmospheric pollutant concentrations are implicitly accounted for in the air quality data used to develop and optimize the model. The same may be said about rollback, since an air quality measurement is used to estimate the ratio of emissions to atmospheric concentrations. Due to the nature of the procedures used in developing a statistical model, information is often available regarding the statistical significance of the variables that are taken into account and the magnitude of the statistical error made by the model; no such information is available for rollback. Other advantages of rollback/statistical models, such as their low development cost and low resource requirements, are primarily pragmatic in nature.

The major disadvantage of rollback/statistical models also arises from their dependence on air quality data. A statistical model is not, in general, applicable under conditions that are outside the range of conditions included within the data used in its development and optimization. The range of conditions commonly includes variations in meteorological variables, but for practical reasons very little variation in the spatial distribution of emissions can be investigated. Consequently, statistical models are not generally suited for applications that involve the consideration of significant changes in the distribution of emissions and, as a result, are not transferable without re-evaluation of their specific empirical parameters or coefficients. Rollback considers only one set of conditions, specifically that set of meteorological conditions and emission rates which existed over that period of time in which the air quality measurement used in the model was made. Therefore, it is also unsuited for the consideration of changes in the emission distribution.

The applicability of rollback/statistical models is more limited than that of a simulation model for other reasons as well. For example, only rather general concentration estimates may be obtained. The dependence of pollutant concentrations on position cannot normally be predicted, nor can individual source contributions at any given position of interest.

If a model that falls into the rollback/statistical category is to be evaluated, the user should consider the applicability of the particular model to the application of interest, keeping in mind the generally limited applicability of such models. Statistical models are often formulated for a very specific purpose. If that purpose coincides with the requirements of the user, and if the range of conditions of interest to the user are included within those used to develop the model, the model is applicable and may give better results than a simulation model. Otherwise, the model may not be appropriate.

7.3 COMPARISON OF ROLLBACK/STATISTICAL MODELS

The only basis that may exist for the comparison of a given statistical model with a given simulation model is the observed performance of each in previous practical applications. In general, the philosophies and goals of these two approaches to estimating atmospheric pollutant levels are sufficiently different as to preclude any systematic, objective, a priori technical comparison.

If, however, estimates of the errors made by the simulation model in applications similar to the one of interest are available, they may be compared directly with the expected error for the statistical model, thereby allowing a comparative evaluation to be made. Unfortunately, even this basis does not exist for rollback, since the emission-concentration relationship is an assumed one, rather than one obtained using accepted statistical procedures.

It may be possible in some cases to make a comparison of a rollback/statistical model with a simulation model by determining the approximations that must be made to reduce the working equations to a linear relation with constant coefficients between the pollutant concentration and the total emission rate. The degree of validity of the necessary approximations in the situation to be modeled is a measure of the degree of comparability of the simulation model and the rollback/statistical model. If this approach is adopted, the Evaluation Form provides a convenient format for recording the necessary information. Furthermore, if the element-by-element comparisons are interpreted as a measure of the validity of the relevant approximations in going from the simulation model treatment to the rollback or statistical model treatment, the information can be summarized easily on Part D of the form. The technical comparison can in this case be made following the same guidelines as are used for the comparison of two simulation models as described in the other sections of this workbook.

It may not always be possible to make a comparison in this manner. A statistical model may still be evaluated on its past performance. However, since rollback is: (1) not really based upon consideration of the application elements discussed in this workbook; (2) not obtained by statistical analysis of appropriate air quality data; and (3) as yet unverified, no basis exists for objectively evaluating the performance of a rollback model.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The workbook describes a technique for the qualitative comparison of modeling approaches on technical grounds. The methodology is based upon an applications approach. The results of the model comparison depend upon the application for which the model is to be used as well as upon the model characteristics. In each application of the technique, the model of interest is compared with a reference model. Any model may be specified as the reference model, as long as it is compatible with the application of interest.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

APPENDIX A

TECHNICAL SUPPORT MATERIAL

CONTENTS OF APPENDIX A

Appendix A: TECHNICAL SUPPORT MATERIAL

Sections A.1-A.8 of this Appendix contain technical discussions of the application elements and describe methods of treating them in models. Brief discussions of the rationale for the importance ratings are given in Section A.9.

A.1 EMISSION CHARACTERISTICS

A.1.1 General

To predict the concentration of a pollutant, a model must treat the emissions of that pollutant and its precursors, if any, as well as the emissions of those substances which react with the pollutant or its precursors. The emissions and their distribution can be characterized by specifying the:

- Source-receptor relationships,
- Emission rates, and
- Composition of the emissions.

These three application elements are discussed together here but the user should make separate comparisons of their treatments.

The source-receptor relationship includes:

- Source location,
- Height at which emissions are released into the atmosphere,
- Receptor location,
- Receptor height,
- For line and area sources, the orientation of the source to a fixed direction, and
- Downwind and crosswind distances between source-receptor pairs.

Thus defined, source-receptor relationship comprises the positional factors which determine the extent to which dispersive, chemical, and removal processes affect pollutant concentrations. Once released at a particular location and height, pollutants travel downwind and are dispersed, ultimately to be detected at the receptors of interest. It is during this time of travel that dispersion, secondary generation, and removal processes are active in altering the concentrations of the pollutant of interest.

Emission rates are clearly important because they determine the total quantities of materials emitted into the atmosphere during the time of intere [illegible] source's emission rate generally varies with time. For example, emission rates from a stack generally vary over time scales ranging from minutes to years. For line and area sources, spatial variation within a single source may also be important. The treatment of these temporal and spatial variations must be considered when two models are compared and are discussed in Appendix A.1.3 dealing with the treatment of emission rates.

Finally, the composition of emissions must be considered in some applications. Chemical composition is important for secondary or reactive pollutants and in some situations where several species of particulate matter are of interest. The size distribution of particulate emissions is also important when fallout, deposition, or precipitation scavenging must be considered. It should be noted that the identification of possible sinks and secondary production mechanisms can depend upon knowing the composition of emissions other than those with which the user is mainly concerned.

The following three subsections describe the treatments of these application elements.

A.1.2 Treatment of Source-Receptor Relationship

In this discussion, location means a specification of the source's horizontal position. The release height specifies the vertical position of the release of emissions to the atmosphere, and does not include a specific discussion of treatments of plume rise, which are discussed as a separate element, plume behavior, in Appendix A.2.

For point sources, there are basically two levels of detail with which horizontal location can be treated. The first allows each source to be accurately located at its true position with respect to some horizontal grid system, thus allowing a maximum degree of spatial resolution. The second and less detailed approach locates each point source only to the extent of identifying a grid cell containing the source, thus sacrificing some degree of spatial resolution. This latter treatment is used by numerical models that treat all point sources lying within a given basic grid cell without regard to their precise location but that do distinguish between sources located in different cells. The loss of resolution between the first and second levels is essentially the same as that incurred in developing an emissions inventory when small point sources are aggregated to area sources. For the purpose of this workbook, however, the inventory is assumed to be given and the less detailed treatment then involves the assignment of the point sources to grid cells despite the availability of more precise information. If the aggregation to area sources is part of the inventory, it should not be considered when comparing models. The comparison should be based on the treatments of the point, area, and line sources given in the inventory.

The location of point sources by grid cell can, of course, be treated at various levels of detail. The most detailed treatments preserve significant spatial resolution on a relatively fine grid. The least detailed sacrifice all spatial resolution and do not distinguish between sources regardless of their location within the region of interest. Models using the least detailed treatment cannot adequately treat situations involving alterations in the spatial distribution of emissions. Detailed treatments also frequently permit a finer grid to be used in areas where the user desires a high degree of spatial resolution. This treatment is somewhat more detailed than one using a fixed grid size, if the block size is smaller while allowing the user the added flexibility of matching the degree of resolution to the needs of the specific application.

Occasionally, a model may aggregate sources on a basis not directly related to location. This occurs when sources are aggregated, for example, by industrial category. Unless this type of treatment is used in conjunction with one of the locational treatments described above, it provides no information on the location of sources and is equivalent to the least detailed treatment of horizontal location.

The release height of point sources is treated in its most detailed form when both the physical stack height (without plume rise) and the elevation of the base of the stack above some reference elevation can be specified for each source. A less detailed treatment assumes flat terrain and considers only the physical stack height or release height above grade. These treatments can be used even when the horizontal locations of the sources are "gridded" by the model onto subareas of the region of interest. Less detailed treatments are frequently used when the model grids the point sources. These involve specifying one or several representative release heights, which may include an elevation correction, for each subarea of the grid. Less detail is available when the same release heights are applied to all the subareas. (When representative release heights must be assigned, the user frequently calculates a representative plume rise and adds it to the physical release height, since models using such treatments generally make no provision for the internal calculation of a typical plume rise.) At the least detailed level release height is not treated explicitly; all emissions are treated as if they are released at the same height. This non-explicit treatment is used in numerical models in which all emissions are treated as part of the boundary condition at ground level.

Before proceeding, it is convenient to discuss receptor location because receptors are usually taken as points. As is the case with point sources, the horizontal locations of receptors can be specified as precise points or as locations in some grid block. When the receptors are located precisely, two methods or a combination of the two are generally used. The first allows the user to locate the receptors arbitrarily. The second places the receptors at the intersections of a grid network, the spacing or scale of which may be fixed or under the user's control. Both methods may provide equivalent levels of detail and the user must decide which is better suited to the particular application. It may also be, of course, that specifying receptor locations by subarea only is sufficient to the user's purpose, but here such treatments will be rated as less detailed than treatments that locate receptors precisely in the horizontal. The level of detail of receptor locations also depends upon whether the elevation of the receptor can be specified. Given comparable specification of horizontal receptor locations, a treatment which allows the user to specify arbitrary receptor heights is more detailed than one which assumes that all receptors are at the same height (usually ground level).

In the context of source and receptor locations, it must be stressed that the user should not always rate one treatment against another solely on the level of detail. Consideration should also be given to whether the level of detail provided is necessary in the particular application. For instance, if the application involves the impact of a single source at a specific location, the ability to locate numerous sources and receptors precisely is irrelevant as long as the pair to be studied can be located as desired. Thus, the comparisons made by use of the tables in the workbook should be modified to reflect the specific requirements of the application of interest. The table assumes that it is desired to locate a number of sources and receptors at arbitrary locations. Since all required cases could not be foreseen, the user must modify this general list to reflect the application of interest.

For area sources, the treatments of source location and release height follow the same general progression as for point sources, that is, a full specification in three dimensions (both horizontal location and release height) at the most detailed level and a complete lack of explicit recognition of different source locations and heights at the least detailed level. Two additional considerations must be given to area sources, however, because of their two dimensional nature. First, a model which accepts area sources at arbitrary locations provides more detail than one which places all area sources on a fixed grid even if the size of the grid can be changed by the user. In the latter case, the user's area sources must be mapped onto the model's gridded areas and hence the differences between areas tend to be averaged out. Such a loss of detail may be unimportant when the difference in emission rates in adjacent areas is small. The user must decide this based on his knowledge of the situation of interest. Second, models which treat arbitrarily sized area sources generally allow greater flexibility than those which limit area sources to one or several set sizes. This can be particularly important when dealing with "true" area sources such as open pit mines or dusty fields. Again the user must decide when comparing models whether this consideration is important in the particular application of interest.

Another difference between point and area sources arises because an area can have an arbitrary orientation with respect to the wind direction. Most models treat area sources on some type of grid system that is fixed in space and hence the orientation of an area cannot be adjusted even when the real physical source is tilted with respect to the model grid. For computational purposes, some models assume a specific orientation which may be unrelated to the actual orientation of the source. This assumption is frequently reasonable when the area sources are aggregates of many small point or line sources. A somewhat more detailed treatment permits the area source to assume an arbitrary orientation; such treatments may be useful when dealing with true area sources where the orientation of the actual source can be arbitrary.

The most detailed treatment of line sources specifies the precise location and orientation of the line by, for example, using its endpoints and provides for some width and height for the line (thus really treating it as an elongated volume source). For infinite lines, only the orientation of the line is specified. Curved lines are usually approximated as series of straight line segments and for highways some width can be provided by allowing the number of lanes, medial strip width, and roadway width to be specified. Less detailed treatments specify only the horizontal location and fail to allow for width; a release height may be specified. Care must be taken with line source models to ascertain whether they allow the line to assume an arbitrary orientation with respect to the receptor. Some models, for example, require that the receptor be located near the perpendicular bisector of the line and will not properly treat a receptor lying near the axis of the line source. As with point and area sources, increasing degrees of aggregation within the model produce less detailed treatments.

In applications involving a combination of source types, the degree of detail of the treatment can be different for different source types. However, an overall evaluation can still be made by comparing the reference model treatment with the study model treatment for each source category and making some assessment of the importance of each category to the particular application.

Some modeling parameters determined by the source-receptor relationship may depend explicitly on the downwind or crosswind distances between source-receptor pairs. For instance, in Gaussian plume models the dispersion parameters are normally functions of the downwind distance. When this is the case these distances must be calculated. It should be noted, however, that a model may not ever need to calculate the downwind or crosswind distance explicitly. For example, a numerical dynamic model may move an air parcel along a trajectory but never use the distance along the trajectory. In such cases, the downwind/crosswind distances are not calculated and their treatment can be ignored. When required by the model these distances are usually assumed to be determined by the horizontal separation between pairs and hence do not depend upon release height or receptor height. When point sources are involved and both the sources and receptors are located as points, the capability exists to calculate a unique downwind and crosswind distance for each source-receptor pair either along a curved trajectory or assuming a steady-state wind in a single direction. When a model grids either sources or receptors, less detail is available, since only average or representative separations can be determined. This is also the case for area and line sources. Finally, no downwind or crosswind distances can be determined if no distinctions between sources and receptors are made on the basis of location. This is the case, for instance, when a box model includes an entire region in a single box.

These treatments of source-receptor relationship are listed by their level of detail in Table 5.1. Treatments by suggested reference models are given in Table B.2.

A.1.3 Treatment of Emission Rate

Once the positional relationships between sources and receptors have been determined, the emission rate of each source must be specified. Two aspects of the element emission rate are important:

- Spatial distribution of emissions and
- Temporal variation of emissions.

The treatment of the spatial distribution of emissions is closely related to the treatment of horizontal location discussed in Appendix A.1.2, since the degree of spatial resolution available depends upon how close to their real positions the model locates sources. For point sources, no additional information is required to describe the spatial distribution beyond what is already given in the treatment of source-receptor relationship. In the case of line or area sources, however, the manner in which the distributed nature of the source is taken into account requires consideration and is discussed in this section. Two points of view exist regarding the treatment of distributed sources. In determining the treatment of distributed sources by a model it is useful to identify which point of view is adopted simply in order to clarify the treatment. In many cases, there is no intrinsic difference in the level of detail associated with the two possibilities.

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From the first point of view, the total contribution of the entire emission distribution is estimated by adding up estimates of the contributions from many individual parts, each consisting of a uniformly emitting area or line segment. For example, sulfur dioxide emissions from residential space heating in an urban area are most commonly represented as a rectangular array of square area sources, each characterized by a given emission rate per unit area. Another example is the representation of automotive emissions as a set of finite line sources, each of which is characterized by a given emission rate per unit length. Each part is considered to be a separate source, and the contribution from each of these parts to the pollutant concentration is estimated. The total contribution from the entire distribution is then estimated by summing all these individual contributions.

From the other point of view, the overall distribution is regarded as a single entity in which, however, the local emission rate may vary from point to point. A single estimate of the total contribution from the given emission distribution is made without explicitly estimating the contribution from each of the individual parts comprising the source inventory, even though the source inventory may have exactly the same form as before. This point of view may be adopted for an array of square area sources as in the first example above, as well as in cases in which only one line or area source is of interest. In the latter situation, the emission rate per unit length or per unit area may be allowed to vary within the source itself.

There is no intrinsic difference in the levels of detail associated with these two points of view if only the total contribution to the estimated pollutant concentration is of interest. If the individual contributions are desired, a treatment which adopts the first point of view is likely to be superior to one which adopts the second. However, much depends upon the level of detail of the methods used to make the individual estimates in the two treatments. In order to estimate individual contributions within a model adopting the second approach, an algorithm for allocating the total calculated contribution among the individual parts must be incorporated. In the first approach the individual contributions are independently estimated.

Whatever point of view is adopted, some technique must be used to estimate the contribution of either the overall distribution or of each of its component parts. The rest of the discussion addresses methods of making these estimates. The various possible methods fall into two general categories:

- Analytic or numerical integration, and
- Source substitution - the replacement of a line or area source with a small number of point sources.

In principle, the most detailed treatment of the spatial distribution of emissions involves the integration over the given distribution of the contribution from an infinitesimal area or line segment, assumed to contribute as a point source. If the spatial distribution and the infinitesimal contribution have a sufficiently simple form, the integral may be evaluated analytically. Thus, for example, the pollutant concentration downwind of a uniform horizontal line source of specified length oriented perpendicular to the wind may be estimated by means of a formula obtained by integrating the Gaussian plume expression for the contribution from each infinitesimal segment of the line. In general, however, the spatial distribution and the point source concentration estimates are sufficiently complicated that such an analytic expression cannot be derived. In such cases, alternative methods must be used.

One alternative is to evaluate the integral by some appropriate numerical procedure. If the numerical procedure is sufficiently detailed that the spatial variation present in both the emissions and the point source formula is taken into account, the result may be equivalent to that which would be obtained by an analytic integration. The level of detail of the treatment is directly related to the distance between sampling points at which the emission rate and point source estimate are evaluated; the smaller the distance, the higher the level of detail. Since for a given receptor the nearby emissions are expected to contribute more heavily than those futher away, treatments which incorporate high resolution near the receptor and progressively lower resolution at greater distances involve a relatively high level of detail.

Another alternative is to simplify the integration by introducing additional approximations so that either an analytic expression may be derived or the numerical integration is made significantly easier. For example, a common approximation used in dealing with an array of area sources is to assume that emissions are uniformly distributed in the crosswind direction. In most urban areas, this may be a reasonable assumption; in general, the level of the treatment depends upon the appropriateness of the assumptions in the user's specific application. The example just given corresponds to what is often called the narrow plume approximation. In this approximation, only the emissions from those area sources which are directly upwind of the receptor, or in general those which are intersected by a trajectory which subsequently passes through the receptor location, have an effect on the estimated pollutant concentration. Further discussion may be found in Appendix A.4.2.

The least detailed treatments involve the replacement of a line or area source by a small number of point sources having a combined emission rate equal to that of the source they are replacing. The smaller the number of effective point sources is, the less detailed is the treatment; a treatment involving the use of a large number of points amounts to the use of a numerical integration procedure. The position of the effective points may be chosen to approximate the spread of emissions within the source being replaced, and the strength of each may depend upon their position.

There are two components to the treatment of temporal variation of emission rates:

- The degree of temporal resolution which the model allows and
- The suitability of the technique for treating the variations to the particular application.

The degree of temporal resolution is determined by the interval at which emission rates can be changed in the model. Even the most detailed treatments can usually handle properly at most hourly variations in emission rates. The overall temporal resolution of a model is often limited by the temporal resolution of the meteorological data. The emission data should reflect a similar resolution at the most detailed level. If a large number of time intervals must be treated, say all 8760 hours in a year, some models take a sample of all the hours and thus treat only a subset of all available time intervals. This approach provides somewhat less detail than accounting for all time intervals but may give results which are equivalent to those obtained from a fully detailed treatment particularly when the accuracy of the model is considered. Less detail is offered by treatments which allow no temporal variation, permitting only constant emission rates to be specified. Within these limits, the shorter the interval over which changes in emission rates can be specified, the more detailed the treatment.

For those models which allow some temporal variation in emission rates, the suitability of the technique of handling the variations must also be considered. One technique is commonly used in dynamic models. The total time period of interest is divided into intervals. Each time interval is modeled in succession, the pollutant distribution at the end of one interval serving as the initial distribution for the next. This type of detailed approach is necessary when significant variations in emission rates occur over the averaging time of interest. In simpler situations, a second technique treating the situation as a set of steady states is applicable; the steady-state approach is generally simpler to implement. This approach looks at each time period separately. It can account for the time sequence, but it ignores the pollutant distribution remaining at the end of each interval when a new interval is considered. The steady state treatment is the more common. Some models allow the entire set of steady-state situations to be treated. Others simulate only a single situation at a time and must be applied repetitively when longer time periods are of interest.

The repititious application of a model allows temporal variations in emission rates to be treated using only constant rates. For example, if it is desired to use a climatological model designed to estimate annual averages from average emissions rates and the sources have significant monthly variatio [illegible] model could be run twelve times with emission rates appropriate for each month and the twelve individual results averaged. It would, of course, also be necessary to use meteorological data appropriate to each month in the individual runs.

As was the case with spatial variation, a model that aggregates sources is inherently less detailed than one which treats each source individually. In aggregating, each source's emission pattern is masked in an average value and some details of the situation are lost.

One further aspect of emission rate must be discussed: the treatment of the amount of emissions based on other input parameters such as vehicle miles traveled (VMT), vehicle mix, or population. When actual emission rates (or a sequence of rates) are supplied to the model, the degree of detail depends upon the degree of detail used in generating these numbers and is not limited by the model itself. When the model itself calculates the emission rates, a model requiring more detailed input generally provides a more detailed treatment. For example, a model which estimates vehicular emissions based on VMT, average speed, and vehicle mix is less detailed than one which uses VMT, vehicle mix, and allows a different average speed to be assigned to each class of vehicles. Since the number of possibilities is large, no attempt to rank treatments will be made here. As a general guideline, the user should compare the levels of detail required in the inputs of the models being evaluated. It should also be noted that evaluating this aspect of emission rate may be impossible; for example, one model might require specific emission rates to be input, while a second model calculates emission rates from other information.

Table 5.2 gives the general treatments of emission rates in order of decreasing level of detail. Specific treatments used by suggested reference models are given in Table B.3.

A.1.4 Treatment of Composition of Emissions

Chemical Composition

In applications involving chemical reactions (secondary generation or reactive pollutants), the chemical composition of emissions is important. At the most detailed level, the emissions of all relevant individual compounds are treated. Somewhat less detail is obtained when several or many related compounds are "lumped" together into a single class and only the total emissions of all members of the class are treated. Two things must be considered when a model treats the emissions of at least some of the relevant compounds in terms of lumped classes. First, the criterion for determining in which class a particular compound belongs must be appropriate for the chemistry to be modeled. Second, the compound chosen to represent the class must also be chosen appropriately; in some cases, it may not be an actual compound but a hypothetical representative compound. For example, ir case of photochemical oxidants, it would be impractical to use full detail and treat the emission of every possible organic compound individually. Consequently, they may be lumped into classes depending upon their degree of photochemical reactivity. Thus, if five reactivity classes were used, each source would have associated with it up to five different emission rates for organic compounds, one emission rate for each reactivity class. This classification would also be appropriate to the oxidant problem whereas classification by, for instance, molecular weight may not be. In general, the greater degree of classification into appropriate, distinct classes, the greater the level of detail of the treatment. Less detail is available when assumptions regarding the composition of emissions are built into the model, such as when a photochemical oxidant model assumes a certain percentage of the organic emissions to be reactive regardless of the actual nature of the sources involved. Still less detailed treatments describe the emissions of only one of several compounds known to interact.

Model treatments must also be checked to ascertain whether all relevant emissions have been treated. For example, models for photochemical oxidants that treat reactive organic compounds but not NO and NO_2 emissions are inherently less detailed than those which treat NO and/or NO_2, because NO can act as an ozone scavenger and the NO_x/organics ratio is important in determining the extent of ozone formation. Expert advice may be needed in making these determinations. With regard to this last point, care must be exercised to consider here only compounds which are actually "emitted" by the sources. These may only be a subset of the total number of compounds which are involved in the chemical kinetics and may not even include the pollutant of interest. For example, ozone "emissions" are negligible or zero but the emissions of the organic precursors must be treated in models for photochemical oxidant. The user would not deem a photochemical model inappropriate because ozone emissions are not treated.

Size Distribution of Particulate Matter

The most detailed treatment of the size distribution of emitted particulate matter would take into account a continuum of particle sizes by allowing the functional form of the particle size distribution to be specified. In somewhat less detail an appropriate distribution is assumed and the parameters necessary to describe that distribution are input. Less detail is available in treatments which treat all particles within a given range of sizes as if they had the same representative size. This treatment is analogous to the lumping of various chemical species described above. Similarly, a treatment using smaller size intervals offers more detail (generally, more size intervals) than a treatment that divides the total range of sizes into fewer, wider intervals. Even less detail is contained in treatments that assume that some fraction of the particulates are affected by the mechanism of interest. This is really a two-class treatment: a fraction of the particulates, for example might be assumed large enough to fall out of a plume, while the remainder are assumed to behave like a gas. The least detail, of course, is offered by treatments which fail to treat the size distribution explicitly in situations in which it may be important. Such is the case when all particulate emissions are treated as a gas, including that fraction which is sufficiently large to be subject to significant gravitational settling.

It should be noted that a complete characterization of the composition of emissions may require a joint treatment of chemical composition and the size distribution. In such cases, the appropriate size distribution may not only vary from source to source but may also vary from chemical compound to chemical compound. Such detail is beyond the level at which models presently operate but the user should be aware of the complexity of a complete specification of the application.

Tables 5.3 and B.4 give the treatments of the composition of emission in general and by suggested reference models, respectively.

A.2 PLUME BEHAVIOR

A.2.1 General

Upon release, an effluent generally has some upward momentum and buoyancy. Mixing with the ambient air begins immediately and continues as the effluent travels downwind and disperses. In the initial phases of this travel, the plume centerline is determined simultaneously by the rise due to the initial momentum and buoyancy and the downwind advection. As mixing continues, the plume centerline is determined by the initial conditions to progressively lesser degrees until it is determined predominantly by the downwind advection. The height to which the initial momentum and buoyancy carry the effluent is called the "plume rise" and this height plus the physical release height is termed the "effective stack height."

As these definitions indicate, some models treat plume rise only for point sources. When area and line sources are aggregates of small point sources, the plume rise associated with each individual area or line source is an average or representative value. This discussion focuses on plume rise from point sources and certain other types of plume behavior. The user should be aware, however, that the same factors as discussed herein must be considered if a model explicitly treats plume rise from area or line sources.

Many interacting factors affect plume behavior. When the stack exit velocity is small compared to the wind speed, the plume may bend over immediately after release and downwash may occur behind the stack. This is one of special situations to be considered when plume behavior is treated. If the stack exit velocity is large, mixing of the effluent and ambient air will be increased, rapidly dissipating the plume's buoyancy and momentum and causing a low plume rise. Plume rise also depends on stability, atmospheric temperature gradient, plume buoyancy and wind speed. The buoyancy of a hot plume is determined by the <u>heat release rate</u>; hotter plumes rise higher than colder plumes, other conditions being the same. The heat release rate depends on the stack exit velocity; the effluent's temperature, molecular weight, and specific heat; the stack diameter; and the atmospheric temperature and pressure. A formula relating these variables may be found in Moses and Kraimer (1972). In addition, the relative humidity and moisture content of the plume may be important. Many plumes contain some water and after release the condensation of gaseous water or vaporization of liquid water adds or removes heat from the plume and hence affects buoyancy. The condensation of water vapor can be large enough to cause a very low plume rise, as can be the case with cooling tower plumes.

The momentum of the plume depends upon the mass of the effluent and the stack exit velocity. The density of the plume is thus important and the product of velocity and stack diameter is a measure of the square root of the momentum release rate. For stacks with very high exit velocities, the momentum term may be much larger than the buoyancy term. This "momentum only" case is not encountered in most common applications, in which the principal interest is in buoyancy effects.

There are other factors which also affect plume rise:

- Terrain and nearby buildings,
- Number of nearby stacks and local heat sources,
- Shape of the stack opening,
- Wind direction in directionally inhomogenous situations,
- Wind shear, and
- Precipitation.

No single treatment of plume rise deals with all these factors and there is no generally accepted treatment; over twenty separate formulae are available and new ones continue to appear. Most analytical formulations make the plume rise directly proportional to the reciprocal of the wind speed at the top of the stack. Two terms, one proportional to the square root of momentum and the other to some power of the heat release rate, are also included but the momentum term is frequently omitted, its effect being negligible in many common situations. When plume rise is treated as a function of distance, data for power plant plumes indicates that the plume rise varies as the 2/3 power of the downwind distance. Th [illegible] be separate formulae for different sized stacks and different stabilities but the treatment of special plume behavior is generally not included in the treatment of plume rise.

The special plume behaviors usually considered include:

- Downwash
- Plume trapping, and
- Inversion breakup fumigation.

The conditions leading to downwash were noted above. A rule-of-thumb says that downwash should be considered whenever the physical stack height is less than about 2 1/2 times the height of the building it is on or the height of nearby obstacles to airflow or whenever the stack exit velocity is less than about 1 1/2 times the windspeed at the top of the stack. This rule-of-thumb is only a rough guide and in many situations, for instance, with a cold plume having little buoyancy, downwash may need to be considered even for stacks whose heights exceed those indicated. Plume trapping occurs when a stable layer exists above a neutral or unstable layer. A plume emitted into the lower neutral or unstable layer will rise until it reaches the base of the stable layer where it becomes trapped between the stable layer and the ground. Very hot plumes may be able to "punch through" the stable layer and thus may not be trapped. Fumigation occurs when a stable surface-based inversion is broken up by heating from the ground. Pollutants that were emitted into the stable layer are then thermally mixed in the vertical and relatively high ground level concentrations can result, as discussed in Appendix A.4.

A.2.2 <u>Treatment of Plume Behavior</u>

As noted previously, there is no generally accepted method of treating plume rise. Several types of treatments of various degrees of detail exist. Within each type, the appropriateness of a given treatment depends upon whether the method has been verified in the field for the application of interest. In fact, the best comparison of two plume rise formulae is obtained by comparing their predictions with observed plume rise values under the conditions of interest.

The most detailed level of treatment would account for the simultaneous rising and dispersing of the plume. This problem is extremely complex and has been treated only in very specialized applications such as self-contamination of buildings where the behavior of the plume immediately after release is of primary concern.

Most models are unable to handle dispersion during the initial rising phase of plume travel and usually treat the situation by separating the rising plume from the dispersing plume and considering two distinct steps:

First, the plume rise is determined based on stack and meteorological parameters. This plume rise may be a function of the downwind distance.

Second, dispersion is treated by assuming a virtual source emitting at an effective stack height equal to the physical release height plus the plume rise.

This is the type of treatment found in most dispersion models for primary pollutants. However, many formulae are used to estimate the plume rise. As noted above, comparison to a reference model's treatment should be based upon which treatment gives better agreement with observed plume rises for the application under consideration. Such comparative results are scanty and another method must normally be used if a comparison is to be made.

Without prejudice to other treatments, models using the following plume rise formulae can be considered applicable in many situations, unless comparative field studies indicate otherwise for the case at hand:

- Briggs' 2/3 power law,
- Holland,
- CONCAWE or CONCAWE simplified, and
- ASME.

The Briggs' and Holland formulae have been "verified" for power plants. Only Holland has a separate momentum term and correction factors have been suggested to account for stability. Briggs uses separate formulae for different stability classes and is the only one that treats plume rise as a function of downwind distance. The CONCAWE formulations consist of single formulae and are the only ones in which plume rise is inversely proportional to a fractional power of the wind speed, except for the Briggs (stable) formula. It must be stressed that this list does not mean that other formulae should not be used. These four are widely used and do a fairly good job of prediction in many cases. Other formulae may be better in specific applications, but the only valid evidence of this is direct comparison with observations.

If the user has an unverified formula in a study model, the following general guidelines, valid for hot, buoyant plumes only, may be helpful:

- Plume rise should be proportional to the reciprocal of wind speed to some power between 1.0 and 0.70 for nonstable conditions. Calm conditions require the omission of wind speed from the formulae used.
- A buoyancy term <u>must</u> be included (heat release rate should be raised to a power between 1/3 and 1).
- Other things being equal, a formula with a momentum term would be preferred.
- Other things being equal, a formula giving plume rise as a function of downwind distance would be preferred. (This consideration is more important for low level sources than for elevated sources.)

It must again be stressed that verification in the field for the application of interest is the preferred decision parameter. Use of the above guidelines is recommended only as a last resort. For ease in comparison, the widely used formulae are compared in Table A.1.

The next lower level in detail still uses the two-step procedure but does not attempt to estimate a specific plume rise based on stack parameters. Instead, the user specifies a value for the product of some power of the wind speed and plume rise. The model then calculates a plume rise for each wind speed. This method usually assumes that plume rise is inversely proportional to the wind speed but does not allow differences between sources or other meteorological parameters to affect the plume rise.

A still less detailed treatment allows plume rise to be considered but only permits a small number of specific values. This treatment is used frequently for aggregate sources and hence is common in the treatment of area sources in urban models. The values of plume rise chosen are average or representative values and are often included in the release height (see Appendix A.1.2).

The least detailed treatment does not deal with plume rise explicitly. This is the case, for example, in proportional models and models which treat vertical dispersion by assuming uniform mixing.

There are only a limited number of treatments of the special plume behavior. Downwash is typically not treated explicitly. Treatments of downwash are normally developed expressly for that problem alone. Halitsky (1965, 1968) and Turner (1969) discuss downwash in general and should be consulted if downwash is expected to be significant. More recent studies of downwash near buildings are found in Huber and Snyder (1976) and Robins and Castro (1977). Several techniques of accounting for building influences on plume dispersion are presented by Huber (1977). In general; many additional studies are necessary to thoroughly understand the complex effects of downwash on ground-level concentrations.

Plume trapping can be accommodated in two-step models by assuming that the plume is reflected from the base of the stable layer aloft and from the ground. Repeated reflections lead to uniform mixing. The plume is assumed to be unaffected by the inversion lid until its vertical spread reaches the stable layer and to be uniformly mixed after some suitable downwind distance thereafter. Between these two distances, interpolation of concentrations is used. (See the discussion of boundary conditions in Appendix A.7.) Carpenter et al.

(1971), Pooler (1965), Hales (1956) and Bierly and Hewson (1962) give treatments that can be used for trapping. The formula developed independently in the latter two papers, and included in Turner (1969), frequently is used in Gaussian plume models.

Inversion breakup is generally not treated by models. Carpenter et al. (1971), Turner (1969), and Pooler (1965) give formulas which can be used to estimate ground level concentrations during inversion breakup if the user must consider this condition. (See the discussion in Appendix A.4.)

One further treatment of plume behavior used to treat the deposition of particulate matter for which gravitational settling is important should be noted. This is called the "tilted plume" approximation and is discussed in Appendix A.6.2.

The various general treatments of plume rise are given in Table 5.4. Treatments of special plume behavior are not rated. The user should note how the study model compares to the reference model in the number of special cases of plume behavior each treats. These treatments should be compared to those given in the references cited above. Treatments by suggested reference models are described in Table B.5.

Table A.1. Comparison of Widely Used Plume Rise Formulae[a]

Formula	Wind Speed Proportionality	Buoyancy Proportionality	Momentum Term Included?	Function of Stability?	Function of Downwind Distance?
Briggs	$(1/u)^{1/3}$ stable $1/u$ neutral, unstable	$Q^{1/4}$ stable[b] $Q^{1/3}$ neutral, unstable	no[b]	yes	yes
Holland	$1/u$	Q	yes	yes[c]	no
CONCAWE	$(1/u)^{0.70}$	$Q^{0.58}$	no	no	no
CONCAWE simplified	$(1/u)^{0.75}$	$Q^{1/2}$	no	no	no
ASME	$(1/u)^{1/3}$ stable $1/u$ neutral, unstable	$Q^{1/3}$ stable $Q^{1/3}$ neutral, unstable	no	yes	no

[a] u = wind speed at top of stack
Q = heat release rate

[b] A momentum term is included in the literature but is omitted in the most common formulations used in models.

[c] When recommended correction factors are used.

A.3 HORIZONTAL AND VERTICAL WIND FIELDS

A.3.1 General

The primary mechanism for the transport of pollution in the atmosphere is advection, the horizontal motion of air which carries pollutants along from one place to another. This transport of pollution by the wind must be accounted for by any deterministic model which attempts to predict the spatial distribution of some material being emitted from a set of known sources. In certain circumstance, there may also be a significant vertical component to the mean atmospheric motion and in these cases pollutants may be transported in the vertical direction as well. This appendix describes the general features of and methods for treatment of the horizontal and vertical transport of pollution by the wind.

Horizontal Wind Field

This term refers to the magnitude and direction of the horizontal component of the wind velocity as functions of horizontal position, height above ground, and time. Hereafter, when the terms wind speed and direction are used they will refer to the horizontal component, in accord with common usage.

The general properties of the wind speed and direction most relevant for pollutant transport are:

- A systematic increase in speed and shift in direction with height above ground which
  - Is very pronounced within an inversion,
  - Becomes less and less pronounced as the atmosphere ranges from stable through neutral to unstable conditions, and
  - Is significantly affected by variations in surface properties upwind and possibly downwind of the location in question;
- A sensitivity to the presence of topographic features such as
  - Hills or mountains
  - River valleys, and
  - Large bodies of water;
- A significant diurnal variation, reflecting the diurnal variation of atmospheric stability; and
- Significant seasonal variations, reflecting seasonal changes in the weather.

The variation with altitude is due to the frictional interaction between wind and the surface of the earth. Its effects are most pronounced near the surface and becomes less evident at higher elevations until at some altitude the surface effects become negligible. The effects of variations in atmospheric stability on the rate at which wind speed and direction change with altitude simply reflect variations in the extent to which the momentum of air at different levels is being mixed by turbulence. Enhanced vertical mixing such as exists under unstable conditions tends to smooth out and decrease the dependence of wind speed and direction on height. In stable conditions, vertical mixing and with it the influence of one layer of air on another is decreased. As a result, both wind speed and direction can have a significant dependence on height in stable, and especially inversion, conditions.

The gross effect of hills, mountains, or river valleys on wind speed and direction is to channel the airflow and to promote the formation of local, organized circulation patterns. More subtle effects can occur as well, such as mountain and valley breezes and drainage flows, and the possibilities are numerous and varied. A useful summary and discussion is given by Slade (1968). The principal effect of large bodies of water is similar to some topographic effects. A surface-based breeze, called a lake or sea breeze depending on the body of water involved, tends to blow from the water toward the land during the day [illegible] result of differences in air temperature above adjoining land and water surfaces. This breeze may blow in a direction opposite to the prevailing wind and may extend a considerable distance inland. In situations in which the lake or sea breeze acts against the prevailing wind, a convergence zone in which there are significant upward vertical motions is formed. Pollutants may be transported inland near the surface, rise in the convergence zone, and be transported back out over the water at heights of several hundred meters. Situations in which the lake or sea breeze acts in the same direction as the prevailing wind are less complex and "circulation cells" such as were just described do not form. Any movement of cool maritime air onto an adjacent, warm land surface results in an elevated temperature inversion extending some distance inland. Continuous fumigation of elevated plumes can occur during this condition, because the base of the inversion is eroded as the air moves onshore.

It should also be pointed out that urban areas themselves have a significant effect on the wind field, ranging from modification of the flow when regional wind speeds are high to the establishment of local circulation patterns due to the urban heat island effect when regional winds are weak. Systematic changes in wind direction and speed occur over urban areas. Even in strong regional flows there is a systematic tendency of the air to rise over cities, accompanied by a net inflow at low levels.

Both seasonal and diurnal variations in the mean wind speed and direction occur. We will not discuss seasonal variations except to point out that they depend on the location of the region of interest and can be significant. Dramatic variations may also occur during frontal passages or other weather changes. Diurnal variations are related to the diurnal variation of stability and the effect of stability on the variations of the wind field with altitude. Diurnal variations are most important during periods of cloudless weather, in which there are strong diurnal variations in stability and correspondingly large variations in the extent of atmospheric mixing. In stable conditions at night, the wind speed near the ground may be very low while at the same time at heights of a few tens of meters it is often quite high. In unstable conditions the wind speed, although usually rather low, is not strongly dependent on altitude. Both high and low wind speeds may occur under neutral conditions, although high wind speeds tend to produce neutral conditions even on clear days and nights, as discussed in Appendix A.4.

The horizontal wind speed and direction are in fact randomly fluctuating quantities with fluctuations occurring over time scales from much less than a second up to years and beyond. Qualitatively, short-term fluctuations are perceived as turbulence while long-term fluctuations are perceived as part of the day-to-day changes in the weather. For the purposes of describing the transport of pollution, the interest is normally in the mean wind speed and direction over some specific time interval, or over each of a sequence of time intervals. The transport of pollutants by the mean wind is the operational definition of advection, and the transport of pollutants by the fluctuations about this mean is the operational definition of dispersion. In any given situation, the averaging time for which mean wind measurements are available determines the distinction between advection and dispersion. Typical averaging times in practice range from about 10 minutes up to about 3 hours.

Vertical Wind Field

The vertical component of the wind velocity is in many cases much less important than the horizontal components, for the simple reason that in many cases it is zero over the averaging time of interest. In some situations, however, primarily those in which there are significant topographic features in the region of interest, significant vertical wind components may be present. When they are, they provide an effective mechanism for vertical transport of pollution and should be taken into account.

A.3.2 Treatment of Horizontal and Vertical Wind Fields

The treatment of the wind field by an air quality model depends on the type of model according to the classification scheme introduced in Appendix A.4. For example, dynamic models treat the time dependence of the wind field in addition to its spatial dependence, numerical models can generally handle more complex spatial variations than semiempirical models, and so on. Thus, treatments of wind field may be classified by the way both spatial and temporal variations are handled.

Spatial variation in either horizontal or vertical directions is usually handled in numerical models by specifying the wind velocity components at discrete points defined by a suitable grid, the grid spacing being chosen to reflect the actual spatial resolution available in the data from which the model wind field is calculated. This grid spacing then determines the spatial resolution of the model as a whole. The grid may be one, two or three-dimensional depending on the model. Similarly, in dynamic models the temporal variation in wind speed and direction at a given point is usually handled by specifying a sequence of mean values representing averages over some basic time step, typically one hour.

An alternative to the use of measured wind speeds and direction in combination with an interpolation procedure is to model the wind flow within the region of interest in a separate calculation using fluid flow modeling techniques and to thereby determine the wind field in a manner suitable for use in the air quality simulation model. This approach is often used with dispersion models for complex terrain, and in principle allows great flexibility in the spatial and temporal variations in the wind field that can be described by the model. The user should be aware, however, that not only are simplifying as is generally introduced in practice, but also that the manner in whic the basic equations are implemented in a computer code must be carefully considered in order to minimize numerical errors. Expert advice may be necessary to properly take these considerations into account.

Treatments at lower levels of detail involve progressively larger numbers of simplifying assumptions regarding both spatial and temporal variations. Most semiempirical models incorporate such assumption in their formulation and, if sufficient information is available, the user should consider whether they are appropriate or acceptable for the specific application of interest. Expert advice may be necessary in these considerations. Often the utility of a semiempirical model designed for use in a limited set of circumstances is extended by making additional assumptions. An example illustrating this practice will be given below.

The nature of the desired results may affect the amount of detail necessary in the treatment of the wind field, particularly in regard to the size of the region of interest and whether or not the entire spatial and temporal distribution of pollutant is desired. It is more important, for example, to be able to describe the spatial variations in the wind field over a large area than over a smaller one simply because the variations are expected to be more significant in the former case. Another example is the situation in which the maximum concentration for a given averaging time is to be estimated, rather than the expected mean concentration value. In this case, assumptions or information on wind persistence may be required.

Another major factor which determines the required level of detail in treating the wind field is the extent to which it is necessary to describe the vertical component. As mentioned above, it is often a reasonably good approximation to assume that the mean vertical component of the wind velocity is zero over the averaging time of interest. If this assumption is made, the practical treatment of the wind field is very much simplified; only the horizontal wind need be treated. The horizontal variation of the wind speed and direction is constrained by the physical requirement that air cannot accumulate anywhere, and normally the simplest possible approximation is made, i.e., that the wind speed and direction are independent of horizontal position over the region of interest and depend only on the height above ground. In practice, the dependence of wind direction on height is often ignored as well. The dependence of wind speed on height is usually given by an assumed functional form which may depend on the surface roughness and atmospheric stability. The most common form is a simple power law dependence with different exponents for different stabilities although a logarithmic form may be used near the ground under neutral conditions. Finally, the simplest treatment in the zero vertical component case is to assume that the wind speed and direction are uniform within the mixing layer over the region of interest. This treatment is often adopted in semiempirical models. The wind speed is normally chosen to be tha would be observed at a height equal to the emission height and this value is often estimated using a measured or assumed value at some lower reference height, usually 10 meters, in combination with an assumed wind profile. This procedure results in a different effective wind speed for each different emission height and potentially each different source as well. Alternatively, a single effective wind speed can be used for all sources regardless of individual differences in emission height.

If the vertical component of the wind cannot be assumed to be zero, the treatment of the entire wind field is complicated again by the requirement that air cannot locally accumulate, except that now there is no constraint on the vertical component. In practice, this requirement provides a relationship between the horizontal and vertical components which is used to calculate the vertical wind speed, given measurements of the horizon components at several locations within the region of interest. Wind fields which satisfy this non-accumulation requirement are often called "mass-consistent" wind fields because the requirement is derived from the concept of the conservation of mass. Any wind field used in a dispersion model should be mass-consistent; otherwise, errors in the estimated concentration will result. Wind fields determined by fluid-flow models are generally designed to satisfy the mass-consistency requirement.

It is relatively easy to satisfy the mass consistency requirement if the vertical wind component may be assumed to be zero. In this case, for example, if the wind speed and direction do not depend on the horizontal position coordinates x and y, the mass consistency requirement is automatically satisfied regardless of the dependence of either speed or direction on height above ground.

An air quality model designed for use in complex situations may either require the wind field to be input and therefore place the burden of determining the proper wind field on the user or require the necessary measurements so that the wind field may be calculated internally. In the latter case, the wind field may be determined prior to or concurrently with the actual dispersion calculations. As indicated above, simplifying assumptions are often incorporated. For example, a model designed for use in flat terrain may be combined with assumptions regarding the flow of air over topographic features to produce a new model which may give results of sufficient validity for the user's purpose. Often such treatments of the vertical component are implicit, being incorporated, for example, in the form of assumptions about the height of the plume centerline above the terrain without an explicit determination of the vertical component that would result in such behavior. For the purpose of this workbook, such assumptions represent an implicit treatment of the vertical wind speed and should be evaluated as such.

The situations in which treatment of the vertical component is desirable are those in which the region of interest contains significant geographic complexities such as mountains or hills, river valleys, large bodies of water, and so on. In the first two cases, the usual problem is to describe the channeling and vertical displacement effects of the terrain on the general wind flow. Models which are capable of doing this have been developed and are in current use. Near large bodies of water, the problem is to describe the effect of a temperature difference between adjacent surfaces. Although models of this situation have been developed, they are primarily of a research nature and have not been incorporated into a dispersion model.

In applications involving averaging times of a month or more, a climatological approach is often used. The entire range of possible wind directions is divided into several (usually 16 or 36) sectors, and the entire range of possible wind speeds is divided into several (typically six) discrete classes. At the same time, the possible range of atmospheric stabilities is also divided into some number (usually six) of discrete classes. The probability of observing simultaneously the wind direction in a given sector, the wind speed within a given class, and the stability within a given class is determined from local observations for each possible combination of wind direction, wind speed, and stability class. The resulting joint frequency distribution is called a stability wind rose. Each combination of the three elements defines a particular meteorological situation for which dispersion calculations are done, normally using a semiempirical model. The long-term average pollutant distribution is obtained by multiplying the results for each meteorological situation by the probability of observing that particular situation and summing over all possible cases. Thus, more information about the wind field than just the mean wind speed and direction over the averaging time of interest is used, although in each meteorological situation the assumption is commonly made that the wind is uniform and constant. The climatological approach is not necessarily restricted to semiempirical models; in principle, any type of model could be used to do the basic dispersion calculations as long as discrete wind field "classes" could be suitably defined and the probability of observing each determined.

The various treatments of the horizontal wind field are listed in Table 5.5 and the treatments of the vertical wind field are given in Table 5.6. Treatments used by suggested reference models can be found in Tables B.6 and B.7 for horizontal wind field and vertical wind field, respectively.

A.4 HORIZONTAL AND VERTICAL DISPERSION

A.4.1 General

One of the most important elements in assessing the impact of emissions on air quality is the estimation of the extent to which the effluent from sources is dispersed by the atmosphere. In comparing the treatments of dispersion by two different models, the user should keep the following three factors in mind:

- The operational definition of dispersion,
- The duration and size of the emission and the source-receptor distance or travel time, and
- The connection between the extent or rate of dispersion and the level of atmospheric turbulence.

These factors determine the applicability of the various treatments of dispersion and the physical features of the problem which need to be taken into account.

The term "diffusion" is used by some authors in exactly the same sense that the term "dispersion" is used throughout this workbook. The term dispersion is used here to avoid any confusion with the process of molecular diffusion, in which the spread of one substance in another is the result of entirely different phenomena than those responsible for atmospheric dispersion.

The operational definition of dispersion is interrelated with that of advection and depends upon the averaging time of interest. The wind speed and direction at a point are randomly fluctuating quantities; rapid fluctuations are perceived as turbulence and very slow fluctuations as part of the day-to-day variations in the weather. The operational definition of advection is the transport of pollutant by the <u>mean</u> wind as measured over some specified averaging time. The operational definition of dispersion is the transport of pollutant by fluctuations about this mean which occur over times less than the averaging time. In other words, advection is the overall downwind movement of the emission as a whole and dispersion is the spreading of the pollutant about this overall motion.

To fix these ideas, consider two photographs of the same continuous plume taken from above: one is a snapshot and the other is a time exposure (Figure A.1). The plume in the snapshot is observed to follow a meandering path called the streakline. The width of the plume at any point is simply the actual physical spread of material about the instantaneous position of the plume centerline. In the time exposure, however, the plume appears to follow a much straighter path and is characterized by a much wider and more smoothly varying cross-section. The longer the exposure, the wider the cross-section appears. The time exposure shows only the mean wind direction over the exposure time, and the observed dispersion about the apparent plume centerline represents not only the physical

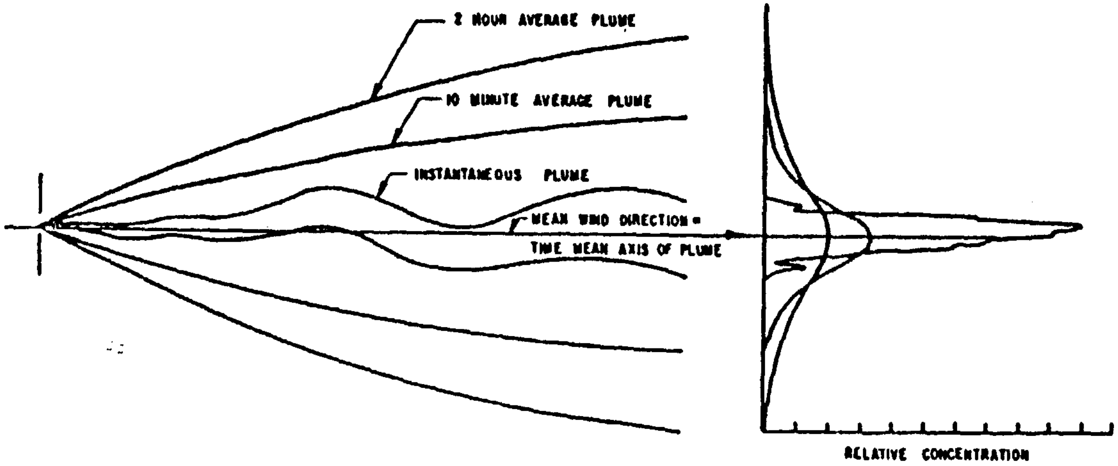

Figure A.1. Dependence of Crosswind Pollutant Distribution from a Continuous Point Source on Averag' [illegible] me.

spread but also the time-average effects of the meandering of the plume. Thus, meanders in the plume which take place over periods of time shorter than the exposure, or averaging, time are considered part of the dispersion. The snapshot clearly exhibits the effects of the short-term wind fluctuations responsible for meandering.

The practical consequence is that for the horizontal case the extent of the dispersion about the mean plume centerline depends on the averaging time. This effect does not occur for vertical dispersion for averaging times longer than about ten minutes due to absence of fluctuations in the vertical component of the wind over these time scales.

The example just given considered the case of a continuous release. A snapshot of the pollutant distribution following an instantaneous release during non-calm conditions shows a cloud of material centered at some point downwind of the source, whereas a time exposure shows a meandering path originating at the source. In both pictures, the observed extent of the dispersion represents the actual crosswind spread of material in the cloud, although dispersion in the downwind direction is not shown in the time exposure. Meandering in the path followed by the cloud should clearly not be treated as part of the dispersion of the cloud.

Based on this type of consideration, and assuming that only the mean wind speed and direction are known over the averaging time of interest, meandering should be considered part of the process of horizontal dispersion from a point source when both the following conditions are met:

- The duration of the release is greater than the averaging time, and
- The averaging time is greater than the source-receptor travel time.

If these conditions are not met, more information about the wind field is required so that a more realistic description of the actual trajectory followed by the pollutant emission may be obtained. In particular, variations in the wind which occur over times greater than the averaging time but less than the travel time should be explicitly taken into account either by assumption or by actual calculation of the trajectory. (See Appendix A.3 for a discussion of treatments of the wind field.)

The initial size of the emission determines the relative importance of any further dispersion in either the horizontal or vertical direction. The larger a plume or cloud of pollutant, the slower is the relative rate of growth due to the action of atmospheric turbulence because as the plume grows an increasingly large part of the turbulence acts over too small a scale to be effective. The effect on the horizontal dispersion estimates of [illegible]ing the averaging time is also diminished for extended sources such a[illegible] and areas for the same reason.

In order to quantitatively estimate the extent or rate of dispersion under specified conditions, the effect of those factors which determine the intensity of atmospheric turbulence must be suitably parameterized, because dispersion is a direct result of the action of turbulence. The most important factors governing the production of turbulence are:

- The wind speed,
- The roughness of the ground surface, and
- The flux of heat being transferred between the ground surface and the air.

The first two factors govern the mechanical generation of turbulence by friction due to the variation of wind speed with height (wind shear), itself caused by the frictional interaction between the general flow of the wind and the roughness of the surface. The third governs the thermal generation of turbulence due to surface heating. The surface heat flux itself depends on:

- The solar angle (during the day),
- The extent of cloud cover (both day and night),
- Thermal properties of the ground surface, and
- The extent of anthropogenic heat generation (in urban areas).

In discussing atmospheric turbulence and dispersion, it is convenient to introduce the concept of atmospheric stability. At a given height, the atmosphere may be classified as unstable, neutral, or stable according to whether the rate of decrease of temperature with height (the lapse rate) is less than, equal to, or greater than a critical value called the dry adiabatic lapse rate (equal to approximately 1°C/100 meters), as shown in Table A.2. The significance of this classification is that near the ground, high levels of turbulence and high rates of dispersion are generally associated with unstable conditions and low levels of turbulence with stable conditions. The terms used in the classification are in fact descriptive of the effects of the different types of temperature gradient on vertical turbulent motions, vertical motion being enhanced under unstable conditions and suppressed under stable conditions. A temperature inversion is said to exist when the lapse rate is negative (temperature increasing with height). The atmosphere is extremely stable within an inversion and turbulence is strongly suppressed. As a consequence both the rate of vertical dispersion and the actual physical spread of a plume in the horizontal direction are strongly suppressed, although considerable meandering of the plume can occur.

Table A.2. General Atmospheric Stability Classification According to Temperature Lapse Rate[a]

Relation of Actual Lapse Rate to the Dry Adiabatic Lapse Rate	Atmospheric Stability Classification
Greater than	Unstable
Equal to	Neutral
Less than	Stable

[a] This classification is not the same as the widely used Pasquill stability classification scheme.

The temperature profile near the ground is itself determined by the same factors listed above as being significant determinants of atmospheric turbulence. At any given time, the difference between the actual lapse rate and the dry adiabatic lapse rate is determined by the balance between two competing effects: 1) the addition to or removal from the air of heat energy due to solar heating or radiational cooling of the ground surface, tending to produce unstable or stable conditions respectively, and 2) the tendency of the turbulence itself, whether mechanically or thermally generated, to smooth out the temperature profile and produce neutral conditions.

In order for an atmospheric dispersion model to be useful in a variety of meteorological situations, some convenient measure of atmospheric stability or turbulence intensity is used to determine the appropriate values of those model parameters (such as σ_y and σ_z in Gaussian plume models) which determine the predicted extent or rate of dispersion. A number of different meteorological parameters or classification schemes have been used for this purpose and an increasing number of models make use of the more fundamental measures of turbulence intensity. Some of the more commonly used ones are given in Table A.3. The user should consult a standard reference (e.g., Slade, 1968) or an air pollution meteorologist for the definitions of the Richardson number or the Monin-Obukhov length if the model being evaluated makes use of one of these parameters. A discussion of the Pasquill-Gifford classification scheme is given by Turner (1969) and the Brookhaven scheme is discussed by Singer and Smith (1966). A review of various systems for characterizing turbulence is given by Gifford (1976).

The basic factors which determine atmospheric stability near the ground have already been mentioned. The dependence of these factors on the time of day, the nature of the topography, and the nature of the ground surface gives rise to certain characteristics of which the user should be aware.

Atmospheric stability near the ground undergoes very significant diurnal variations due to the rising and setting of the sun. On sunny days, the ground is v and heat is added to the air near the surface, causing the air temperature to rise and producing unstable conditions. On clear nights, the ground cools more rapidly than the air, heat is removed from the air near the ground, and a ground-based "radiation inversion" is produced. At any time, cloud cover tends to balance the exchange of heat and produce neutral conditions.

There are important differences between urban and rural areas. Urban areas are normally much rougher than the surrounding rural areas, and the heat produced by anthropogenic activity in the city is an important factor at night all year round as well as during the daytime in winter. The combination of these factors results in substantially higher levels of turbulence, and correspondingly higher rates of dispersion, over cities during both day and night. The frequency of surface inversions is much lower in cities than in rural areas; when a surface inversion exists in the surrounding countryside, the temperature profile within an urban area generally corresponds to neutral or weakly stable conditions.

Table A.3. Commonly Used Measures of Atmospheric Stability and Turbulence Intensity

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Continuous Measures

1. Temperature gradient or, equivalently, temperature difference between two reference heights.
2. $S = \frac{g}{T} \frac{\partial\theta}{\partial z}$

   $\frac{\partial\theta}{\partial z}$ = (dry adiabatic lapse rate)-(ambient lapse rate)

   $= (1°C/100m + \partial T/\partial z)$

   g = acceleration due to gravity.

   T = ambient temperature.

   (S is negative in unstable conditions, zero in neutral conditions and positive in stable conditions.)
3. Standard deviation of the horizontal component of the wind direction (σ_θ) or of the vertical component (σ_ϕ).
4. Richardson number.
5. Monin-Obukhov length.

Discrete Classification Schemes

1. Pasquill-Gifford stability classification.
2. Brookhaven gustiness classification.

Topography may significantly affect stability. The nocturnal inversion within a valley, for example, may be much deeper and longer lasting in the morning than that over flat terrain. This is caused by a combination of uneven heating of the ground surface due to the variable angle with which the sun's rays strike the ground and the tendency of cooler air to settle in low places in the terrain. The presence of fog also delays the heating of the ground and prolongs the existence of stable conditions. Forested areas and regions of complex terrain also have surface roughness comparable to those of urban areas, and rates of dispersion are correspondingly higher than over gently rolling grassland, for example.

The stability of the atmosphere at higher elevations is also an important factor for atmospheric dispersion. At any given time the stability of the atmosphere at heights above a few hundred meters is determined mainly by the large scale features of the weather as well as by the general properties of the atmosphere as a whole. Below 10-15 km, the atmosphere is on the average slightly stable, so that turbulence generated at the surface can propagate upwards only so far before it is damped out. This results in an upper limit, called the mixing height, to the altitude to which pollutants will disperse over a short period of time. In the absence of an elevated inversion, this mixing height is determined by the same variables that determine the stability. An elevated inversion may exist, however, usually in association with a large high pressure area. Such inversions are called subsidence inversions and are very effective in limiting vertical dispersion. Subsidence inversions exist at altitudes of the order of 1000 m and the maximum mixing height on any given day is limited by the height of the base of these inversions. Since relatively low wind speeds are also associated with these large high pressure areas, they cause some of the worst pollution episodes.

An additional factor, relating primarily to vertical dispersion, is the fact that the earth's surface forms a barrier which limits not only the extent of mixing in the vertical direction but also the physical size of the turbulent fluctuations which cause the dispersion. The first effect is normally handled as a boundary condition, but the second implies that the higher the altitude above ground, the greater the size of fluctuation that can exist. In addition, the relative importance of mechanically generated turbulence compared to thermally generated turbulence decreases with altitude. Thus, the rate of vertical dispersion from elevated sources is somewhat different from that ground level sources, at least until the emission from the elevated source reaches the ground.

Since horizontal and vertical dispersion are considered to be separate elements in this workbook, and in order to tie the previous discussions together, it is useful to summarize here those factors which relate specifically to either horizontal or vertical dispersion, or both. These summaries are given in Tab' 4 and A.5.

Table A.4 Factors Affecting the Level of Atmospheric Turbulence and the Rates of Horizontal and Vertical Dispersion

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- Wind shear, itself dependent on
  - Wind speed, and
  - Surface roughness
- Surface heat flux, itself dependent on
  - Solar angle,
  - Cloud cover,
  - Surface thermal properties, and
  - Anthropogenic heat production.
  - Orography (ground slope relative to solar angle)
- Atmospheric stability, itself dependent on
  - The factors listed above, and
  - Synoptic weather features (particularly above a few hundred meters altitude)

Table A.5. Factors Determining Meandering Contribution to Horizontal Dispersion

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- Duration of pollutant release
- Source-receptor travel time
- Desired averaging time for pollutant concentrations
- Initial size of the emission
- Orographic barriers
- Street canyons

A.4.2 Treatment of Horizontal and Vertical Dispersion

In order to evaluate the treatments of horizontal and vertical dispersion in a specific model, the user should know:

- The technical benefits and limitations of the different types of treatments and
- The various ways of parameterizing the effects of the important meteorological variables in each type.

The remainder of this section addresses these points.

A.4.2.1 Treatment Classification

Treatments of dispersion may be usefully classified in the following two ways:

: : :

1) According to the general modeling approach adopted:

   - Numerical methods, which involve the numerical solution of equations describing the conservation of mass,
   - Semiempirical methods, which assume a particular functional form for the pollutant distribution, and
   - Methods which do not treat dispersion explicitly; and

2) According to the way the time dependence of the pollutant distribution is treated:

   - Dynamic treatments, which predict the pollutant concentration as a function of time as well as position,
   - Steady state treatments, which predict the average pollutant concentration as a function of position only for short averaging times, and
   - Climatological treatments, which predict the average pollutant concentration as a function of position only for long averaging times using a statistical distribution of meteorological conditions.

Methods which do not explicitly treat horizontal dispersion, vertical dispersion, or both may still in some cases be simulation models and examples will be discussed below. Empirical or statistical models, which also do not generally contain explicit treatments of dispersion, are discussed in Section 7.

Numerical Methods

The most advanced and sophisticated models of atmospheric dispersion fall into this category. The current state of the art is represented by "closure models" which consider both the concentration and the flux of pollutant as well as most of the meteorological variables as unknown functions of position and time to be determined by numerical solution of the relevant equations. The flux obtained in this approach is directly related to the rate of dispersion. This type of treatment is still in its formulative stage and has not yet been used in practical applications. For this reason, closure models will not be discussed further here.

The usual approach in numerical models is to describe the flux in terms of the concentration distribution, so that the flux is no longer an independent quantity. This is done by making the "gradient-transfer" approximation, which assumes that the pollutant flux is proportional to the concentration gradient. The proportionality factor is called the eddy diffusivity and is usually symbolized by the letter K, hence this approach is often referred to as "K-theory." The result of making this approximation is an equation, called the advection-diffusion equation, which predicts the poll concentration as a function of position and time. Treatments of the wind field are discussed in Section A.3. The advection-diffusion equation must usually be solved by any of a variety of numerical methods, including, for example, finite-difference or particle-in-cell techniques, but the user should not be too concerned with the details of the numerical method used by a model being evaluated. There are certainly advantages and disadvantages with the various approaches, but the focus here is more on the parameterization and treatment of meteorological and other factors.

The eddy diffusivities for dispersion in different directions are not necessarily equal, but this discussion will be restricted to what is by far the most common case, that in which only two eddy diffusivities are used, one for vertical dispersion and one for horizontal dispersion. The eddy diffusivity values reflect the level of atmospheric turbulence and their parameterization in terms of observable meteorological quantities should be considered by the user in evaluating a numerical model.

Semiempirical Methods

This category includes all treatments in which an explicit functional form is assumed for the concentration distribution. The assumed form may be based on observation, theoretical considerations, numerical simulation, or a combination of these. It may be a function determined elsewhere and assumed appropriate for the given application or it may be determined specifically for the application of interest in the process of running the model itself.

The most common example of a semiempirical method is the Gaussian plume treatment of dispersion from a continuous source as described by Turner (1969). This particular approach involves the assumption that the horizontal crosswind pollutant distribution from such a source may be described, on average, by a Gaussian function and that, except for the effects of the ground, so can the vertical distribution. The only parameters beside the wind speed which appear explicitly in these functions and which reflect the prevailing meteorological conditions are the horizontal and vertical standard deviations, or dispersion coefficients, corresponding to the assumed horizontal and vertical Gaussian distributions.

Another example of a semiempirical model is the simple box model, which assumes a spatially uniform pollutant distribution within some region. Dispersion is not explicitly treated in such a model, but additional assumptions are implicitly being made. If the pollutant distribution is taken to be uniform in the vertical direction up to some specified height, the process of vertical dispersion is implicitly being assumed fast enough to justify that treatment over the time scale of the problem. The assumption of uniformity in the horizontal crosswind direction is often used and is justified if the distribution of emissions is relatively uniform; this approximation, when used in conjunction with the determination of p levels due to area source emissions, is called the narrow-plume approximation. A type of narrow-plume approximation may also be used for treating point sources in climatological models and will be discussed in that context later in this section.

Dynamic Treatments

This category includes all methods in which the concentration is predicted explicitly as a function of time. Treatments in which one or more trajectories of pollutant releases are calculated from wind field data, or are simply assumed on any reasonable basis, are also included under the definition of dynamic models followed in this workbook. Dynamic treatments may be either numerical or semiempirical in nature.

Dynamic models must be able to properly handle situations involving changing meteorological conditions and the resulting changes in the rate of dispersion. There is usually no difficulty in doing this in numerical models, but if a time-dependent generalization of a semiempirical steady-state method is used, problems can arise in making sure that the model parameters which describe the extent of dispersion at any given time are continuous functions of time. For example, if the horizontal crosswind pollutant distribution about some trajectory is assumed to be Gaussian, the horizontal standard deviation should be a continuous function of time. Most commonly used formulae or graphs give the standard deviation as a function of downwind distance or travel time only for the case in which the meteorological conditions are constant, and are not directly applicable under changing conditions. A treatment which uses a description of the rate of change of the standard deviation as a function of meteorological conditions is usually preferable for dynamic models.

Examples of numerical/dynamic treatments are 1) those using the numerical solution to the full time-dependent three-dimensional advection-diffusion equation and 2) those using the narrow-plume approximation for a grid of area sources over which a trajectory is calculated and treating vertical dispersion by numerically solving the one-dimensional (vertical) time-dependent diffusion equation. An example of a semiempirical/dynamic treatment would be one in which a trajectory originating at the location of a point source is calculated and the pollutant distribution about the trajectory is assumed to be Gaussian. Gaussian puff models, in which a plume is treated as a series of puffs which follow their own trajectories, are also semiempirical/dynamic models.

Steady-State Treatments

[illegible]is category includes all methods in which temporal variations of all rel[illegible]uantities are ignored and in which the treatment of advection uses only the mean wind speed and direction for the averaging time of interest. This type of treatment predicts the average concentration as a function of position only. Steady-state methods may be either numerical or semiempirical in nature. The most familiar example of a semiempirical/steady-state treatment is the basic Gaussian plume model and an example of a numerical/steady-state treatment is one in which the time-independent version of the advection-diffusion equation is solved numerically.

Climatological Treatments

This category includes methods which predict the average pollutant distribution for long averaging times, typically a month, season, or year, using a joint frequency distribution which gives the probability of simultaneously observing specified wind speed, wind direction, and other meteorological variables. In this approach, more information about the wind field than just the mean wind speed and direction over the desired averaging time is used in order to avoid treating variations which occur over time scales less than the averaging time as part of the horizontal dispersion process. Climatological models may in principle use either a numerical or semiempirical approach for the individual calculations, although in practice semiempirical/steady-state treatments are almost always used.

A.4.2.2 Benefits and Limitations

Numerical Methods

The main benefit to be gained by using a numerical approach is flexibility in the specification of the wind field and the meteorological variables determining atmospheric turbulence levels as functions of position and time and in the specification of boundary conditions. In principle, numerical methods allow the description of dispersion for a realistic wind field in complex situations. They are also, in principle, capable of treating the spatial distribution and temporal behavior of chemically reactive pollutants.

The main technical limitation is one of spatial resolution. Numerical methods calculate concentration values at only a finite number of points in space, normally corresponding to some conveniently defined grid, and the resolution which can be achieved is fixed by the grid spacing. In addition, the grid spacing should not be considered arbitrary, since it may be determined to a large extent by the way the wind field is determined (see Appendix A.3). Variations in the concentration distribution, in the wind speed and direction, and in the emissions themselves which occur over distances smaller than the grid spacing cannot be resolved. This lack of resolution has several consequences:

- Emissions from point or line sources into a specific grid cell are in effect dispersed instantaneously within the cell, rather than described in terms of a sub-grid scale distribution;
- The value of the eddy diffusivity must reflect the intensity of turbulent fluctuations up to the size of the grid spacing and is therefore partially determined by that spacing; and
- Pollutant concentrations cannot be predicted at arbitrary receptor locations, except by interpolation from concentration values at grid points.

The seriousness of these consequences depends on the specific application, and on the existance of practical limits to the amount of computational effort required and to the computer storage requirements. In general, however, the numerical approach is inappropriate for the treatment of dispersion when the size of the emission being dispersed is smaller than the grid spacing.

Another way of stating this conclusion is that the numerical approach using the eddy diffusivity concept is inappropriate when the size of the pollutant distribution being dispersed is smaller than or comparable to the size of any turbulent eddies contributing significantly to the dispersion. As a result, the eddy diffusivity approach is not fundamentally suitable for describing horizontal dispersion, and in particular the meandering contribution, but because of constraints on the size of vertical fluctuations due to the presence of boundaries at the ground and at the mixing height, can be justified for the treatment of vertical dispersion from ground level sources or from elevated sources after the plume has reached the ground. Treatments of horizontal dispersion using the eddy diffusivity approach do exist, however, in spite of the physical fact that dispersion by meandering cannot be considered a gradient-transfer process. Such treatments describe horizontal dispersion in a phenomenological way, rather than in a manner which reflects the basic physical processes, and the selection of an appropriate value for the horizontal eddy diffusivity must be based on more empirical grounds than is the case for the vertical diffusivity. (See the discussion of parameterization in numerical models later in this appendix.)

It is sometimes possible to describe the pollutant distribution on a scale smaller than the grid spacing in an empirical or theoretical way, and use the numerical approach to describe the large scale distribution. This is in fact desirable in the case of point sources in order to minimize the numerical errors resulting from the poor resolution near the source.

Another limitation in most cases is the lack of fundamental knowledge and appropriate meteorological data upon which to base the prediction of eddy diffusivity values, particularly at heights above 100 meters or so. This means that further assumptions must be made regarding the appropriate values to us [illegible] model.

Semiempirical Methods

The principal technical benefit gained in this type of approach is that the assumed shape of the pollutant distribution may be based upon actual observational data. Furthermore, the distribution observed experimentally may be assumed to be the same under similar meteorological and topographical conditions, thus eliminating the need for new observations for each new application. In some cases, the assumed distribution may be derived on the basis of theoretical considerations.

The semiempirical approach has two advantages over the numerical approach from a technical point of view:

- Better spatial resolution can often be achieved in practice and
- The effect of meandering may be treated in a more appropriate way.

The general limitation on this type of approach is that it should not be used in situations in which there is insufficient observational data or theoretical results from which to determine the proper functional form. If the assumed shape is derived theoretically, its suitability depends on the nature of the assumptions made in the derivation. These may not be appropriate for the real situation.

As indicated above, the most common example of this type of approach is the Gaussian plume treatment of continuous emissions. In their basic form, Gaussian-plume based methods are inherently restricted to:

- Flat or gently rolling terrain for a considerable distance upwind and downwind of the source,
- Primary pollutants, and
- Conservative pollutants, i.e., no significant physical or chemical sinks.

It is possible to extend the utility of Gaussian models to applications involving complex terrain by making various assumptions regarding the extent to which the plume follows the terrain and by making modifications to the basic formulae. These models all fall within the category of semiempirical models and in view of the wide range of possible modifications and interpretations expert advice may be required in making a comparison. The only general guideline that can be given is that the basis or justification for the assumed pollutant distribution should be scientifically sound. Ideally, modifications to the basic Gaussian distribution should be based on appropriate observational data, often in combination with theoretical considerations. If no information is available regarding the basis for any particular assumed pollutant distribution, it is impossible to accurately assess its validity except through an appropriate field measurement program.

It should be point out that, given certain approximations, the standard Gaussian plume formula represents the steady-state solution to the advection-diffusion equation for a single point source. The conditions which have to be met are that 1) the wind field must be uniform, constant, and have no vertical component, 2) the rate of pollutant dispersion along the direction of the wind must be negligible compared to the rate of pollutant transport by advection, and 3) the horizontal and vertical eddy diffusivities must also be uniform and constant. The extent to which the application of interest deviates from these assumptions determines the need for modifications to the formula or for a different modeling approach, e.g., a numerical model.

It is also possible to extend the basic Gaussian model to non-conservative pollutants. (See Appendices A.5 and A.6 for discussions of possible treatments.)

Limitations to the basic Gaussian plume model also exist because of the steady-state nature of the model. These are discussed in the subsection on dynamic treatments.

The narrow plume approximation mentioned earlier deserves further comment at this point. This approximation can be used for either point or area sources, although its use for point sources is restricted to climatological models except for the short-term mode of the Valley Model. For area sources, the narrow plume approximation amounts to the assumption that emission rates from nearby sources are sufficiently similar that the pollutant distribution may be assumed to be horizontally uniform. In the narrow plume approximation, pollutant concentrations along some well-defined trajectory are functions of height above ground and possibly travel time but not of horizontal crosswind position. The narrow plume approximation may be used in either a steady-state or a dynamic approach and the trajectory may be a straight line, a constant path determined, for example, by topography, or it may be determined from actual wind field data. The accompanying treatment of vertical dispersion may be either semiempirical or numerical.

Dynamic Treatments

The main benefits are:

- The ability to describe the temporal variation of the pollutant concentration and
- The ability to treat the effects of time variations in and correlations between emissions, meteorological parameters, and removal processes.

Technical limitations depend upon how the time dependence is handled. Time dependence may be incorporated in an empirical or ad hoc way, in which case the suitability of the treatment in a given application depends on the observational or theoretical basis for that particular treatment, as with the empirical methods discussed above.

Time dependence is more commonly treated by dividing the total period of [illegible]t into a number of sequential time steps. The variation of some quantity such as an emission rate is then simulated by prescribing a sequence of values, one for each time step. Such an approach predicts the concentration at a finite number of points in time and the temporal resolution of the method is determined by the size of the time step. Time variations more rapid than the time step cannot be resolved.

Steady State Treatments

No significant technical benefits are gained by using a steady-state model in preference to a dynamic approach. Steady-state models are generally simpler and easier to use, however, and the decision to use such an approach is based on these considerations as well as on the fact that the most widely used semiempirical approach, the Gaussian plume method, is a steady-state method.

Limitations include the assumptions of a constant emission rate and a constant level of atmospheric turbulence. The specified averaging time should be greater than the source-receptor travel time, as pointed out in the general discussion, so that the effect of meandering is properly treated. The assumption of constant emission rate guarantees that the duration of the release is longer than the averaging time, and the steady-state approach is clearly limited to the treatment of those sources which satisfy this requirement. Instantaneous or very short releases must be treated using dynamic methods. Within its limitations, the steady-state approach is just as applicable as the dynamic approach for the calculation of average concentration values.

Climatological Treatments

This type of approach is used in practice only for the calculation of long-term average concentrations, the principal benefit being one of convenience compared with the alternatives of using a dynamic model or a sequence of a large number of steady-state calculations.

A calculation is done for each set of meteorological conditions which is represented in the joint distribution being used, and the average pollutant distribution is obtained with the contribution from each set of conditions being weighted by its probability of occurrance.

Limitations of the method may be divided into two categories:

- Limitations of the model used to do each separate calculation, and
- Limitations of the climatological approach, per se.

The former are described in other parts of this section and the only additional remark that needs to be made here is that the model used must be of sufficiently general applicability to be able to handle the variety of meteorol[illegible]nditions represented in the climatological frequency distribution. The latter include the approximations incurred by representing the wide range of conditions that occurs in nature by a finite number of specific situations, by the suitability of those situations which are used, and by the omission of meteorological variables such as precipitation and mixing height from the joint frequency function.

In the treatment of dispersion, at least one of the parameters defining the frequency function should be a measure of the level of atmospheric turbulence. The measure of turbulence most commonly used in climatological models is the Pasquill stability classification, although others could be used. It is also common to use the narrow plume approximation for point sources. This approximation requires an assumption that the crosswind or angular distribution of pollutant from a point source over a sufficiently long period of time is given simply by the frequency distribution of the wind direction. This assumption is reasonable if the variation in the wind direction frequency function is negligible over an angular interval corresponding to the angular width of the plume. Since the wind direction frequency function takes the form of probabilities of observing wind from within well defined sectors (commonly 10° or 22.5° wide), this approach is also referred to as "sector averaging."

A summary of the different general types of treatment is given in Table 5.7. It should be pointed out that in any given model, horizontal and vertical dispersion may be treated in completely different ways (although both will be either dynamic or steady-state) and the treatments in any case should be evaluated separately. In Table 5.7, the treatments are ranked in order of decreasing level of detail, but the user is cautioned that in the cases of horizontal and vertical dispersion the relative level of detail of two treatments is not by itself a reliable indication of their relative technical performance. As discussed above, there are limitations on the applicability of certain approaches, and the user must determine for his specific application if these are violated. If they are, those approaches should not be used. If the two models being compared use the same, or two equally applicable approaches, the relative level of detail may be used as a valid indicator.

A.4.2.3 Parameterization

Atmospheric dispersion models are generally designed for use in a variety of conditions, each characterized by a different level of atmospheric turbulence and consequently different rates of dispersion. Various meteorological conditions are handled within a given model by using different numerical values for the relevant model parameters such as eddy diffusivities or Gaussian st[illegible] deviations. The determination of the appropriate values from meteoro-l[illegible] and other data is an important part of the total procedure by which predictions of pollutant concentrations are made. In an evaluation, the user should take into account any constraints on these parameters that are inherent in or built into the model, particularly if they clearly preclude the use of the correct values. An example of such a constraint is a built-in eddy diffusivity or standard deviation value which is not appropriate for the user's application and which the user cannot conveniently modify. The determination of the appropriateness or correctness of any such specific parameter value may require expert assistance but a general guideline is that the value in question should be obtained from observations or theoretical analysis as closely associated as practicable with the specific location and meteorological conditions of interest. If sufficient information about the source of the values used in a given model is available, the appropriateness of those specific parameter values should be considered in making the evaluation. Table 5.10 provides a list of some of the possibilities for both numerical and semiempirical models.

Some general remarks regarding the way in which atmospheric stability and surface roughness are treated by various types of models are in order here.

Numerical Models

Confining our attention to gradient-transfer models only, the horizontal and vertical eddy diffusivities are the parameters through which the influences of stability and surface roughness on dispersion are manifested.

As indicated above, the eddy diffusivity approach is not in general appropriate for the treatment of horizontal dispersion. For this reason, the basis for choosing a specific value of the horizontal diffusivity needs to be considered further. It is possible, by appropriate selection of the time or space dependence of the horizontal diffusivity, to force a numerical model to reproduce approximately the results of a more sophisticated calculation, or of a semiempirical model. If this is the case, the parameterization of the horizontal diffusivity needs to be judged on the basis of the treatment being reproduced.

In general, the horizontal diffusivity may be expected to be roughly independent of horizontal position except when significant terrain features are present.

The vertical diffusivity near the ground may be reasonably estimated in terms of the wind speed, surface roughness (given in terms of a parameter called the "roughness length", see Slade (1968) or Pasquill (1974) for the definition and estimates for different situations), and parameters which determine the rate of heat-exchange between the earth's surface and the air. An expert should be consulted for the details of the formulation.

At higher altitudes, there is very limited data and the exact parameterization of the vertical diffusivity is a subject of current research. Consequently, any parameterization must be based on further assumptions and it is not uncommon to simply use a convenient functional form having the desired qualitative behavior and having the correct behavior near the ground.

Semiempirical Models

Since the Gaussian plume model is by far the most common example, the discussion will be restricted to this case. The user should be able to follow a similar line of thought for other treatments. In the Gaussian plume approach as described by Turner (1969), the horizontal and vertical standard deviations need to be parameterized. Atmospheric stability is divided into several discrete classes and the stability class to be used in a given situation is determined from the wind speed, solar angle, and the extent of cloud cover. The horizontal and vertical standard deviations are then prescribed functions of the stability class and downwind distance from the source. The effects of surface roughness may be accounted for in the nature of the prescribed functions or by additional modification of the basic standard deviation or may not be treated explicitly.

Tables 5.8 and 5.9 list various treatments of atmospheric stability and surface roughness, respectively. Tables B.8 and B.9 list treatments of horizontal and vertical dispersion, respectively, used by suggested reference models.

A.5 CHEMISTRY AND REACTION MECHANISM

A.5.1 General

There are two common situations in which chemistry plays a role in determining atmospheric pollution levels. On one hand, the pollutant of interest may undergo chemical reaction with some other atmospheric component; that is, a chemical sink exists for that pollutant and it is referred to as being reactive. (If the pollutant undergoes no reaction, it is called inert.) On the other hand, the pollutant of interest may be produced in the atmosphere by chemical reactions involving other pollutants (precursors); such a substance is called a secondary pollutant. (If the pollutant is directly emitted by sources, it is called primary.) Clearly, in each case the chemical reactions involved affect the concentration of the pollutant of interest. In the first case they provide a process for the removal of that pollutant and serve to decrease its ambient concentration, while in the second case they serve to generate the pollutant and increase its concentration. Examples of primary reactive pollutants are the hydrocarbon precursors of photochemical smog. Exa of secondary, relatively inert materials are sulfate and photochemical aerosol. A pollutant may be both secondary and reactive; examples are nitrogen dioxide (NO_2) and ozone (O_3). If the pollutant of interest is both primary and inert, the element of atmospheric chemistry is irrelevant and does not need to be considered.

As pointed out in Section 3.3, the decision to regard a pollutant as being either reactive or inert depends upon the effective rate of reaction compared to the length of time that the pollutant spends within the region of interest. If the user is interested in a short-range application involving a slowly reacting material, that pollutant may be regarded as effectively inert for the application even though over a longer range this would be a poor approximation. An example of such a pollutant is sulfur dioxide (SO_2).

In the case of a secondary pollutant, some treatment of the chemical reactions which produce that pollutant will be required. Otherwise, the connection between precursor emissions and the concentration of the pollutant of interest is completely lost.

The subject of atmospheric chemistry encompasses an extremely wide range of topics and only those very basic or general aspects that are directly relevant can be described in this workbook. If atmospheric reactions play a significant role in the user's application, the advice of an expert should be sought regarding the level of detail with which the particular set of chemical reactions used by the model represents the system to be simulated.

This discussion will refer primarily to reactions between gaseous materials. The extent to which atmospheric particulate matter actually participates in chemical reactions with gaseous components is not at present well understood but if this possibility exists, the advice of an expert should again be sought. However, many of the same considerations apply as in the completely gaseous case.

The basic problem in modeling the dispersion of reactive systems is to describe the rates of production and removal of various pollutants. Equally as important is the interaction between the chemical reaction processes and the dispersion process. In order to assess the treatment of chemical reactions by a model, the user must consider two different aspects of that treatment:

- The level of detail with which the chemical reaction mechanism is described, and
- The manner in which the effects of spatial inhomogeneity on the average rates of change of the pollutant concentrations are treated.

It will be useful for the user to understand a few basic facts regarding the general nature of chemical reaction rates. The rate of a chemical reaction may be defined with sufficient precision for the purpose of this workbook as the magnitude of the time rate of change of the conce n of a reactant or product of the reaction in question. (The reactants are the chemical species actually undergoing reaction.) The reaction rate depends on the concentrations of all of the atmospheric components participating in the reaction.

Reactions can be classified as either elementary or complex. An "elementary reaction" is one in which the chemical reaction as written reflects the true sequence of events on the molecular level. For example, an important reaction in photochemical smog is that between ozone and nitric oxide (NO). This reaction involves the collision of a molecule of NO with a molecule of O_3, followed by a reaction and the separation of the products, one molecule each of NO_2 and oxygen (O_2). The most important property of elementary reactions is that the rate of such a reaction is a predictable, simple function of the reactant concentrations. In the example above, the rate of the reaction is simply equal to a constant (the rate constant) times the product of the ozone and nitric oxide concentrations. On the other hand, a "complex reaction" is essentially a statement of the <u>net</u> effect of some (possibly large) number of elementary reactions operating simultaneously, with only the initial reactants and final products being explicitly written. In general, the rate at which the initial reactants disappear is not equal to the rate at which the final products appear. Neither rate is a predictable function of the concentrations of only the initial and final chemical species. The sequence of elementary reactions whose net effect is of interest forms what is called the "reaction mechanism" and the description of the pollutant concentrations as functions of time must usually be made in terms of what is known about the reaction mechanism. It should be pointed out that, in addition to the main reactants and products of interest, the mechanism of a complex reaction usually involves the existence of other chemical species that should also be treated.

An extreme example of a complex reaction is the generation of photochemical smog from nitric oxide and hydrocarbons under the action of sunlight. In this case the reaction mechanism involves literally hundreds or even thousands of reactions.

As mentioned above, the expression for the rate of an elementary reaction can be predicted in an a priori way. In practice only three cases need to be considered; these three cases are outlined in Table A.6, in which the "order" of each type of reaction is also defined. The constant appearing in the rate expression for a given reaction is called the rate constant for that reaction.

The most important feature in Table A.6 of which the user should be aware is that the rate of a first-order reaction is a <u>linear</u> function of the pollutant concentration. The rates of second and third-order reactions are <u>nonlinear</u> functions of the pollutant concentrations. This fact has signifi[illegible]sequences when the spatial distribution of reactive pollutants is of int[illegible].

Table A.6. Elementary Reaction Rate Expressions

Rate Expression	Reaction Order
(constant) x (the concentration of one single reactant)	First
(constant) x (the product of the concentrations of two reactants)	Second
(constant) x (the product of the concentrations of three reactants)	Third

In order to describe the evolution of a complex reacting system, it is normally necessary to know the reaction mechanism. This mechanism consists of a set of (elementary) reactions whose rates are known functions of the pollutant concentrations. If the initial pollutants are uniformly mixed within some closed volume, their concentrations as functions of time may be predicted by numerical solution of a set of coupled ordinary, non-linear differential equations derived from the reaction mechanism. In practice, a simplified mechanism may be used in which many of the reactions of lesser importance have been omitted. Also the net effect of many reactions may have been expressed in terms of a few characteristic reactions using some kind of average or composite rate constant. The level of detail with which the reaction mechanism is treated affects the accuracy of the results and the mechanism being used should be justified by comparison with experimental studies.

Knowledge of the reaction mechanism includes not only knowledge of the reactions which can occur but also knowledge of the values of the rate constants of these reactions. The appropriate values are normally supplied with the model so that the user generally does not need to supply them. However, there is often considerable uncertainty in the experimental measurement of rate constants and the values of constants important in atmospheric chemistry are continually being redetermined. Obviously, in a practical application the values used should be as up-to-date as possible. In addition, rate constants depend on temperature. In some cases it may be important to use values appropriate for the ambient temperature in the user's specific application.

Further complications arise when dispersion is considered. It is important to emphasize at this point that chemical reactions are <u>local</u> phenomena in the sense that the rate of an elementary reaction at some point in space depends upon the reactant concentration(s) <u>at that point</u>. Thus, the rate of a given reaction is in general a function of position and time, reflecting the spatial and temporal variation in reactant concentrations. For most reactions of interest, the rate expression is a nonlinear function of pollutant concentrations, because most reactions of interest happen to be second-order. This implies that in most cases of interest the <u>average</u> rate of a given reaction with[illegible] some finite volume of interest <u>cannot</u> be obtained from the rate expression sim[illegible] nserting the average reactant concentrations, unless all reactants are uniformly mixed within this volume. In this case, there is no spatial variation in the reactant concentrations and hence no spatial dependence of the reaction rate. The only other situation in which the average reaction rate is given by the rate expression using the average pollutant concentration is that of a first-order reaction. In most cases of interest, spatial inhomogeneity in the reactant concentrations causes the chemical and dispersion processes to be coupled in a very complicated way.

The nature of turbulent dispersion and the small size of most real emission sources guarantee that in applications of practical interest there are significant variations in the concentrations of reactive pollutants over distances much smaller than the spatial resolution of most current models. The degree of inhomogeneity depends on the level of atmospheric turbulence and on the spatial distribution of the sources. In principle, the effect on the average reaction rate of this inevitable inhomogeneity at distance scales below the resolution of the model should be taken into account. In practice, however, this has proved to be a difficult problem and is still fundamentally unsolved.

A.5.2 Treatment of Chemistry and Reaction Mechanism

It is convenient to divide the discussion of treatments into two separate parts, the first dealing with the special case in which all relevant reactions are first-order reactions, the second with the more general situation.

As pointed out in the general discussion, most chemical reactions of importance in air pollution are second-order reactions. This being the case, it may seem unrealistic to consider an application in which all the reactions of interest are first-order. There are two situations, however, in which only first-order reactions need be considered. The first involves the treatment of radioactive rather than chemical transformations; radioactive decay is rigorously a first-order process. The second arises as a result of approximating the disappearance of one pollutant and the appearance of its reaction products as a first-order process with some empirically derived effective rate constant.

A first-order process has the property that the rate of that process is a linear function of the concentration of the reactant involved. As a result, it turns out that the effect of one or more first-order processes on the reactant and product concentrations may be determined independently from the effect of dispersion; in other words, first-order transformation processes and the dispersion process are completely separable and any of the many treatments of dispersion may be used. Furthermore, in cases where more than one sr [illegible] s involved, the contribution from each may be evaluated and the total predicted concentration obtained by simply adding the individual source contributions.

The simplest case arises with a primary pollutant subject to some first-order removal process. In this case, the affect of the process is simply to cause the pollutant concentrations to decay exponentially with a half-life which may be easily determined from the rate constant for the process. Many dispersion models now in use have the capability of simulating this situation.

More often, however, the user's application involves a system of chemical reactions, most of which are second-order; the most common example is photochemical smog. In general, a numerical/dynamic model is required, since the chemical mix evolves in time in a nonlinear way. The observational basis for a semiempirical approach is not usually available, although statistical models have been developed for some limited applications.

Two aspects of the treatment by a given model should in principle be evaluated:

- The level of detail used in the reaction mechanism, and
- The treatment of the effect of inhomogeneous mixing on average reaction rates.

With regard to the treatment of reaction mechanism, little can be said in general, because so much depends on the specific details of the chemistry. The simplest case is that in which either the disappearance of a particular pollutant, or the appearance of its reaction products, or both are of interest. In this case, if the reaction time scale is rather long compared to the dispersion time scale and if the reaction products are relatively inert so that, for example, the original pollutant is not regenerated by further reaction, it may be sufficient to approximate the reaction by a first-order process using an effective rate constant determined empirically. In this approximation, all details of the actual reaction mechanism are ignored. The conversion of sulfur dioxide to sulfate aerosol over long distances is commonly treated in this manner.

In more complex cases, such as that of photochemical smog, the mechanism should be treated at some more appropriate level of detail. The required level of detail depends on the nature of the reactions being described and the number of different chemical species involved. The user should seek expert advice in evaluating a model with respect to the mechanism being used. In any case, the assumed mechanism should be sufficiently valid so as to give reasonable agreement with experimental observations.

In the photochemical smog case, three approximations are commonly used and will be discussed briefly as examples of the possibilities that [illegible]n arise.

The first deals with the treatment of highly reactive intermediates which are present in photochemical smog. These intermediate species can be treated just like any other pollutant in that their concentrations may be described explicitly as functions of time. Due to their high reactivity, however, the approximation is usually made that they exist in a steady or stationary state such that for each the rate of removal equals the rate of production. Making this approximation allows their concentrations to be expressed mathematically in terms of those of measurable pollutants and thus eliminated from the rate expressions altogether. By eliminating these species from the equations, considerable simplification occurs. This approximation, called the steady-state or stationary-state approximation, should be tested for validity in any specific case and there are indications [Farrow and Edelson (1974)] that it is not necessarily valid for the photochemical smog case even though it is commonly used. This approximation is not restricted to applications involving photochemical smog but may be used in describing any reactive system in which highly reactive intermediate species are present.

A second and less detailed treatment is sometimes used when the reaction mechanism may be approximated by a small number of fast reactions such that each one in the set is accompanied by its reverse reaction. For example, over a short period of time the photochemical smog system may be approximated by a mechanism consisting of only two reactions: 1) the photolysis (absorption of light, followed by chemical reaction) of NO_2 to produce NO and O_3 and 2) the reverse reaction of NO and O_3 to produce NO_2. If each reaction in the set is fast enough, the entire system responds very rapidly to changes in composition brought about by dispersion, and the chemical composition of the pollutant mixture at any point may be predicted by assuming the system of chemical reactions to be in equilibrium. This approximation, called the equilibrium approximation, is equivalent to the assumption that the rate of removal equals the rate of production for every chemical species present, not just the reactive intermediates. The equilibrium approximation is valid when the reaction time for each reaction in the system is much shorter than the time required for significant concentration changes resulting from dispersion processes.

The equilibrim approximation may be used in steady-state as well as dynamic models. It allows the prediction of the chemical composition of the pollutant mixture at a given point given (1) the composition of the original pollutant emission, (2) the composition of the surrounding air into which that emission is being dispersed, and (3) the concentrations predicted on the basis of the dispersion model alone.

The third approximation deals with the very large number of hydrocarbons which are actually present in the polluted atmosphere, all of which participate in the formation of photochemical smog. As a practical matter it is impossible to the concentration of each even if their emission rates were known, which they are not in general. The approximation is made that classes of hydrocarbon may be defined such that all members of a given class share some desirable property, such as having similar reaction rates or reaction products. The total concentration of all members of each class is then modeled using a simplified reaction mechanism involving the use of average class rate constants. This technique is termed "lumping" of hydrocarbons. The validity of the procedure should be determined by comparison of predictions with observations from experiments.

For the purpose of comparing two models it should be assumed that, all other things being equal, it is better to treat reactive intermediates explicitly than to employ the steady-state approximation. The more accurate the reaction mechanism being used the better.

If the detailed spatial and temporal evolution of a dispersing reactive system is to be described, the system of chemical reactions should be treated in some detail. For other purposes, particularly involving secondary pollutants, experimental and/or observational data may be used to provide the necessary link between the concentration of the pollutant of interest and the precursor levels at an earlier time. This may be especially useful for cases in which not enough is known about the reaction mechanism or in which only a maximum concentration regardless of location is desired.

The other aspect that needs to be evaluated is the way in which the rates of change of the average pollutant concentrations are evaluated. Dispersion models for reactive pollutants generally attempt to predict the average concentrations of all relevant pollutants within some suitably defined volumes or cells as functions of time. Thus these models should be able to evaluate the time rates of change of these quantities. As discussed earlier, if the pollutants are uniformly distributed within a given cell, the appropriate rates of change may be calculated from the elementary reaction rate expressions using the average concentrations appropriate to the given cell. Errors will be introduced if this procedure is used in cases in which spatial inhomogeneities exist in the pollutant concentrations over distances smaller than the cell size. At present, this effect is generally not treated at all. This is not to imply that modelers are unaware of the effect, but the problem of providing an adequate general treatment is still essentially unsolved.

In summary, most dispersion models for reactive pollutants use elementary reaction rate expressions which are truly valid only in homogeneous regions and make no attempt to account for imperfect mixing at sub-grid distances. If the user is confronted with a model which does in fact treat the effect of inhomogeneities in some fashion, expert advice should be sought on the manner of treatment before making an evaluation. However, in general, a reasonable treatment would be better than none at all. Table 5.12 gives the treatments of chemistry and reaction mechanism that have been discussed. No table of treatments of the effect of spatial inhomogeneities on the rate of change of average pollutant concentrations is provided. At this writing no practical general treatments exist except in models developed solely for the purpose of doing basic research. Table 8.10 gives the treatments of chemistry and reaction mechanism used by suggested reference models.

A.6 PHYSICAL REMOVAL PROCESSES

A.6.1 General

The two major physical removal processes which affect ambient atmospheric pollution levels are dry deposition and precipitation scavenging. In identifying them as physical processes, the intention is to distinguish them from the chemical processes discussed in Appendix A.5, even though on a fundamental level there are chemical aspects to each. After defining these elements, each will be discussed in turn. For a more technical discussion the user is referred to the article by Hidy (1973) as well as the proceedings of the symposia on precipitation scavenging [Engelmann and Slinn (1970)] and on atmosphere-surface exchange of particulate and gaseous pollutants [Engelmann and Sehmel (1976)]. Technical but still introductory discussions are also given by Van der Hoven and Engelmann in Slade (1968).

Dry deposition is defined as the removal of a gaseous or particulate pollutant at the earth's surface by any of the several processes, including impaction, absorption, and chemical reaction. The important point is that this process occurs only at the surface.

Precipitation scavenging is defined as the removal of a gaseous or particulate pollutant by precipitation. In the past, the distinction has been made between the absorption or other collection of pollution by cloud droplets before precipitation actually occurred (denoted by the term "rainout") and the scavenging of pollutant by the precipitation itself as it falls through the polluted air (denoted by the term "washout"). For purposes of this workbook, this distinction will not be emphasized but the user should be aware of its existence.

Dry Deposition

The rate of removal of an atmospheric pollutant per unit area of ground surface is called the deposition rate (dimensions: mass/time/area). It depends upon

- The nature of the mechanism by which the pollutant, once transported to the ground, interacts with and is removed at the ground surface and

  The rate of vertical transport of that pollutant.

The pollutant is removed from the air near the ground, thereby creating a non-zero vertical concentration gradient near that surface. Vertical dispersion processes tend to smooth out this gradient by transporting pollutants downwards, thereby providing more for possible removal. The ambient pollutant concentration near the ground is lower than it would be otherwise, with the magnitude of the depletion depending on the relative rate of removal at the surface. A corresponding net decrease per unit downwind distance in the total amount of pollutant being advected by the wind is also observed.

The deposition rate depends on the nature of the interaction between pollutant and ground surface and as such depends on a wide variety of pollutant and surface characteristics. Although these are highly dependent on the specific application of interest, a few general statements can be made. The deposition of gaseous pollutants, for example, increases as the solubility or reactivity of the gas increases. The deposition of airborn particulate matter is highly dependent on particle size. If the pollutant of interest is found predominantly greater than a certain size range, this added factor should be taken into account in the treatment, as discussed below.

The deposition rate also depends strongly on the rate of vertical transport and therefore on the same factors as does vertical dispersion. (See Appendix A.4 for a discussion of these factors.)

With regard to the deposition of particulate matter, these remarks on deposition refer primarily to particles smaller than approximately 10 microns in size. Particles larger than this are sufficiently massive that gravitational settling becomes significant and these particles simply drift downward at a rate dependent on their size and weight. This deposition mechanism is very different from that described so far and in general must be treated differently; see for example the discussion in Slade (1968). Particulate matter smaller than 10 microns behaves much like a gas in many respects and gravitational settling is usually negligible.

If the removal is efficient enough, a significant fraction of the pollutant may be removed before it is transported out of the region of interest and ambient atmospheric concentrations can be significantly affected. In some application, the deposition rate or the total deposition within a given area over some specified period of time may be of interest, in addition to or instead of the actual ambient concentration. In either case, dry deposition is an important phenomenon.

Precipitation Scavenging

This term includes processes which take place within clouds, such as the formation of cloud droplets about pollutant particles which serve as condensation nuclei and the absorption of pollutants into existing [illegible]ets, as well as the scavenging action of precipitation falling through p air. The importance of each of these processes depends strongly on the characteristics of the pollutant, as in the case of dry deposition, and again only very general comments can be made. For gaseous pollutant, the solubility in water is the most important factor and this often depends to a significant extent on the presence of other dissolved material in the precipitation. The solubility of sulfur dioxide, for example, decreases as the acidity of the precipitation increases. The particle size is again the most important factor for the scavenging of aerosols. The rate of pollutant removal by falling precipitation is also determined to a significant extent by the size of the falling drops and the rainfall rate.

A.6.2 Treatment of Dry Deposition

As indicated above, the removal of pollutant at the ground surface has two major effects on ambient pollutant concentrations:

- A depletion of the mass of pollutant being advected by the wind, resulting in lower concentrations than would otherwise be expected, and
- A reduction of ground level concentrations compared to those at higher elevations, resulting in a non-uniform vertical distribution.

All treatments of dry deposition that are used in practice describe the first effect but not all describe the second.

The net downward pollutant flux resulting from removal at ground level is commonly assumed proportional to the pollutant concentration at ground level, the proportionality constant actually being dependent on a variety of factors such as:

- The nature of the pollutant,
- The nature of the ground surface, and
- The prevailing meteorological conditions, particularly the atmospheric stability near the ground.

The proportionality constant is called the "deposition velocity" and its value in any given situation determines the significance of the effect of dry deposition on pollutant concentration. Theoretical procedures exist whereby appropriate values may be estimated for a specific application but their accuracy is uncertain and values derived from field observations are nearly always used in practice.

Assuming that the downwind flux of pollutant may be parameterized in this way, the problem of treating dry deposition becomes one of describing its effect on atmospheric pollutant concentrations and of calculating the amount of pollutant deposited in the area of interest. Different types of models treat these effects in different ways, depending specifically on the way [illegible]al dispersion is treated and on the way the dependence of the pol[illegible] concentration on height above ground is predicted.

Since pollutant removal occurs at the ground surface, the best treatment of dry deposition is to mathematically specify the appropriate boundary condition at the earth's surface and to determine or describe the corresponding effects numerically or analytically. The mathematical statement of the boundary condition, which is used in models which treat vertical dispersion by a numerical method, involves both the vertical eddy diffusivity and the deposition velocity and defines the relationship between the pollutant concentration and the concentration gradient at the ground. Numerical solution of the diffusion equation in the vertical direction then determines the predicted pollutant concentration as a function of height as well as the predicted rate of pollutant deposition on the ground. This procedure may be used in either dynamic or steady-state models.

Models which treat vertical dispersion by a semiempirical method do not necessarily handle dry deposition in a less appropriate way than do numerical models. If, for example, the assumed form for the vertical concentration distribution is based on suitable analytic solutions of the vertical diffusion equation obtained using the correct boundary conditions, the treatment may be as appropriate as any other. Normally, however, semiempirical models incorporate certain assumptions which are to some extent invalid for the treatment of dry deposition.

Most semiempirical models incorporate the perfect reflection boundary condition, as discussed in Appendix A.7. Mathematically, this corresponds to the assumption that there is no net vertical pollutant flux and no net removal of pollutant from the atmosphere at the ground. An additional result is that the pollutant concentration is nearly independent of height near the ground. This also corresponds to the special case of a zero value for the deposition velocity. A model incorporating the perfect reflection boundary condition cannot treat the effect of dry deposition on the vertical concentration profile. If this approximation is used in a model, as it is in most Gaussian plume models, but it is still desirable or necessary to allow for the depletion of the plume as it is advected along, a time or downwind distance-dependent factor may be applied to the concentration value calculated by the basic semiempirical formula. This factor serves to simulate a reduction in the total mass of pollutant in the plume and to model pollutant removal by dry deposition. In essence, this type of treatment involves the determination of an effective source strength which is a decreasing function of travel time or downwind distance. The simplest example of this treatment is the use of an exponential decay factor in several currently available models. By appropriate choice of the value of the decay constant, it is possible to simulate crudely the effect of the removal of pollutant. An implicit assumption in this treatment is that the shape of the vertical concentration distribution is unaffected by the removal process. This assumption is valid only if the rat[illegible]tical mixing is large compared to the rate of pollutant removal.

A somewhat more detailed treatment, described in Slade (1968), involves the assumption that the pollutant is removed at a rate proportional to the ground level concentration. However, this concentration is given by the Gaussian plume formula with perfect reflection, modified by a factor to account for that mass of pollutant already lost. The effective source strength as a function of downwind distance must be determined by quadrature for the specific parameter values involved and presented for use in graphical or tabular form. As in the simpler and less detailed exponential decay treatment, the implicit assumption is made that the shape of the vertical pollutant distribution is unaffected.

The special case of particulate matter for which gravitation settling is important is generally treated by what has come to be known as the tilted plume approximation. The vertical pollutant distribution is determined as a function of time or downwind distance using whatever model is appropriate. A downward motion with a velocity equal to the appropriate settling velocity is added to whatever other motion has been predicted for the distribution. For steady-state models, the effect is to tilt the plume centerline downwards with a slope determined by the ratio of the settling velocity to the horizontal wind speed. One should in principle use a different settling velocity, and hence a different slope, for particulate matter in different size ranges.

Table 5.13 lists possible treatments of dry deposition. Table B.11 lists the treatments used by suggested reference models.

A.6.3 Treatment of Precipitation Scavenging

The various processes whose net effect is called precipitation scavenging are not usually modeled individually except perhaps in specialized research-level models. Instead, the total effect is generally treated in an approximate way.

Both the removal of pollutants in clouds and the scavenging by falling precipitation are usually considered to be exponential processes. This may not be strictly true in all cases. For example, the uptake of SO_2 by cloud droplets is not really an exponential process because of chemical reactions which occur in the droplets themselves. Precipitation falling through a polluted layer may take up a soluble gas at one height and release it at a lower height because of evaporation of the drops exposed to a clean atmosphere. These effects must be modeled on an individual case-by-case basis.

If removal in clouds is treated as an exponential process, the decay constant is called the rainout coefficient. If removal by falling precipitation is treated as an exponential process, the decay constant is called the washout coefficient. These coefficients in principle depend on a wide variety of [illegible] pollutant characteristics. Empirical values are often used and it is often assumed that the relationship between the washout coefficient and the total rainfall rate may be expressed by a power law. The washout coefficient is a function of drop size. A more detailed treatment would take this into account and determine the total rate of pollutant removal by integrating over an assumed drop size distribution function. This is rarely done in practice.

If the rainfall rate is variable, so is the washout coefficient. The pollutant concentration then decreases in a manner reflecting this variability; the decrease is not represented by simple exponential decay. For the purpose of describing the effect of rainfall on pollutant concentrations, the washout coefficient must be known or assumed, including any time variation due to variations in the rainfall rate.

If the application involves an averaging time sufficiently long that more than one rainfall occurrence needs to be treated, even simpler methods are often used. For example, the assumption may be made that every time it rains the ambient pollutant level is decreased by some constant factor which may be empirically derived or estimated from the average duration of rainfall in the area. If a climatological model is being used, the correlation between frequency of rainfall and other meteorological parameters, particularly wind direction, should be taken into account. Ignoring this correlation represents an even less detailed treatment and corresponds to simply superimposing total rainfall contours on calculated concentration contours to estimate the effect on long-term average concentration values. This correlation is most simply handled in climatological models by including precipitation in the set of meteorological variables for which the joint frequency function is used. In this case, exponential decay may be an appropriate treatment of the effects of precipitation. Many climatological models now available provide the option of specifying an exponential decay rate but do not specifically treat precipitation conditions separately. These models apply the exponential decay factor in <u>every</u> distinct meteorological condition modeled. This is <u>not</u> an appropriate treatment of precipitation scavenging due to the intermittancy of rainfall.

Table 5.13 lists the possible treatments of precipitation scavenging which are within the scope of this discussion. Table B.11 lists the treatments used by suggested reference models.

A.7 BACKGROUND, BOUNDARY AND INITIAL CONDITIONS

A.7.1 General

An air pollution model describes the pollutant distribution within a limited volume of space for a limited period of time. This volume is bounded on the bottom by the earth's surface, on the sides by the perimeter of the region of interest, and on the top by the upper limit to vertical dispersion. Even for models which calculate only ground level co[illegible]ations explicitly, the three dimensional nature of dispersion is accounted for through inclusion of such parameters as stack height, plume rise, or mixing height. In any case, treatments of the following four aspects of the given application are required:

- Effects due to the existence of a finite upper limit to dispersion,
- The effect of the earth's surface as a barrier to dispersion and as a potential sink for atmospheric pollutants,
- The contribution to pollutant levels within the volume of interest from upwind sources not included in the model, and
- The initial concentrations throughout the volume of interest at the beginning of the time period of interest.

Numerical and semiempirical models treat the first three aspects in different ways; dynamic and steady-state models treat the last aspect in different ways.

The first two aspects are generally called boundary conditions in both numerical and semiempirical models, because they relate to effects at well defined physical boundaries. The upper limit to dispersion is commonly treated as an absolute barrier which keeps pollutants above it from entering the modeled volume and which prevents pollutants dispersing upward within the modeled volume from going any higher. In such cases, there is no net flux of pollutant through the boundary. This condition is called the perfect reflection boundary condition and is a common assumption used for the upper boundary; other assumptions regarding the upper boundary condition are less common. However, there are circumstances in which pollutants may enter the modeled region through the upper boundary. For example, pollutants lying above the mixing layer can be entrained within the modeled volume as the mixing height increases in the morning as a result of solar heating. In practice, only numerical/dynamic models treat such situations in detail. A great deal of imprecision exists in specifying the flux (or flow) of pollutant across the upper boundary due to the lack of reliable estimates of such transfer in real situations. Even when perfect reflection is assumed, the exact value of the mixing height is generally subject to error, being based on extrapolations from measurements made at different locations or times than those being modeled.

Two effects determine the nature of the lower boundary condition:

- The behavior of the earth's surface as a barrier to downward dispersion, and
- The rate of removal of the pollutant at that surface.

These two effects are usually assumed to be related, because the rate of removal is proportional to the ground-level concentration. Various processes determine the degree of absorption and which are most important depends upon the particular situation. For example, large particles can settle out (be perfectly absorbed) under the influence of gravity. Sulfur dioxide can be absorbed by vegetation and ozone can react chemically with various materials on the earth's surface. The ground can also serve as a source of pollutants as, for example, when settled particles are reentrained in sufficiently strong winds or when some pollutant is being emitted by vegetation. It would be exceedingly complex to attempt to treat any of these processes in detail and models must rely on approximate treatments of the most important processes. When removal at the surface can be ignored, there is no net flux of pollutant through the lower boundary and the perfect reflection boundary condition is appropriate. When the removal rate is very large the situation approaches the condition which would be called "perfect absorption." Between these two extremes both effects must be treated. Their relative importance is determined by the rate of removal compared to the rate of vertical transport. It is thus important that applications involving physical sinks at the earth's surface handle vertical transport in an adequate manner. The removal of pollutants at the earth's surface is termed "dry deposition" and is discussed in more detail in Appendix A.6.

It should also be noted that numerical models generally treat at least some fraction of the emissions of pollutants by specifying the appropriate flux through the lower boundary as part of the lower "boundary condition." In this discussion, the "boundary condition" refers to what happens to pollutants already emitted; emissions treated as occurring at the boundary should be considered as aspects of source location and emission rate (Appendix A.1).

The third aspect, advection of pollutants into the volume of interest, is related to the concept of a background level. Such concentrations are due to natural and man-made sources not being modeled, because they are outside the modeled region. This definition of background differs from another sometimes used in which the background level is taken as the concentration which would exist if all sources in the modeled inventory ceased to emit. The latter definition would include contributions from sources within the modeled region but not included in the inventory. In the sense used here, background might be defined operationally as the pollutant concentration measured just outside the upwind boundary of the region of interest. Such a concentration would frequently depend on the direction of the wind, the location of the measurement, or the time when the measurement was made. For non-conservative pollutants, this concentration would be expected to change as the air is advected through the study region due to the operation of various removal mechanisms. For secondary pollutants, the incoming fluxes of precursors must also be taken into account, because they will generally interact significantly with emissions within the region and greatly affect the predicted levels of the pollutant of interest.

Ozone, which is both reactive and secondary, illustrates the situation well. "Background" ozone concentrations measured just upwind of [illegible] areas are frequently reduced within these areas due to the initial scavenging of ozone by precursor nitric oxide emissions. Downwind of the urban area, the precursors react and ozone concentrations rise again to high levels. Background is thus usually not a simple additive term but is a function of position and time within the region of interest. A single, additive background number can be defined only for primary conservative pollutants. Otherwise, the flux of pollutant and/or precursors into the study region at the vertical boundaries must be known. Even for primary conservative pollutants, the incoming flux must be known as a function of position and time if significant variations occur over time or distance scales small compared with the averaging time and the size of the region of interest. Rural SO_2 or sulfate levels provide examples of situations in which a single, additive background level is likely to be appropriate.

It has been assumed in this discussion of background and the side boundary conditions that the study region has been chosen carefully to include all important sources. It would be improper, for example, to estimate the total 24-hour maximum SO_2 concentration in the vicinity of a power plant while treating the contribution of a nearby plant as a background value. Both plants would need to be included in the study region and modeled. The second plant could be excluded only if the contribution of the first plant alone, rather than the total concentration, were desired.

One other point needs to be made about background. Circumstances may arise in which background is negligible, any background concentration being small in comparison to the concentration of interest. For example, in cases where the maximum short-term concentrations near a large, relatively isolated source are being estimated, background can usually be ignored. In such cases, models ignoring background are applicable. The user must consider the application carefully when making such a determination.

The last aspect covers the initial conditions, those concentrations existing throughout the study region at the beginning of the time period of interest. These concentrations are not treated explicitly in steady-state models but must be specified in order to solve the equations used in dynamic models. Initial concentrations may be included implicitly in steady-state models when background levels are estimated. They are likely to be most important for short-term averages for which the initial concentrations can constitute a substantial part of the final time-averaged concentration. This situation would occur most frequently when the initial concentrations are large and travel time across the region of interest is equal to or greater than the averaging time of interest. As noted in Appendix A.4, this type of situation calls for a dynamic, rather than a steady-state, treatment. The concentrations of secondary and reactive pollutants are particularly sensitive to the initial concentrations and distributions of precursors and potential reactants, respectively. Initial conditions are thus important for such pollutants and a dynamic approach is better suited to their treatment. This is particularly true when short-term concentrations are desired as is the case, for example, with ozone.

A.7.2 Treatment of Background, Boundary and Initial Conditions

Since numerical and semiempirical models treat dispersion from different points of view, they employ different methods for handling background and boundary conditions. Initial conditions are treated differently by dynamic and steady-state models. The user should be aware that both "boundary conditions" and "initial conditions" signify two related but not entirely equivalent concepts. First, they mean a set of mathematical expressions required to solve the partial differential equations used in numerical models and second, the physical conditions being modeled. The mathematical expressions are the representations of the physical conditions in a form suitable for numerical models. Semiempirical models must treat the same physical conditions, still often referred to as the boundary conditions, using different methods. The discussion is conveniently divided by considering first the treatments of background and boundary conditions by numerical and semiempirical models and then the treatments of initial conditions by dynamic and steady-state models.

Background and Boundary Conditions

Part of the difference between the treatments of background and boundary conditions by numerical and semiempirical models is simply a difference in the methodologies used to express the same physical condition. As will be seen, however, the numerical approach generally provides a more detailed and flexible treatment of these conditions. At this point, the user should keep in mind that applicability of both approaches to the application as discussed in Appendix A.4.

As noted above, many processes can take place when a pollutant contacts the earth's surface. Perfect reflection or absorption are generally approximations to the real situation. The appropriateness of the approximation being used must be assessed by the user when comparing models. Numerical models treat perfect reflection mathematically by requiring that the vertical gradient of pollutant concentration be zero at the surface, that is, what comes down must go back up. Perfect absorption corresponds to the requirement that the concentration be zero at the boundary. Perfect reflection is normally assumed, because it is usually a much better approximation to the physical situation than is perfect absorption. Both of these situations may also be handled easily by semiempirical models. Semiempirical models treat perfect reflection at the lower boundary by including an "image source" equivalent to the real source but located like its mirror image with the earth's surface as

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the mirror. The "method of images" is the technique employed in the most widely used forms of the Gaussian plume model and can only be used to handle perfect reflection or absorption.

Partial reflection at the earth's surface is treated in numerical models by using the concept of a "dry deposition velocity." This parameter is a measure of the rate of pollutant removal at the earth's surface. In essence, the mathematical formulation allows part of the incoming pollutant to be absorbed so that the total amount being dispersed is depleted after reflection. Most semiempirical models developed to date cannot treat partial reflection as a boundary condition. An approximate treatment of dry deposition as a pollutant removal process by assuming an exponential decay of the pollutant is frequently used. This is discussed in more detail in Appendix A.6. Dry deposition could also be treated as a boundary condition by semiempirical models if the assumed functional form of the pollutant distribution were based upon analytical solutions of the diffusion equations subject to the appropriate boundary condition. Numerical models can also change the amount of absorption to represent different conditions throughout the study region; semiempirical models can usually only deal with one overall average dry deposition rate throughout the region of interest.

At the mixing height, perfect reflection is generally assumed. Numerical models use the same form of mathematical boundary condition as at the surface but apply it at the height corresponding to the top of the mixing layer, which can vary with location and time. These models could also be used in principle to cover the case of partial penetration of the mixing layer (partial reflection) simply by altering the boundary condition as is done to treat dry deposition at the surface. They can also account for the transfer of pollutants into the region of interest by suitable modifications of the upper boundary conditions and thus treat fumigation or entrainment. It should also be noted that numerical models require a finite upper limit to dispersion in order to solve the relevant equations.

As at the ground, semiempirical models generally treat only the case of perfect reflection. Two methods are commonly used. The first is the method of images in which image sources are added above the mixing height to account for the reflections from that barrier, which is generally assumed to have a constant elevation. It turns out that an infinite number of images are required to account for the multiple reflections from the ground and the mixing height [see Turner (1969)] and the result is expressed as an infinite sum. In most cases only the first few terms of the sum contribute significantly and the sum may be evaluated easily to sufficient accuracy. A more common treatment relies upon the observation that near the source the plume is not affected by conditions at the top of the mixing layer and that far enough downwind, the pollutant is [illegible]ly mixed within the entire mixing layer. Between the distance at which the plume first feels the effects of the finite mixing height and the distance at which the vertical profile becomes uniform, the concentration is obtained by interpolation [see Turner (1969)]. A variation of this treatment used in some Gaussian plume models treats the effect of the mixing height implicitly by limiting the vertical spread of the plume by requiring that σ_z remain constant after the vertical spread of the plume (σ_z) exceeds some fraction of the mixing height. Pasquill (1976) discusses the limitations of the undisturbed and uniform mixing approximations and has presented a table for use in interpolating results in cases where the sum must be evaluated. [See also Yamartino (1977)]. Evaluating the sum will generally give more accurate results than interpolation. The gain in accuracy is slight considering the magnitude of other inaccuracies in modeling treatments and interpolation is used more frequently. Semiempirical models can also, in essence, ignore the upper boundary condition by using a functional form for the vertical concentration profile that places no limits on the height to which pollutants can disperse. This may be an appropriate representation of the real situation of the large mixing heights at short distances from the source. Semiempirical models can be modified to account for fumigations by using equations (functional forms) for predicting concentrations during the time of the fumigation. (See, for example, the equations in the appropriate references cited in Appendix A.2.)

Numerical models treat the conditions at the sides of the region as mathematical specifications of the pollutant flux into the region. As noted above, this is the most fundamental way of treating background levels. Semiempirical models cannot treat these as boundary conditions and "background" can only be treated as a general additive term. This term may be a function of location within the region but is generally treated as a single constant value thus ignoring directional dependence and spatial variations. Any temporal variation is also generally ignored.

Initial Conditions

As pointed out previously, initial conditions are treated explicitly only by dynamic models. Any contributions to the concentrations due to pollutants initially present would be handled as part of the additive background level by steady-state models. As such they would be indistinguishable from the concentrations assumed to be advected into the region as "true" background. In dynamic treatments, more detail is available when the initial conditions can be arbitrary functions of location than when single uniform values must be assumed throughout the region of interest.

A final word is in order about climatological models and temporal variations. As noted in Appendix A.4, this approach can make use of any of the basic types of models discussed although a steady-state method is most often used. Thus, the treatment of background, boundary and initial conditions by climatological models will depend upon the nature of the model [illegible] the dispersion calculations. Both dynamic and sequential steady-st[illegible]els can, of course, account for temporal variations in background and boundary conditions. Dynamic models usually allow important parameters to change relatively smoothly over time; sequential steady-state models allow parameters to assume new values at the beginning of each new time interval over which a steady-state is assumed to hold. Dynamic models most frequently treat the amount of material advected or entrained into the region of interest or the mixing height as time dependent; sequential steady-state models most frequently treat only temporal variations in the mixing height.

The ranking of treatments of background, boundary, and initial conditions is given in Table 5.14. In treating these elements, almost any combination of types of treatments at the various boundaries can occur. In rating a model, the user should rate the model's treatment of each element separately and combine them to arrive at an overall rating. Table B.12 lists the treatments of background, boundary and initial conditions used by suggested reference models.

A.8 TEMPORAL CORRELATIONS

A.8.1 General

As noted in previous subsections, many of the elements or quantities used to parameterize an element treated by a model can vary with time. The variations of these quantities about their mean values are frequently correlated in the situation being modeled. For example, the application may involve a source with a diurnally varying emission rate and meteorology with the typical diurnal variations in atmospheric stability described in Appendix A.4. When such correlations occur it is usually important that the model correlate the time-dependent quantities, that is, treat them in such a way that concentration estimates are made on the basis of values which do occur together in the application of interest.

Implicit in the last statement is a realization that the treatment of correlations is closely related to the degree of temporal resolution obtainable in the model. In particular, the resolution time for the correlated quantities must be less than the time over which the variations can occur. For example, if two correlated quantities vary hourly, the model must treat each of them with a time resolution of one hour or less for the treatment of correlations to be possible.

As pointed out previously, there is a limit, frequently based on practical considerations or data availability, to the resolution time and hence to times over which correlations can be considered. The limiting factor is that element or quantity with the minimum degree of time resolution among those elements which are important to the particular application and which exhibit sufficiently large temporal variability to affect the model results. The primary interest i[illegible]lly in correlating emission rates, meteorological parameters, and rat[illegible] of removal and transformation processes. Of course, in applications where emission rates are almost constant, correlations involving them are small and may be ignored. Generally speaking, the correlations between the various meteorological parameters also need to be treated.

Dynamic and sequential models handle temporal correlations automatically within the time resolution used by the model. These models generally allow the values of most important parameters to be changed at each time step and since the data for each step are generally input as a unit by the user, they are automatically correlated. Steady-state models which treat one or several specific sets of emission and meteorological data treat correlations which occur on a time scale longer than the averaging time of the data automatically and ignore those which occur over shorter times. The correlations are implicit in the structure of the input data as in the dynamic case. This type of treatment is frequently encountered in models which estimate short-term concentrations.

On the other hand, climatological models use statistical wind roses and hence the only correlations inherent in this approach are between those parameters upon which the wind rose is based, typically atmospheric stability, wind speed, and wind direction. A three-hour resolution is typical of wind roses. All other correlations, particularly those involving emissions, must be treated separately.

Two factors should be considered when evaluating the treatment of correlations:

- The magnitude of the variations in the given application over time scales less than the averaging time, and
- The importance to the application of the quantities involved.

The first factor has been discussed above. As for the second, simply correlating many time-dependent quantities may be less important than correlating a few critical quantities, e.g., wind direction and emission rate when the effect of a peaking power plant at a specific location is desired.

A.8.2 Treatment of Temporal Correlations

Beginning with the most detailed, there are basically three levels at which temporal correlations can be treated:

- Sequential and fully correlated,
- Non-sequential with limited correlation, and
- Not treated explicitly.

The first type of treatment is found in dynamic models or in sequential models. In these models, the correlations are treated automatically. The second type of treatment is exemplified by climatological models. Although s[illegible] statistical models may implicitly treat correlations by their choice of varia[illegible] hey are classified here as using the third type of treatment and are discussed in Section 7.

Within the first two treatments there is a variation in the level of detail depending on:

- The degree of temporal resolution and
- The quantities allowed to vary.

The determinants and importance of these aspects have been discussed in the general discussion in Appendix A.8.1.

Table 5.15 lists the treatments of temporal correlations and the treatments by suggested reference models are given in Table B.13.

A.9 IMPORTANCE RATINGS FOR APPLICATION ELEMENTS

Source - Receptor Relationship

The source-receptor relationship is assumed to be of at least medium importance in all applications. Many factors influencing transport and dispersion depend on the source-receptor separation and orientation. The relationship is somewhat more important for secondary pollutants, because of the need for a detailed description of the mixing of various precursors. For similar reasons, it is also somewhat more important when chemical sinks are involved. Short-term concentrations are more sensitive to this relationship than long-term concentrations, since changing meteorological conditions tend to average differences in concentrations from point to point. The concentration distribution in situations involving limited numbers of sources depends heavily on the source-receptor relationship. In situations involving multiple sources where small inaccuracies in one relationship are likely to be balanced by inaccuracies in another, this relationship is less important. Area source applications require a little less detail than point or line applications, because the spatial extent of an area source makes an error in the source-receptor relationship less significant in affecting concentration estimates. The importance of this element is somewhat enhanced in complex geographic situations which place considerable importance on the precise relationship between source, receptor, and geography. Short-range applications are more sensitive to the source-receptor relationship than long-range applications. At long distances emissions have usually become relatively uniformly mixed and a change in separation or orientation that would be critical at short range produces only a negligible effect. The importance of the source-receptor relationship to each of the applications is given in Table 4.2.

Emission Rate

[illegible] things being equal, concentrations of primary pollutants are propo[illegible] to emission rates. For secondary pollutants, the relative concentrations of the precursors are very important factors in determining concentrations. Emission rates were thus always rated as of at least medium importance to all applications, and as somewhat more important for secondary than for primary pollutants. The same consideration applies to reactive pollutants, making emission rate slightly more important when chemical sinks are involved than when only physical sinks or inert pollutants are modeled. Emission rates must generally receive more attention in short-term or short-range applications than in long-term or long-range applications where other factors such as changing meteorology and removal processes normally can assume greater importance for determining concentrations. Emission rates are rated as somewhat more important in situations involving a limited number of sources, because of the likelihood of compensating errors in the multiple source case. No distinction is made between different source geometries nor between the importance of emission rates in simple and complex geographic situations. Ratings of the importance of emission rates to the various applications are given in Table 4.3.

Composition of Emissions

This discussion deals only with the chemical composition of emissions. If the user's application requires the specification of a size distribution for particulate matter, the importance ratings in Table 4.4 should be reconsidered. No general statements can be made in this case, and the user should consult an expert to determine importance ratings appropriate to the application of interest.

Chemical composition of emissions is critically important when secondary pollutants or chemical sinks are involved and of little importance when dealing with primary pollutants and either no sinks, or physical sinks only. No difference in importance between long-term and short-term applications is assumed. A slight extra importance is assigned to applications involving multiple sources or long-range transport, because of the increased possibility for chemical reactions when many different emissions are mixed or a long time is allowed for reactions to occur. The importance in simple and complex geographic situations is the same. The importance ratings for the chemical composition of emissions are given in Table 4.4.

Plume Behavior

Table 4.5 gives the importance of plume behavior to each of the indexed applications. Plume behavior is equally important for both primary and secondary pollutants but is rated more important in cases where physical sinks are present than when chemical or no sinks are present. This is because the plume behavior determines how easily the plume contacts the ground, allowing the physical removal process to operate. Chemical removal can occur throughout the entire volume of mixing. Plume behavior is also rated more important in short-term than in long-term averages, because over short-time spans small variations, masked by averaging over long time spans, may be signifi[illegible] The greater spatial inhomogeneities associated with point sources mak[illegible] behavior more important for point sources than for line sources. Similarly, it is somewhat more important for line than for area sources. In complex geographic situations, plume behavior is important in determining whether the plume will be affected by the complex situation or rise above its influence. Over a long range, vertical mixing tends to become uniform and hence plume behavior is relatively unimportant.

Horizontal Wind Field

The horizontal wind field is generally an important element in any application, because advection is the principal process for pollutant transport. It is considered somewhat more important when chemical reactions are important and when short-term rather than long-term averages are desired, because of the need to know the wind field more precisely. The determination of the horizontal wind field is more important in complex terrain due to the channeling of the wind and other effects. The horizontal wind field is somewhat more important in limited point or line source cases than area or multiple source cases. Finally, the horizontal wind field is considered to be very important in those situations in which the actual trajectory of a parcel of air must be determined, because the temporal and spatial variation must be reproduced. This is the case for long range transport and for very short release times (puffs). Table 4.6 gives the importance rating of horizontal wind field for each application.

Vertical Wind Field

The vertical wind field is considered generally unimportant in many cases of interest, because it is nearly zero on average. Vertical wind field is important in situations requiring the estimation of concentrations at moderately short ranges in regions containing complex terrain due to the effect of the terrain on the (three-dimensional) wind field. Vertical wind field is considered slightly more important in applications involving chemistry than those in which chemistry is unimportant due to the need for a more accurate description of the wind field. Vertical wind field is also considered more important in estimating short-term rather than long-term estimates. No distinction was made for different source geometries or numbers. Table 4.7 gives the importance ratings of vertical wind field for the indexed applications.

Horizontal Dispersion

Table 4.8 gives the importance rating of horizontal dispersion for each of the indexed applications. Horizontal dispersion is considered to be of at least medium importance in every application. Horizontal dispersion is more important at short range than at long range, because the dispersion process is the most rapid and produces the greatest changes in concentration estimates at short ranges. Horizontal dispersion is considered less important for area sources than for line sources, and less for line than for point sources due to the emission size effect. In the case of secondary pollutants and/or the case of chemically reactive pollutants, it is very important to be able to describe the mixing of emissions with the ambient air, since chemical reaction rates are sensitive to local concentrations; therefore horizontal dispersion is considered quite important in these cases. Similarly, if physical sinks are present, it is generally more important to handle horizontal dispersion properly, depending on the nature of the removal process. The importance of horizontal dispersion is considered to be higher for short-term averages than for long-term, because the averaging which can occur over long times generally allows simpler treatments to be adequate. Finally, horizontal dispersion is considered to be equally important in either simple or complex terrain.

Vertical Dispersion

Table 4.9 gives the importance rating of vertical dispersion for each of the indexed applications. Vertical dispersion is given at least a medium rating for every application. Its importance is considered independent of averaging time, and approximately independent of the type of terrain. Vertical dispersion is considered much more important at short range than at long range, and more important for secondary and/or chemically reactive pollutants or if physical removal processes, particularly by deposition, are operative. Finally, the importance of vertical dispersion is considered independent of source type or number.

Chemistry and Reaction Mechanism

The importance of chemistry and its treatment is determined primarily by the chemical nature of the pollutants involved and to some extent by the travel distance; no other characteristics of the application need be considered. Chemistry is irrelevant for primary inert pollutants, is of importance for primary reactive or secondary inert pollutants, and is of even more importance for secondary reactive pollutants. The importance of chemistry is rated lower for primary reactive and secondary inert pollutants than for secondary reactive pollutants. If chemical reactions provide both a source and a sink for a given pollutant, chemistry is more important than if they provide either source or sink, but not both. This is a somewhat arbitrary ranking; the real importance of a detailed treatment of chemistry depends on the complexity of the system of reactions and the number of pollutants involved. Chemistry is considered slightly more important for long-range than for short-range applications due to the longer travel time and greater opportunity for reactions to occur. Table 4.10 gives the list of importance ratings of chemistry and reaction mechanism for each of the indexed applications.

* * *

Physical Removal Processes

We consider two processes in this category: dry deposition and precipitation scavenging. Physical removal is important, by definition, in those applications for which the user has taken the physical or chemical/physical sink branch on the Application Tree. Physical removal is also slightly more important for pollutants with chemical sinks than conservative ones. Physical removal is more important for long-range than for short-range applications, because of the cumulative effects of the process. Its importance is considered roughly independent of source type and averaging time. Physical removal is considered slightly more important in complex rather than simple terrain, due to the increased surface roughness. It should be pointed out that the importance of precipitation scavenging, as a removal process, depends primarily on the fraction of the time during which precipitation occurs in the application of interest. Thus, for short-term applications precipitation scavenging may usually be neglected, while for long-term, or possibly long-range, applications a convenient measure of its importance is the rainfall probability. Table 4.11 lists the importance ratings of physical removal for the indexed applications.

Background, Boundary and Initial Conditions

The importance ratings of background, boundary and initial conditions to the indexed applications are given in Table 4.12. These conditions were rated as highly important for secondary pollutants where precursor background levels can significantly influence the pollutant concentrations in the region of interest and for applications involving sinks where the advected concentrations might be significantly depleted during transit. These elements are crucial for applications involving reactive pollutants where the details of the pollutant mix must be known. These elements are equally important for short and long-term averaging times and for short and long-range transport. They are independent of the specific source characteristics and geography and are assumed to be of at least medium importance to all applications.

Temporal Correlations

Temporal correlations relate the time variations of the other application elements in their proper sequence. The importance of temporal correlations to the indexed applications is given in Table 4.13. They are rated more important for secondary than for primary pollutants, because the exact sequence and correlation of emissions and meteorology determine whether the pollutants are brought into contact so that reactions can occur. The ambient concentration is less sensitive to correlations for primary pollutants. Similarly, when physical and chemical sinks are involved, it is important to treat correlations. When treating short-term averages, it is generally important to know the detailed shor[illegible] fluctuations in the relevant factors and to correlate them properly; such detail is usually unnecessary when treating long-term averages. Thus, correlations are more important in short-term than in long-term applications. No distinctions are made between the various source types. More importance is associated with temporal correlations in complex geographic situations. Here correlations between emissions and dispersion factors can determine whether a particular emission passes within the perturbing influence of the complex geography. Short-range applications usually require more attention to temporal correlations. At short range, rapid changes normally occur in plumes whereas at long range these changes are slower and require less detail to treat adequately.

APPENDIX B
BACKGROUND MATERIAL ON SUGGESTED REFERENCE MODELS

Appendix B. BACKGROUND MATERIAL ON SUGGESTED REFERENCE MODELS

Appendix B is divided into two parts. The first, Appendix B.1, consists of Table B.1 which provides the classification of each suggested reference model, and Tables B.2-B.13 which provide the treatment of each of the twelve application elements used by these models. The second part, Appendix B.2, provides abstracts of and the working equations used by the suggested reference models. A glossary of symbols is provided at the end of Appendix B.2.

CONTENTS OF APPENDIX B

B.1. REFERENCE MODEL TREATMENTS OF APPLICATION ELEMENTS

This appendix provides the classification of each suggested reference model in Table B.1 and the treatment used by each model of the twelve application elements in Tables B.2-B.13.

Table B.1. Reference Model Classification

Suggested Reference Model	Classification
APRAC-1A	Semiempirical/Sequential (steady-state)
ATM	Semiempirical/Climatological (steady-state)
CDM	Semiempirical/Climatological (steady-state)
Single Source (CRSTER)	Semiempirical/Sequential (steady-state)
DIFKIN	Numerical (vertical)/Semiempirical (horizontal)/ Dynamic
HIWAY	Semiempirical/Steady-state
RAM	Semiempirical/Sequential (steady-state)
SAI	Numerical/Dynamic
STRAM	Semiempirical/Dynamic
Valley (short-term)	Semiempirical/Steady-state
(long-term)	Semiempirical/Climatological (steady-state)

Table B.2. Treatment of Source-Receptor Relationship by Reference Models

a. Horizontal Source and Receptor Location

Reference Model	Source Geometry	Method of Treatment
APRAC-1A	Line and area	User specifies line sources (traffic links) with arbitrary locations and lengths.
		Area sources (off link traffic) allocated to 2 mi x 2 mi grid.
		For each receptor both are aggregated onto wedge-shaped areas of a polar grid centered on a receptor (a different grid is used for each receptor) such that:
		1) Radii of circular boundaries increase in geometric progression.
		2) Radial boundaries are 22.5° beyond 1000 m and 45° under 1000 m from receptor. (3,3 for area, line)^a
		Up to 10 arbitrarily located receptors. (1)^b
		Street canyon submodel: Four internally located receptors on each user-designated street. (2 for line)^a (4)^b
ATM	Point, area, and line	Arbitrary location for all sources. (1 for all source types)^a
		Areas should be roughly square or circular.
		Arbitrary receptor location. (1)^b
		Assumes flat terrain; elevation not treated.
		Treats multiple point, area, and line sources.
		Treats up to ten receptors.
CDM	Point and area	Arbitrary location for point sources. (1 for point)^a
		Area sources are squares of uniform size in user-defined grid; user may specify sources which are integer multiples of the grid size, but these must be superimposable directly on the grid. (2 for area)^a
		Receptors located arbitrarily. (1)^b
Single Source^c (CRSTER)	Point	Up to 19 sources all assumed to be located at same user-specified, arbitrary position. (1-2)^a
		Receptor locations restricted to 36 azimuths (every 10°) and five radial distances. (3)^b

Table B.2 (Cont'd)

a. (Cont'd)

Reference Model	Source Geometry	Method of Treatment
DIFKIN	Point and area	All sources aggregated to square 2 mi x 2 mi grid cells in an array 25 cells x 25 cells. (2,2 for point, area)[a]
		Sources classified as points (power plants, refineries), distributed stationary, and mobile.
		Receptors located arbitrarily within boundaries of emission grid. (2)[b]
HIWAY	Line	Straight finite line segments (will treat up to 24 parallel segments), arbitrarily located. (2)[a]
		Arbitrarily located receptors. (1)[b]
		Cut section mode:
		Emissions treated as coming from 10 lines at top of cut. (2-3)[a]
		Receptors cannot be in cut. (2)[b]
RAM	Point and area	Arbitrary location for point sources. (1 for point)[a]
		Receptors may be:
		1) Located arbitrarily, (1)[b]
		2) Located internally near individual source maxima, (4)[b]
		3) Located on internally generated hexagonal grid to give good coverage in user-defined portion of region of interest. (4)[b]
		Area sources are multiples of unit squares on a grid; user controls scale of grid. (2 for area)[a]
SAI	Point and area	All sources aggregated to square grid of arbitrary spacing and up to 25 x 25 cells. (2,2 for point, area)[a]
		Sources classified as points (power plants), distributed stationary and mobile.
		Multiple receptors located arbitrarily within boundaries of emission grid. (2)[b]
		Concentrations also calculated in each grid cell (up to 25 x 25 x 5 estimates).
STRAM	Point	Arbitrary location for each source. (1)[a]
		Up to 10 arbitrarily located receptors plus receptors at intersections of a grid of up to 13 x 13 equally spaced boundaries. (1,3)[b]
Valley	Point and area	Arbitrary location and elevation for each point source. (1 for point)[a]
		Arbitrary location, elevation, and size for square area sources. (1 for area)[a]
		Must be less than 51 sources.
		Receptors (112) on 16 direction radial grid; relative radial distances fixed internally; scale and origin of grid defined by user. (3)[b]

b. Release and Receptor Heights

Reference Model	Source Geometry	Method of Treatment
APRAC-1A	Line and area	Sources assumed at ground level. (3,3 for line, area)[c]
		Receptors assumed at ground level. (7)[d]
ATM	Point, area and line	Arbitrary release height for each source. (2,3,2 for point, line, area)[c]
		Receptors at ground level. (7)[d]
CDM	Point and area	Assumes flat terrain; arbitrary stack height for each source. (2,3 for point, area)[c]
		Chooses larger of input stack height or 1 m.
		Receptors at ground level. (7)[d]
Single Source[g] (CRSTER)	Point	Arbitrary stack height for each source. (1)[c]
		Unique topographic elevation for each receptor: must be less than each stack height.
		Receptors must be at ground level. (combination of 2,7)[d]
DIFKIN	Point and area	Emissions treated as upward pollutant fluxes at ground surface. (3,3 for point, area)[c]
		Receptors at equally spaced heights from the ground to the mixing height. (4)[d]
HIWAY	Line	Arbitrary release heights. (2)[c]
• • • • • •		Arbitrary receptor heights. (1)[d]

Table B.2 (Cont'd)

b. (Cont'd)

Reference Model	Source Geometry	Method of Treatment
RAM	Point and area	Arbitrary release height for each point source. (2 for point)[c]
		Up to three effective release heights (appropriate for 5m/sec winds) may be specified for area sources. (2 for area)[c]
		Value for a particular area must be one of these three.
		Receptors all of same height at or above ground level; flat terrain assumed. (7)[d]
SAI	Point and area	Arbitrary release height for point sources (power plants). (1 for point)[c]
		Point source emissions assumed uniformly mixed throughout vertical column in which emission takes place.
		Other emissions treated as upward fluxes at ground surface; arbitrary topographic elevation. (Combination of 1,3 for area)[c]
		Receptors at ground level. (7)[d]
STRAM	Point	Arbitrary release height for each source. (2)[c]
		Receptors at ground level; flat terrain assumed. (7)[d]
Valley	Point and area	Arbitrary release height for each source. (1, combination of 1, 3 for point, area)[c]
		Receptors at ground level at any elevation on existing topographic features. (combination of 7)[d]

c. Downwind/Crosswind Distances[e]

Reference Model	Source Geometry	Method of Treatment
APRAC-1A	Line and area	Uses exact downwind distances to the two radial boundaries of each gridded area source. (1 for area)
ATM	Point, area	Unique downwind and crosswind distances for each point source-receptor pair, for three points within each area source, and for nine points along each line source. (1 for all source types)
CDM	Point and area	Calculates unique downwind distance for each point source-receptor pair. Calculates representative distances for area source-receptor pairs. (1, 2 for point, area)
Single Source[g] (CRSTER)	Point	Calculated from source to each receptor location. (1)
DIFKIN	Point and area	Not applicable. Distance traveled along computed trajectory not used explicitly.
HIWAY	Line	Precise downwind and crosswind distances for each point along line. (1)
RAM	Point and area	Unique downwind and crosswind distances for each point source-receptor pair. (1 for point)
		Downwind distance calculated for points along rays which intersect area sources. (1 for area)
SAI	Point and area	Not applicable.
STRAM	Point	Not applicable; concentration calculated at each receptor based upon distance along and distance from trajectory centerline.
Valley	Point and area	Exact downwind distance calculated for each point-source receptor pair. (1 for point)
		Single representative downwind distance used for area sources. (2 for area)

d. Orientation[f]

Reference Model	Source Geometry	Method of Treatment
APRAC-1A	Line and area	Traffic links (lines) may have arbitrary horizontal orientation but this detail is lost when links are gridded onto the receptor-centered polar grid. (2,3 for area, line)
ATM	Point, area and line	Orientation of areas not treated explicitly. (3 for area) Lines horizontal, arbitrary orientation. (1 for lines)
CDM	Point and area	Sides of areas must lie along grid directions.
Single Source[g] (CRSTER)	Point	Not applicable.
DIFKIN	Point and area	Areas oriented by fixed grid boundaries. (2)

Rule 932, Continued

Table B.2 (Cont'd)

d. (Cont'd)

Reference Model	Source Geometry	Method of Treatment
HIWAY	Line	Line assumed horizontal with arbitrary orientation. (3)
RAM	Point and area	Sides of areas must lie along grid directions. (2)
SAI	Point and area	Areas oriented by fixed grid boundaries. (2)
STRAM	Point	Not applicable.
Valley	Point and area	Area sources assumed oriented with one side parallel to wind direction. (Somewhat less detailed than 2)

[a] Numbers in parentheses refer to treatments of horizontal source location for the appropriate source type as given in Table 5.1 a.

[b] Numbers in parentheses refer to treatments of receptor location as given in Table 5.1 e.

[c] Numbers in parentheses refer to treatments of release height for the appropriate source type as given in Table 5.1 b.

[d] Numbers in parentheses refer to treatments of receptor height as given in Table 5.1 f.

[e] Numbers in parentheses refer to treatments of downwind/crosswind distances for the appropriate source type as given in Table 5.1 c.

[f] Numbers in parentheses refer to treatments of source orientation for the appropriate source type as given in Table 5.1 d.

[g] CRSTER should be used only when the receptor is below stack height.

Table B.3. Treatment of Emission Rate by Reference Models

Reference Model	Source Geometry	Method of Treatment: Spatial Variation[a]	Method of Treatment: Temporal Variation[b]
APRAC-1A	Line and	Arbitrary line source emissions aggregated onto grid described under source-receptor relationship (Table B.1). Arbitrary off-link grid squares assumed uniform and aggregated to same grid. Area source contributions from grid obtained by numerical integration of narrow plume approximation formulas; contributions calculated from all upwind sources located within the wedge-shaped grid. (2 for gridded area sources)	Daily traffic volume for each link and off-link grid square is input and modified to produce hour-by-hour emissions. (Equivalent to 2b) Street canyon submodel: Hourly emission rate for link of interest is input by user. (5)
ATM	Point, area, and line	Arbitrary rate for each point, line and area source. Area sources transformed into polar areas each of which is represented by three effective point sources; shape of area depends upon angle subtended by area at each receptor. Total area source contribution estimated as a sum of individual contributions. Line sources treated as ten effective points. Areas and lines assumed uniform. (1, modified 4,4 for point, area, line) Treats "windblown" source as an area source of TSP with emission rate determined by user input values of type of material, density, saltation diameter, and suspension diameter appropriate to each source and the wind speed. ("Windblown" source: modified 4)	Constant emission rates. (5)
CDM	Point and area	Arbitrary emission rate for each point and area source. Area sources assumed uniform. Area source contributions integrated numerically one 22.5° sector at a time, based on sampling points located at specific angular and radial intervals on a polar grid centered at receptor. (1, 3 for point, area)	Day/night variations in emissions; same variation for all sources. (2b)
Single Source[c] (CRSTER)	Point	Arbitrary emission rate for each source. (1)	Monthly variation in emission rate allowed. (3)

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• • •

Table B.3 (Cont'd)

Reference Model	Source Geometry	Method of Treatment: Spatial Variation[a]	Method of Treatment: Temporal Variation[b]
DIFKIN	Point and area	Emissions treated as upward pollutant fluxes at ground surface. Individual rate for each 2 mi x 2 mi grid square: Rates for mobile sources determined from user-supplied emission factors and traffic data. Rates for stationary sources input by user. Calculates contributions from grid squares along trajectory. (1, modified 3 for point, area) Program option allows user to input directly arbitrary surface pollutant fluxes for up to three pollutants (not necessarily photochemically reactive).	Sequence of hourly average rates for mobile sources. Stationary source rates assumed constant. (1,3)
HIWAY	Line	Uniform emission rate for each traffic lane. Each lane integrated numerically to obtain contribution. (3)	Constant emission rates. (5)
RAM	Point and area	Arbitrary emission rate for each point and area source. Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulas for area source with given effective release height. Includes only those areas intersected by the upwind ray. (1 for point; 4,3 for area)	Constant emission rates. (5)
SAI	Point and area	Point source emissions distributed homogeneously throughout entire vertical column above grid square containing the source; emission rates supplied by user. Other emissions treated as upward pollutant fluxes at ground surface. Rates for mobile sources determined from user-supplied emission factors and traffic data. Rates for stationary sources input by user. (Modified 1,3 for point, area)	Sequence of hourly average rates for mobile sources. Stationary source rates assumed constant. (1,3)
STRAM	Point	Arbitrary emission rate for each source. (1)	Constant emission rates. (3)
Valley	Point and area	Arbitrary rate for each point and area source. Area sources treated as single effective point sources. Total area source contribution estimated as a sum of individual contributions. (1,4 for point, area)	Constant emission rates. (3)

[a] Numbers in parentheses refer to treatments of spatial variation as given in Table 5.2.

[b] Numbers in parentheses refer to treatments of temporal variation as given in Table 5.2.

[c] CRSTER should be used only when the receptor is below stack height.

Table B.4. Treatment of Composition of Emissions by Reference Models

Reference Model	Method of Treatment	
	Chemical Composition	Size Distribution
APRAC-1A	Not applicable; model designed for primary, unreactive pollutant.	Not applicable; model designed for gaseous pollutants.
ATM	Not applicable; model designed for primary, unreactive pollutant.	User inputs single particle size (and density) for use in calculating terminal velocity for particulates. Treats three types of sand (uniform, naturally graded, wide size range) and single saltation and suspension diameters (and single density) for windblown sources. (4)[b]
CDM	Not applicable; model designed for primary pollutants.	Not treated explicitly. (7)[b]
Single Source[c] (CRSTER)	Not applicable; model designed for primary, unreactive pollutant.	Not treated explicitly. (7)[b]
DIFKIN[d]	Treats emissions of CO, NO, and reactive hydrocarbons. Emissions of NO_x in inventory assumed to be entirely NO_2; converted internally entirely into NO. Hydrocarbons in inventory assumed to be total hydrocarbons; reactive fraction of mobile source hydrocarbon emissions assumed to be 70.4% by weight. Stationary source hydrocarbons assumed to be 100% reactive. (4,5)[a] Program option: User directly input fluxes up to three arbitrary pollutants (for applications not involving photochemical smog). (Not applicable: chemical reaction not treated.)	Not applicable; model designed for gaseous pollutants.
HIWAY	Not applicable; model designed to treat primary, unreactive pollutant.	Not applicable; model designed for gaseous pollutants.
RAM	Not applicable; model designed to treat primary, unreactive pollutant.	Not treated explicitly. (7)[b]
SAI[d]	Treats emissions of reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2, and CO. User inputs mobile source emissions of hydrocarbons, NO_x, and CO. Mobile source hydrocarbon emissions split internally into 67.4% (mole fraction) reactive fraction and 32.6% unreactive fraction. Mobile source NO_x emissions assumed to be 99% NO_2; converted internally to NO. User inputs stationary source (both point and area) emissions of reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2 and CO. (4,5)[a]	Not applicable; model designed for gaseous pollutants.
STRAM	Treats two compounds; one is assumed to be SO_2 the other, sulfate ($SO_4^{=}$). (4)[a]	Not treated explicitly. (7)[b]
Valley	Treats only one compound. Capable of treating at most one compound or a single representative compound in cases where chemical reactions occur. (6)[a]	Not treated explicitly. (7)[b]

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[a] Numbers in parentheses refer to treatments of chemical composition in Table 5.3.

[b] Numbers in parentheses refer to treatments of size distribution in Table 5.3.

[c] CRSTER should be used only when receptor height is below stack height.

[d] Designed specifically to treat photochemical oxidants.

Table B.5. Treatment of Plume Rise by Reference Models

Reference Model	Treatment of Plume Rise[a]	Treatment of Downwash/Fumigation
APRAC-1A	Not treated explicitly. (5)	Does not treat either.
ATM	For each point source, user inputs a value representing the product of plume rise with 1) wind speed and 2) the cube root of the wind speed for neutral and stable conditions, respectively. Maximum effective stack height limited to 1500 m. (Modified 4b) No plume rise for area and line sources; a constant value could be included in user-supplied release height. (4e,5) Uses "tilted plume" approximation to treat deposition of particulates (see Table 5.13).	Does not treat either.
CDM	Briggs' 2/3 (1971) neutral/unstable formula used for point sources. If (stack height) + (plume rise) exceeds mixing height, ground level concentrations are assumed equal to zero. (Modified 4a) As an alternative to Briggs', the user may input a value of the product of plume rise and wind speed for each point source. (Alternative : 4e) No plume rise calculated for area sources; a constant value could be included in user-supplied release height. (4e,5)	Does not treat either.
Single Source[b] (CRSTER)	Briggs' (1971, 1972) final plume rise formulae; plume rise not treated as a function of downwind distance. If plume height exceeds mixing height, concentrations further downwind assumed equal to zero. (4a)	Does not treat either.
DIFKIN	Not treated explicitly. (5)	Does not treat either.
HIWAY	Not treated explicitly but could be included in release height. (4e,5)	Does not treat either.
RAM	Uses Briggs' (1971, 1972) downwind distance dependent plume rise formulae for point sources. If plume height exceeds mixing height, ground level concentrations assumed zero. (Modified 4a) No plume rise calculated for area sources; could be included in release height. (4e,5)	Does not treat either.
SAI	Uses Briggs' formulae (1971) for point sources (power plants only) to determine if plume penetrates inversion. If plume height exceeds mixing height, emissions from source are not treated. Other power plant emissions included in ground level flux. (4a) Treats emissions as ground level fluxes; plume rise not treated explicitly. (5)	Does not treat either.
STRAM	Not treated explicitly; could be included in release height for each source. (4e,5)	Does not treat either.
Valley	Uses Briggs' (1971, 1972) plume rise formulae for both point and area sources. Option: A single constant plume rise value may be input for any or all sources. (Option: 4e) If plume height exceeds mixing height: A. For long-term calculations, ground level concentrations assumed equal to zero. B. For short-term calculations, maximum plume height is limited to the mixing height. (Modified 4a)	Does not treat either.

[a] Numbers in parentheses refer to treatments as given in Table 5.4.

[b] CRSTER should be used only if receptor height is below stack height.

Table B.6. Treatment of Horizontal Wind Field by Reference Models

Reference Model	Method of Treatment[a]
APRAC-1A	Constant, uniform wind speed and direction assumed for each of a sequence of hours. Wind speed, direction values input by user. (4,7,2) Street canyon sub-model: specific positional and height dependence built in; constant in time. (3,5,4)
ATM	Constant, uniform wind speed and direction. Climatological treatment with sixteen wind sectors, 6 wind speed classes used. (4,7,3)
CDM	Constant, uniform wind speed and direction. Wind speed is estimated value at release height, correction from value at reference height (10m) dependent only on stability class. Climatological treatment with sixteen wind sectors, 6 wind speed classes used. (4,6,3)
Single Source[b] (CRSTER)	Constant, uniform wind speed and direction assumed for each of a sequence of hours. Wind speed, direction values input by user;[c] speed corrected for release height depending on stability class. (4,7,2b)
DIFKIN	Trajectory model. Wind speed and direction specified for each of a sequence of time steps at point on a horizontal grid, interpolated from nearest 1, 2, or 3 surface measurements. Discrete user-specified number (n) of wind directions allowed, 4 ≤ n ≤ 99; Arbitrary wind speed values allowed. Wind speed, direction independent of height. (2,7,2b) Program option allows direct user input of trajectory.
HIWAY	Constant, uniform wind speed and direction. Wind speed, direction values input by user for the hour of interest. (4,7,4)
RAM	Constant, uniform wind speed and direction assumed for each of a sequence of hours. Wind speed, direction values input by user.[d] Wind speed is modified to correspond to value at release height, modification dependent only on stability class. (4, modified 6,2b)
SAI	Fixed grid model. Wind speed and direction specified for each of a sequence of hours at point on a horizontal grid, interpolated from surface measurements. Arbitrary wind speed, direction values allowed. Wind speed, direction independent of height. (2,7,2b)

Table 5.6 (Cont'd)

Reference Model	Method of Treatment[a]
STRAM	Trajectory model. Wind speed and direction specified at 12-hour intervals on a horizontal grid, interpolated from radiosonde measurements. Wind speed and direction interpolated in time between measurements. Arbitrary wind speed, direction values allowed. Wind speed, direction independent of height. (2,7,2a)
VALLEY	1. Long-term calculations: Constant, uniform wind direction and speed, except for stable conditions over complex terrain for which implicit treatment of locational height dependencies is implemented - effect of plume deflection by terrain is accounted for by linear interpolation of centerline concentrations between 10-m value at impingement point and zero at 400 m above impingement point. (6,8,5) Climatological treatment with 16 wind sectors, 6 wind speed classes. Wind speed class values input by user, used without correction for height. (4,7,3) 2. Short-term techniques: Same as long-term except primary intent is for use where terrain elevations approach or exceed plume height. In such cases, intent is for user to input single wind speed, e.g. 2.5 mps, for typically one wind direction(and stability).

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[a] Numbers in parentheses refer to the dependence on horizontal location, height above ground, and time as given in Table 5.5.

[b] CRSTER should be used only if the receptor height is less than the stack height.

[c] Assumes wind directions given to nearest 10°, randomizes wind direction by addition of the amount (n-4)° where n is a random number between 0 and 9.

Table B.7. Treatment of Vertical Wind Field by Reference Models

Reference Model	Method of Treatment[a]
APRAC-1A	Assumed equal to zero. (4b,4b,3) Street canyon sub-model: specific positional and height dependence built in, assumed constant in time. (3,3,3)
ATM	Assumed equal to zero. (4b,4b,3)
CDM	Assumed equal to zero. (4b,4b,3)
Single Source[b] (CRSTER)	Assumed equal to zero. (4b,4b,3)
DIFKIN	Assumed equal to zero. (4b,4b,3)
HIWAY	Assumed equal to zero. (4b,4b,3)
RAM	Assumed equal to zero. (4b,4b,3)
SAI	Vertical wind speed specified for each of a sequence of hours at points on a three-dimensional grid. Values assumed linearly increasing functions of height, values near surface determined from horizontal wind speed and directions using mass consistency requirements. (2,3,2b)
STRAM	Assumed equal to zero. (4b,4b,3)
Valley	1. Long-term calculations: Assumed equal to zero for stable atmospheric conditions, except for implicit treatment of deflection by terrain above impingement elevation as noted in Table B.6. Implicit treatment for neutral and unstable conditions: plume assumed to remain at a constant height above terrain. No time dependence (4a,4a,3) 2. Short-term calculations (24-hour maximum only): as in long-term calculations for stable conditions. (4b,4b,3)

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[a] Numbers in parentheses refer to the dependence on horizontal location, height above ground, and time as given in Table 5.6.

[b] CRSTER should be used only if the receptor is less than the stack height.

Table B.8. Treatment of Horizontal Dispersion by Reference Models

Reference Model	Classification	Method of Treatment
AFRAC-LA	Semiempirical/sequential (steady-state)	Sector averaging (narrow plume approximation) 45.0° less than 1 km. 22.5° beyond 1 km. Atmospheric stability not treated explicitly. Surface roughness not treated explicitly. (4b,3,3,na)^a
ATM	Semiempirical/climatological (steady-state)	Uniform horizontal distribution assumed within each of 16 22.5° sectors (sector averaging). Atmospheric stability not treated explicitly. Surface roughness not treated explicitly. Averaging time assumed long enough for sector averaging to be valid. (5c,3,2a,na)^a
CDM	Semiempirical/climatological (steady-state)	Uniform horizontal distribution assumed within each of 16 22.5° sectors (sector averaging). Atmospheric stability not treated explicitly. Surface roughness not treated explicitly. Averaging time assumed long enough for sector averaging to be valid. (5c,3,3,na)^a
Single Source^c (CRSTER)	Semiempirical/sequential (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into seven classes. Surface roughness not explicitly treated. One hour averaging time used. (4a,2b,3,3)^a
DIFKIN	Numerical (vertical)/ Semiempirical (horizontal)/dynamic	Narrow plume approximation about calculated trajectory. (3a,3,3,na)^a
HIWAY	Semiempirical/steady-state	Gaussian plume function assumed for each point along line; numerical integration along line. Atmospheric stability divided into six (Pasquill-Gifford) classes. Dispersion coefficients from Zimmerman and Thompson (1975) less than 100m, from Turner (1969) beyond 100m. Level grade mode - initial value of dispersion coefficient set at 3.0 m. Cut section mode - initial value of dispersion coefficient an empirical function of wind speed. Surface roughness not treated explicitly. One hour averaging time used. (4a,2b,3,3)^a
RAM	Semiempirical/sequential (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes. Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user option. Surface roughness not treated explicitly. One hour averaging time used. Point sources: (4a,2b,3,3)^a; Area sources: (4b,3,3,na)^a
SAI	Numerical/dynamic	Numerical solution of advection-diffusion equation in three dimensions. Horizontal eddy diffusivity value assumed uniform and constant and is fixed in the code. (1b,3,3,3)^a,(4,4,3)^b
STRAM	Semiempirical/dynamic	Crosswind distribution about calculated trajectory assumed Gaussian. Atmospheric stability divided into six (Pasquill-Gifford) classes. Same stability class assumed to hold over entire region of interest. Surface roughness not treated explicitly. Dispersion coefficients determined by integration of expressions for rates of change; based on Turner (1969) up to 100km, Heffter and Ferber (1975) beyond 100 km. Averaging time specified by user. (3b,2b,3,3 and 3)^a
Valley	Semiempirical/climatological (steady-state)	Long-term calculations: Uniform horizontal distribution assumed within each of 16 22.5° sectors (sector averaging). Atmospheric stability not treated explicitly. Surface roughness not treated explicitly. Averaging time assumed long enough for sector averaging to be valid. (5c,3,3,na)^a
	Semiempirical/steady-state	Short-term calculations (24-hour maximum only): Uniform horizontal distribution assumed within each of 16 22.5° sectors (sector averaging). Atmospheric stability not treated explicitly. Surface roughness not treated explicitly. Averaging time: 24 hours. (5c,3,3,na)^a

Table B.8 (Cont'd)

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[a] Numbers in parentheses refer to treatments listed in Tables 5.7, 5.8, 5.9 and 5.10 respectively. The user should refer to the appropriate section (numerical or semiempirical) of Table 5.10 according to the model classification.

[b] Numbers in parentheses refer to the dependence of the horizontal eddy diffusivity on horizontal location, height above ground, and time as given in Table 5.11.

[c] CRSTER should be used only when the receptor is below stack height.

Table 5.9. Treatment of Vertical Dispersion by Reference Models

Reference Model	Classification	Method of Treatment
APRAC-1A	Semiempirical/sequential (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into six (modified Pasquill-Gifford) classes. Dispersion coefficient modified from McElroy and Pooler (1968). Surface roughness not treated explicitly. Downwind distance dependence of dispersion coefficient assumed ax^b for purposes of doing analytic integration. In street-canyon submodel, semiempirical function of wind speed, street width, and direction is used. (4a,2b,3,3)[a]
AQDM	Semiempirical/climatological (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes. Dispersion coefficients from Turner (1969) or Hosker (1973), (user option). Surface roughness characterized by a user-specified roughness parameter (Hosker dispersion coefficients only) (4a,2b,2a,3)[a]
CDM	Semiempirical/climatological (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes, with neutral stability divided into day and night cases. Stability class decreased by one class (more unstable) for area sources. Surface roughness not treated explicitly. Dispersion coefficients from Turner (1969). (4a,2a,3,3)[a]
Single Source[c] (CRSTER)	Semiempirical/sequential (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into seven (P-G) classes. Surface roughness not treated explicitly. Dispersion coefficients from Turner (1969). (4a,2b,3,3)[a]
DIFKIN	Numerical (vertical)/ Semiempirical (horizontal)/ dynamic	Numerical integration of diffusion equation in vertical direction. Vertical eddy diffusivity values specified hourly by user at user-defined discrete heights above ground. (1b,2a,3,2)[a], (4,3,2b)[b]
HIWAY	Semiempirical/steady-state	Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes. Dispersion coefficient from Zimmerman and Thompson (1975) less than 100m, from Turner (1969) beyond 100m. Level grade mode - initial dispersion coefficient set at 1.5m. Cut section mode - initial dispersion coefficient an empirical function of wind speed. (4a,2b,3,3)[a]
RAM	Semiempirical/sequential (steady-state)	Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes. Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user's option. Surface roughness not treated explicitly. (4a,2b,3,3)[a]
SAI	Numerical/dynamic	Numerical solution of advection-diffusion equation in three dimensions. Vertical eddy diffusivity an empirical function of wind speed and height above ground. (1b,3,3,2)[a], (4,3,2b)[b]
STRAM	Semiempirical/dynamic	Two options are available to the user: 1) Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes. Same stability class assumed to hold over entire region of interest. Surface roughness not treated explicitly. Dispersion coefficients determined by integration of expressions for rates of change; based on Turner (1969) up to 100 km, Heffter and Ferber (1975) beyond 100 km. 2) Uniform vertical distribution up to mixing height assumed. (3b or 3d,2b,3,3)[a]
Valley[a]	Semiempirical/climatological (steady-state)	Long-term calculations: Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes. Surface roughness not treated explicitly. Dispersion coefficients from Turner (1969). (4a,2b,3,3)[a] All input stable conditions are treated as neutral in urban option.
	Semiempirical/steady-state	Short-term calculations (24-hour maximum only): Gaussian plume function assumed. One stability class (stable: Pasquill-Gifford "F") used when terrain elevation approaches or exceeds stable plume height. Surface roughness not treated explicitly. Dispersion coefficients from Turner (1969). (4a,2c,3,3)[a] All input stable conditions are treated as neutral in urban option.

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[a] Numbers in parentheses refer to treatments listed in Tables 5.7, 5.8, 5.9 and 5.10, respectively. The user should refer to the appropriate section (Numerical or Semiempirical) of Table 5.10 according to the model classification.

[b] Numbers in parentheses refer to the dependence of the vertical eddy diffusivity on horizontal location, height above ground and time is given in Table 5.11.

[c] CRSTER should be used only when the receptor is below stack height.

Table 5.10 Treatment of Chemistry and Reaction Mechanism by Reference Models

Reference Models	Method of Treatment[a]
APRAC-1A	Not treated explicitly. (7)
ATM	Not treated explicitly. (7)
CDM	Treats only first-order removal processes: exponential decay. Single, constant user-supplied halflife used. (6)
Single Source[b] (CRSTER)	Not treated explicitly. (7)
DIFKIN	Photochemical smog system: (4) Sixteen reactions involving 10 chemical species (NO, Hc, NO_2 O_3, HNO_2, NO_3, N_2O_5, OH, RO_2, CO). Lumping approximation for 2 species (Hc, RO_2). Steady-state approximation for 4 species (NO_3, N_2O_5, OH, RO_2). User specifies NO_2 photolysis rate constant as function of time (up to 300 sequential values). No adjustment made for effects of incomplete turbulent mixing below the resolution of the grid. Program option allows user to prescribe arbitrary chemical reaction mechanism (up to 20 chemical species, up to 20 reactions).
HIWAY	Not treated explicitly. (7)
RAM	Treats only first-order removal process: exponential decay. Single, constant user-supplied halflife used. (6)
SAI	Photochemical smog system: (4) Fifteen reactions involving 10 species (NO, NO_2, O_3, Hc, O, OH, HO_2, RO_2, NO_3, HNO_2). Lumping approximation for 2 species (Hc, RO_2). Steady-state approximation for 6 species (NO_3, O, RO_2, OH, HO_2, HNO_2). NO_2 photolysis rate calculated internally as a function of time. No adjustments made for the effects of incomplete turbulent mixing below the resolution of the grid.
STRAM	SO_2-sulfate aerosol system: SO_2 to sulfate conversion approximated by a first-order process with internally defined value of the rate constant. (6)
Valley	Treats only first-order removal processes: exponential decay. Single, constant user-supplied halflife used. (6)

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[a] Numbers in parentheses refer to treatment numbers in Table 5.12.

[b] CRESTER should be used only if receptor height is less than stack height.

Table 3.11. Treatment of Physical Removal Processes by Reference Models

Reference Model	Method of Treatment
APRAC-1A	Not treated explicitly. (4,5)[a]
ATM	Dry deposition: (2a)[b] Pollutant removal simulated by effective source treatment. Multiplicative factor determined by downwind integration of removal rate. Rate of removal determined from ground-level pollutant concentration and a constant deposition velocity. Deposition velocity (gases) adjusted within internally defined range of values by user-supplied measure of surface roughness, related to extent and type of vegetation cover. Effect of atmospheric stability not treated explicitly. Deposition velocity (particulate matter) is the greater of the gravitational settling velocity or 0.01 m/sec. Tilted plume approximation used for particulate matter if gravitational settling velocity is greater than 0.01 m/sec. (3)[b] Effect on vertical concentration profile not treated explicitly except in tilted plume case. Precipitation scavenging: (2)[c] Exponential decay with constant washout coefficient. Removal occurs only for fraction of time equal to frequency of occurrence of rainfall (input by user); not correlated with any other meteorological variables. Washout coefficient calculated internally from user supplied mean rainfall rate.
CDM	Treats only first-order removal processes; exponential decay. Single, constant user-supplied halflife used. (2b,5)[a]
Single Source[d] (CRSTER)	Not treated explicitly. (4,5)[a]
DIFKIN	Not treated explicitly. (4,5)[a]
HIWAY	Not treated explicitly. (4,5)[a]
RAM	Treats only first-order removal processes: exponential decay. Single, constant user-supplied halflife used. (2b,5)[a]
SAI	Not treated explicitly. (4,5)[a]
STRAM	Dry deposition: (2a)[b] Pollutant removal simulated by effective source treatment. Multiplicative factor determined by downwind integration of removal rate. Rate of removal determined from ground-level pollutant concentration and constant deposition velocity. Deposition velocities for SO_2, sulfate aerosol are fixed in the program at 1.0 and 0.1 cm/sec., respectively. Effects of surface roughness or atmospheric stability not treated explicitly. Effects on vertical concentration profile not treated explicitly. Precipitation scavenging: (5)[c] Not treated explicitly.
Valley	Treats only first-order removal processes: exponential decay. Single, constant user-supplied halflife used. (2b,5)[a]

[a] First number refers to treatments of dry deposition in Table 5.13, second number refers to treatments of precipitation scavenging in Table 5.13.

[b] Numbers refers to treatments of dry deposition in Table 5.13.

[c] Numbers refers to treatments of precipitation scavenging in Table 5.13.

[d] CRSTER should be used only if receptor height is less than stack height.

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Table B.12. Treatment of Background, Boundary and Initial Conditions by Reference Models

Reference Model	Classification	Method of Treatment
		a. Background[a]
APRAC-1A	Semiempirical/sequential (steady-state)	Value calculated for each receptor; box model used to estimate contributions from upwind sources beyond 32 km based on wind speed, mixing height and annual fuel consumption. (2) In street canyon sub-model, contribution from other streets is included in the background. (2)
ATM	Semiempirical/climatological (steady-state)	Not treated explicitly. (3)
CDM	Semiempirical/climatological (steady-state)	Single constant input values for each pollutant. (2)
Single Source[a] (CRSTER)	Semiempirical/sequential (steady-state)	Not treated explicitly. (3)
DIFKIN	Numerical (vertical)/ Semiempirical (horizontal)/dynamic	Not applicable.
HIWAY	Semiempirical/steady-state	Not treated explicitly. (3)
RAM	Semiempirical/sequential (steady-state)	Not treated explicitly. (3)
SAI	Numerical/dynamic	(Treated as a <u>boundary condition</u> on flux at vertical boundaries.)
STRAM	Semiempirical/dynamic	Not treated explicitly. (4)
Valley	Semiempirical/climatological (steady-state)	Long-term calculations: Not treated explicitly. (3)
	Semiempirical/steady-state	Short-term calculations (24-hour maximum only). Not treated explicitly. (3)
		b. Upper Boundary Condition (at Mixing Height)[b]
APRAC-1A	Semiempirical/sequential (steady-state)	Perfect reflection: ignores effect until concentration equals that calculated using box model; uses box model (uniform vertical distribution) thereafter. (Intermediate between 2-3) Mixing height determined from morning radiosonde data and during day, surface temperature variations: Midnight to dawn: constant at pre-dawn value obtained using minimum urban temperature; Dawn to sunset: afternoon maximum temperature used to obtain maximum height; hourly values obtained from surface temperature variations; Sunset to midnight: linear interpolation over time.
ATM	Semiempirical/climatological (steady-state)	Treated implicitly by limiting vertical dispersion coefficient to be no larger than mixing height. (4)
CDM	Semiempirical/climatological (steady-state)	Perfect reflection: no effect until vertical dispersion coefficient equals 0.8 of the mixing height, uniform vertical mixing assumed thereafter. (2)
Single Source[a] (CRSTER)	Semiempirical/sequential (steady-state)	Perfect reflection: method of multiple images treated by summation of series until vertical dispersion coefficient = 1.6× (mixing height); uniform vertical mixing thereafter. (1) Mixing height for a given hour obtained by interpolation of radiosonde data (see Appendix B.4 for algorithm).
DIFKIN	Numerical (vertical)/ Semiempirical (horizontal)/dynamic	Perfect reflection: flux required to be equal to zero at boundary. (3) Mixing height can change at hourly intervals.
HIWAY	Semiempirical/steady-state	Perfect reflection: 1) Stable conditions or mixing height greater than 5000m: assume no effect (treats only reflection from ground); (3) 2) Neutral or unstable conditions with mixing height less than 5000m: method of multiple images treated by summation of infinite series until vertical dispersion coefficient > 1.6 * (mixing height); uniform vertical distribution thereafter. (1)
RAM	Semiempirical/sequential (steady-state)	Perfect reflection: 1) Neutral and unstable conditions: method of multiple images treated by summation of infinite series until σ_z = 1.6*(mixing height); uniform mixing assumed thereafter; (1) 2) Stable conditions: mixing height assumed to have no effect. (3) Mixing height for a given hour obtained interpolation of radiosonde data (see Appendix B.8 for algorithm).
SAI	Numerical/dynamic	Perfect reflection for pollutants within region of interest (turbulent diffusive flux = 0). Allows [illegible]ment of pollutants from above mixing layer. (1)

Table B.12 (Cont'd)

b. (Cont'd)

Reference Model	Classifications	Method of Treatment
STRAM	Semiempirical/dynamic	Two options: 1) Uniform mixing (perfect reflection) (4) or 2) Mixing height assumed to have no effect. (3)
Valley	Semiempirical/climatological (steady-state) and Semiempirical/steady-state	Perfect reflection: 1) Neutral and unstable conditions: perfect reflection; method of multiple images treated by summation of infinite series; (1) 2) Stable conditions: ignores effect of upper boundary, except all input stable conditions treated as neutral in urban option. (3) 3) Input afternoon mixing height internally adjusted according to stability

c. Lower Boundary Condition (at Earth's Surface)[c]

Reference Model	Classification	Method of Treatment
APRAC-1A	Semiempirical/sequential (steady-state)	Perfect reflection; single image source.[f] (Intermediate between 3-4).
ATM	Semiempirical/climatological (steady-state)	Perfect reflection; single image source.[f] (4)
CDM	Semiempirical/climatological (steady-state)	Perfect reflection; single image source.[f] (3)
Single Source[g] (CRSTER)	Semiempirical/sequential (steady-state)	Perfect reflection in plane at same height as receptor; multiple image sources.[f] (2)
DIFKIN	Numerical/(vertical)/ Semiempirical (horizontal)/ dynamic	Emissions treated as upward fluxes at the ground. Implicit perfect reflection; no adjustment made to fluxes to account for removal. (3)
HIWAY	Semiempirical/steady-state	Perfect reflection by method of multiple images.[f] (2)
RAM	Semiempirical/sequential (steady-state)	Perfect reflection by method of multiple images.[f] (2)
SAI	Numerical/dynamic	All non-point source (power plant) emissions treated at upward fluxes at ground. Implicit perfect reflection; no adjustment made to fluxes to account for removal. (3)
STRAM	Semiempirical/dynamic	Perfect reflection by method of single image source.[f] (4).
Valley	Semiempirical/climatological (steady-state) and Semiempirical/steady-state	Perfect reflection by method of single image source in stable cases and multiple image source in neutral and unstable cases.[f] (stable: 4; other: 3).

d. Boundary Condition at Vertical Sides[d]

APRAC-1A	Semiempirical/sequential (steady-state)	Not applicable; treated as background.
ATM	Semiempirical/climatological (steady-state)	Not applicable; treated as background.
CDM	Semiempirical/climatological (steady-state)	Not applicable; treated as background.
Single Source[g] (CRSTER)	Semiempirical/sequential (steady-state)	Not applicable; treated as background.
DIFKIN	Numerical (vertical)/ Semiempirical (horizontal)/ dynamic	Not treated explicitly; horizontal uniformity assumed. (3)
HIWAY	Semiempirical/steady-state	Not applicable; treated as background.
RAM	Semiempirical/sequential (steady-state)	Not applicable; treated as background.
SAI	Numerical/dynamic	Treated as a function of position and elevation; total flux normal to side of region required to be continuous across boundary at each point. (1)
STRAM	Semiempirical/dynamic	Not applicable; treated as background.
Valley	Semiempirical/climatological (steady-state) and Semiempirical/steady-state	Homogeneously [illegible] across 2π/16-radian sector; linear interpolation then effected be[illegible] sector centerlines.

Table B.12 (Cont'd)

e. Initial Conditions[e]		
APRAC-1A	Semiempirical/sequential (steady-state)	Not applicable.
ATM	Semiempirical/climatological (steady-state)	Not applicable.
CDM	Semiempirical/climatological (steady-state)	Not applicable.
Single Source[g] (CRSTER)	Semiempirical/sequential (steady-state)	Not applicable.
DIFKIN	Numerical (vertical)/ Semiempirical (horizontal)/ dynamic	User specifies arbitrary initial concentrations for all species not treated by steady-state assumption (all but NO_3, N_2O_5, HO_2, OH) at each discrete height above ground. (1)
HIWAY	Semiempirical/steady-state	Not applicable.
RAM	Semiempirical/sequential (steady-state)	Not applicable.
SAI	Numerical/dynamic	Mean initial concentrations of 6 species (reactive HC, NO, O_3, NO_2, CO, unreactive HC) specific for each grid cell. (1)
STRAM	Semiempirical/dynamic	Not applicable.
Valley	Semiempirical/climatological (steady-state) and Semiempirical/steady state	Not applicable.

[a] Numbers in parentheses refer to treatments of background given in Table 5.14a for models having the same classification as the reference model.

[b] Numbers in parentheses refer to treatments of the upper boundary condition (at the mixing height) given in Table 5.14b for models having the same classification as the reference model.

[c] Numbers in parentheses refer to treatments of the lower boundary condition (at the earth's surface) given in Table 5.14c for models having the same classification as the reference model.

[d] Numbers in parentheses refer to treatments of the boundary condition at vertical sides given in Table 5.14d for models having the same classification as the reference model.

[e] Numbers in parentheses refer to treatments of initial conditions given in Table 5.14e for models having the same classification as the reference model.

[f] See also the description of the treatment of the upper boundary condition.

[g] CRSTER should be used only when the receptor height is below the stack height.

Table B.13 Treatment of Temporal Correlations by Reference Models

Reference Model	Type of Treatment	Degree of Temporal Resolution and Quantities Correlated[a]
APRAC-1A	Sequential; correlations automatic.	Emissions a function of hour of the day and day of the week. Wind speed, direction, stability and mixing height are functions of hour of the day. (1a)
ATM	Non-sequential (climatological); limited correlation between some meteorological parameters.	Wind speed, wind direction, stability correlated via stability wind rose. Emission rates constant, not correlated with other parameters. Mixing height correlated with stability class through limits on σ_z, different limit for each class. (2b)
CDM	Non-sequential (climatological); limited correlation between total emission rate and meteorological parameters.	Wind speed, wind direction, stability correlated via stability wind rose. Mixing height adjusted according to stability class; Class A—1.3 x (afternoon climatological value). Class D (night)—average of morning and afternoon climatological values. Class E—morning climatological value. Class B, C, D (day)—appropriate climatological value. Emission rates: day-night variations allowed; all sources vary by same factor. (2b)
Single Source[b] (CRSTER)	Sequential; correlations automatic for meteorological parameters.	User supplies hourly values of wind speed, wind direction, height, and other meteorological variables required ing stability class and plume rise. ion variation allows limited emission-meteorology (1c)

Table 3.13 (Cont'd)

Reference Model	Type of Treatment	Degree of Temporal Resolution and Quantities Correlated[a]
DIFKIN	Sequential treatment up to 24 hours; correlations automatic.	Parameters updated each hour: mobile emissions from each grid square, wind speed and direction (trajectory); vertical diffusivity values at each height, mixing height, NO₂ photolysis rate constant. Update based on user input values. (1b)
HIWAY	Not applicable.	Not applicable: user inputs specific parameter values for the hour of interest.
RAM	Sequential treatment; correlations automatic for meteorological parameters.	User supplies hourly values of wind speed, wind direction, mixing height, and other meteorological variables required for determination of stability class and plume rise. Emission rates constant, not correlated with other parameters. (1c)
SAI	Sequential treatment up to 24 hours; correlations automatic.	Parameters updated every hour; mobile source emission for each ground-level grid square, point source (power plant) emissions, wind speed and direction, mixing height at every vertical column of grids, vertical eddy diffusivity at every vertical interface of grid cells, incoming fluxes at boundaries, NO₂ photolysis rate constant. Update based on user input values. (1a)
[illegible]	Sequential treatment; correlations automatic for meteorological variables.	Stability class and mixing height changed each hour based on user-input values. Horizontal components of windfield updated at 12 hour intervals based on radiosonde data; changed each hour by interpolation between updates. Emission rates constant; not correlated with other parameters. (1c)
Valley	Non-sequential (climatological); limited correlation for meteorological variables.	Wind speed, direction, stability correlated via stability wind rose. Emission rates constant; not correlated with other parameters. Mixing height adjusted according to stability class: (2b) •Long-term mode Class A: 1.5x (afternoon value) Class B,C: Afternoon value. Class D(day): Afternoon value for 40% of cases. Class D(night): Urban—0.5x((afternoon value) + (nighttime value)) for 40% of cases. Rural—0.5x(afternoon value for 40% of cases. Class E,F: Urban—nighttime mixing height (dispersion treated as Class D). Rural—No limit. •Short-term mode Class A,B,C,D: Afternoon value. Class E,F: Same as long-term mode.

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[a] Numbers in parentheses refer to treatment numbers in Table 3.13.

[b] CRSTER should be used only when receptor height is below stack height.

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B.2 REFERENCE MODEL ABSTRACTS AND EQUATIONS

This appendix provides abstracts and working equations for each reference model identified and suggested for use with this workbook. A glossary of symbols is given at the end of this appendix.

B.2.1 CDM

Reference: Busse and Zimmerman (1973), Brubaker, et. al. (1977).

Abstract: The Climatological Dispersion Model (CDM) is a climatological steady-state Gaussian plume model for determining long-term (seasonal or annual) arithmetic average pollutant concentrations at any ground level receptor in an urban area.

A statistical model based on Larsen (1968) is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

$$\chi_{\text{point}} = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{\ell=1}^{6} \sum_{m=1}^{6} Q_n \, \phi_{k_n \ell m} \, S_{\ell m}(\rho_n)/\rho_n$$

$$\chi_{\text{area}} = \frac{16}{2\pi} \int \left[\sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m} \, S_{\ell m}(\rho) \right] d\rho$$

$$\text{with } q_k(\rho) = \int_{\text{Sector } k} Q(\rho,\theta)\,d\theta$$

$$S_{\ell m}(\rho) = \frac{2}{\sqrt{2\pi}\,\sigma_z\,u_\ell} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \exp\left[-\frac{0.692\rho}{u_\ell T_{1/2}}\right] \quad \text{for } \sigma_z \le 0.8L$$

$$S_{\ell m}(\rho) = \frac{1}{u_\ell L} \exp\left[-\frac{0.692\,\rho}{u_\ell T_{1/2}}\right] \quad \text{for } \sigma_z > 0.8L$$

$\sigma_z = a\rho^b$; a, b = functions of stability class (m) and downwind distance (ρ) – three ranges of distance used: 100 – 500, 500 – 5000, 5000 – 50000 m

Calibration: $\chi_{\text{calibrated}} = \chi_{\text{background}} + A + B\,\chi_{\text{uncalibrated}}$

with $\chi_{\text{uncalibrated}} = \chi_{\text{point}} + \chi_{\text{area}}$

Statistical transformation of averaging times for 1-24 hour averages.

B.2.2 RAM

Reference: Hrenko and Turner (1975).

Abstract: RAM is a steady state Gaussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day in urban areas from point and area sources. Level or gently rolling terrain is assumed. Calculations are performed for each hour.

Equations:

Contribution from single upwind area source

$$\chi_A = \frac{Q}{u}\int_{x_1}^{x_2} f\,dx, \quad \text{integral evaluated numerically}$$

x_1, x_2 = points of intersection of ray from receptor through area source in question.

Stable conditions: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_2$

$$\chi_{point} = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_2$$

Neutral or stable conditions with $\sigma_z \leq 1.6L$

$$f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_3$$

$$\chi_{point} = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_3$$

Neutral or unstable conditions with $\sigma_z > 1.6L$

$$f = \frac{1}{L}$$

$$\chi_{point} = \frac{Q}{\sqrt{2\pi}\, uL\sigma_y} g_1$$

In which

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\}$$

Mixing Height Algorithm:

Two different mixing heights can be calculated. One is for basically rural surroundings; the other is for urban locations. The user is given the option to specify which he wants to use. The way in which hourly mixing heights are determined from maximum mixing heights (MXDP) for yesterday (i-1), today (i) and tomorrow (i+1) and minimum mixing height (MNDP) for today (i) and tomorrow (i+1) is depicted in Figure B.1.

For urban mixing height, between midnight and sunrise; if the stability is neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ ①, if stability is stable use $MNDP_i$ ②. For hours between sunrise and 1400, if the hour before sunrise was neutral, interpolate between $MXDP_{i-1}$ and $MXDP_i$ ③. For sunrise to 1400, if the hour before sunrise was stable, interpolate between $MNDP_i$ and $MXDP_i$ ④. For 1400 to sunset, use $MXDP_i$ ⑤. For hours between sunset and midnight; if stability is neutral interpolate between $MXDP_i$ and $MXDP_{i+1}$ ⑥, if stability is stable interpolate between $MXDP_i$ and $MNDP_{i+1}$ ⑦.

For rural mixing height between midnight and sunrise, interpolate between $MXDP_{i-1}$ and $MXDP_i$ ⑧. For hours between sunrise and 1400, if the hour before sunrise was neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ ⑨. For sunrise to 1400, if the hour before sunrise was stable, interpolate between 0 and $MXDP_i$ ⑩. For 1400 to sunset, use $MXDP_i$ ⑪. For sunset to midnight, interpolate between $MXDP_i$ and $MXDP_{i+1}$ ⑫.

B.2.3 Single Source (CRSTER)

Reference: EPA (1977).

Abstract: Single Source (CRSTER) is a steady state Gaussian plume technique applicable where terrain elevation does not exceed physical stack height. The purposes of the technique are: 1) to determine the maximum 24-hour concentration from a single point source of up to 19 stacks for one year, 2) to determine the meteorological conditions which cause the maximum concentrations, and 3) to store concentration information useful in calculating frequency distributions for various averaging times. The concentration for each hour of the year is calculated and midnight-to-midnight averages are determined for each 24-hour period.

Equations:

$$\chi = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 g_3 \qquad \text{for } \sigma_z \leq 1.6L$$

$$\chi = \frac{Q}{2\pi u L \sigma_y} g_1 \qquad \text{for } \sigma_z > 1.6L$$

χ = 0 (stability class 7)

L = constant, independent of downwind distance

D = (stack height + plume rise) – (difference in elevation between receptor and base of stack)

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{2nL-D}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2nL+D}{\sigma_z}\right)^2\right]\right\}$$

<u>Mixing Height Algorithm:</u>

Two different mixing heights can be calculated. One is for basically rural surroundings, the other is for urban locations. The user is given the option to specify which he wants to use. The way in which hourly mixing heights are determined from maximum mixing heights (MXDP) for yesterday (i-1), today (i) and tomorrow (i+1) and minimum mixing height (MNDP) for today (i) and tomorrow (i+1) is depicted in Figure 3.2.

For urban mixing height between midnight and sunrise; if the stability is neutral interpolate between MXDP$_{i-1}$ and MXDP$_i$ ①, if stability is stable use MNDP$_i$ ②. For hours between sunrise and 1400, if the hour before sunrise was neutral, interpolate between MXDP$_{i-1}$ and MXDP$_i$ ③. For sunrise to 1400, if the hour before sunrise was stable, interpolate between MNDP$_i$ and MXDP$_i$ ④. For 1400 to sunset, use MXDP$_i$ ⑤. For hours between sunset and midnight; if stability is neutral interpolate between MXDP$_i$ and MXDP$_{i+1}$ ⑥, if stability is stable interpolate between MXDP$_i$ and MNDP$_{i+1}$ ⑦.

For rural mixing height between midnight and sunrise, interpolate between MXDP$_{i-1}$ and MXDP$_i$ ⑧. For hours between sunrise and 1400, if the hour before sunrise was neutral interpolate between MXDP$_{i-1}$ and MXDP$_i$ ⑨. For sunrise to 1400, if the hour before sunrise was stable, interpolate between 0 and MXDP$_i$ ⑩. For 1400 to sunset, use MXDP$_i$ ⑪. For sunset to midnight, interpolate between MXDP$_i$ and MXDP$_{i+1}$ ⑫.

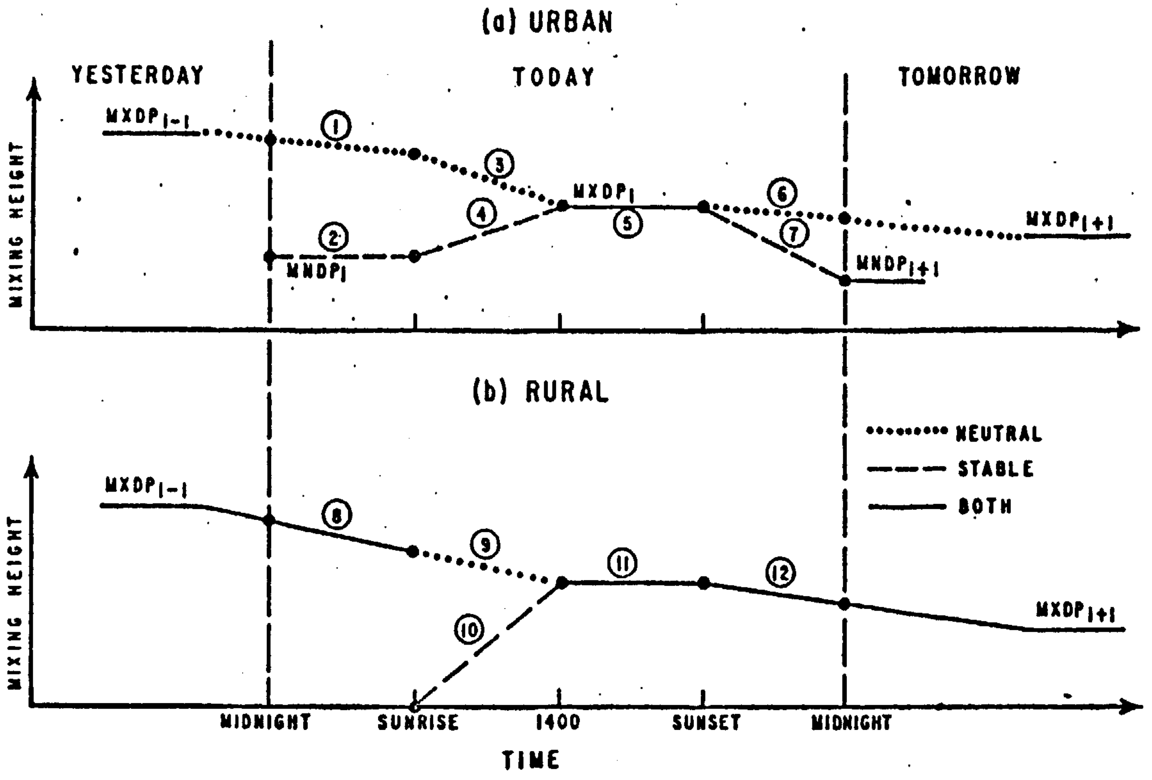


Figure B.1. Mixing Height [illegible]orithm Used in RAM

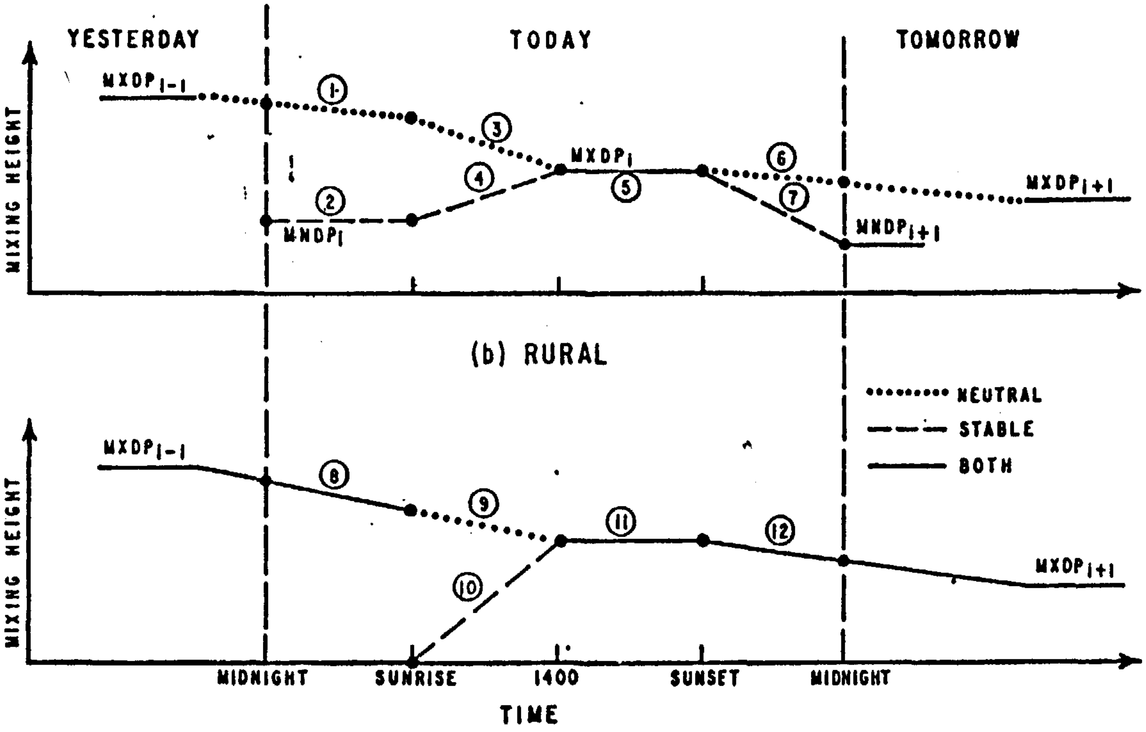


Figure B.2. Mixing Height Algorithm Used in CRSTER

B.2.4. Valley

Reference: Burt (1977).

Abstract: Valley is a climatological, Gaussian model whose primary intended use is the estimation of the maximum 24-hour SO_2 and TSP concentrations at ground level from single facilities in rural complex terrain, although annual average SO_2 and TSP concentrations may also be estimated and flat terrain applications are possible.

Equations:

- Long-term calculations:

$$\chi = \sum_{n=1}^{N} \chi_n \text{ ,where}$$

$$\sum_{1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m}\, \theta_{km}\, \chi_{k\ell mn}$$, where θ_{kn} is a function of crosswind distance of the receptor from the mean position of the plume from source n for direction k, and where for:

Neutral or unstable conditions -

$$\chi_{k\ell mn} = \frac{16}{2\pi \rho_n} \frac{Q_n}{u_\ell} g_3 \exp -\left[\frac{0.693\rho_n}{u_\ell T_{1/2}}\right]$$

$$g_3 = \frac{2}{\sqrt{2\pi}\,\sigma_{zm}} \sum_{i=-5}^{5} \exp\left[-\frac{1}{2}\left(\frac{2iL_m + H_{\ell mou_\ell}}{\sigma_{zm}}\right)^2\right]$$

for $\sigma_{zm} \leq 2L_m$

$$g_3 = \frac{1}{L_m} \text{ for } \sigma_{zm} > 2L_m$$

$$\chi_{k\ell mn} = 0 \text{ if } H_{\ell mou_\ell} > L_m$$

Stable conditions -

$$\chi_{k\ell mn} = \frac{16}{2\pi\rho_n} \frac{Q_n}{u_\ell} \frac{2}{\sqrt{2\pi}\sigma_{zm}} \exp\left[-\frac{1}{2}\left(\frac{H_{\ell m o u}}{\sigma_{zm}}\right)^2\right] \exp\left[-\frac{0.693\rho_n}{u_\ell T_{1/2}}\right]$$

Define D = (stack height + plume rise) - (receptor elevation)

if $D \geq 10$ meters, set $H = D$

if $D < 10$ meters, set $H = 10$ meters and interpolate concentration linearly to zero at a height of 400 meters above (stack height + plume rise).

- Short-term calculations:

(Maximum 24-hour concentration for a single elevated point source.)

$$\chi = \frac{6}{24} \chi_{k\ell mn}$$

with $\chi_{k\ell mn}$ given by the stable conditions formula on the preceding page, and with

ℓ = wind speed class index corresponding to $u_\ell = 2.5$ meter/sec, and.

m = 6 (Pasquill-Gifford "F" stability class).

k may be assigned the full range from 1 to 16, or any part(s) thereof, depending upon the relative location of sources and receptors. If k, ℓ, m or n assumes multiple values, then a summation must be effected as in long-term concentrations above; in this case, H and σ_z should be subscripted with ℓ and/or m, as appropriate. This is not the recommended method of application.

$H_{\ell m o u}$ is reassigned the value of the adjusted L_m if the calculated or assigned $H_{\ell m o u} > L_m$.

B.2.5. ATM

Reference: Culkowski and Patterson (1976).

Abstract: The Atmospheric Transport Model (ATM) is a climatological steady-state Gaussian plume model for use in mesoscale range (up to 50 km) modeling. This model includes the effect of surface roughness on dispersion coefficients, treats dry deposition and precipitation scavenging, and treats gravitational settling of heavy particulates using a tilted plume approximation. The model is primarily intended for calculating monthly averages but averages for other time periods can be estimated by the use of appropriate climatological data. Although the treatment of ATM is comprehensive in the Workbook, the model should only be used for point source deposition applications at this time.

Equations:

$$\chi_{point} = \sum_{1}^{N} \sum_{\ell=1}^{8} \sum_{m=1}^{6} \overline{Q}_{n\ell m}(\rho_n)\phi_{k_n \ell m}\, S_{\ell m}(\rho_n)/\rho_n$$

with $\overline{Q}_{n\ell m}(\rho_n) = Q_n\left[f_w \exp(-\lambda\rho_n/u_\ell) + \exp\left[-(v_g/u_\ell)\, f_m(\rho_n)\right]\right]$

= effective source strength

= true source strength modified by depletion of pollution due to deposition and washout at distances less than ρ_n.

λ = washout coefficient

= $5.55\left[\text{Rainfall rate (mm/hr)}\right]^{0.6}$

v_g = dry deposition velocity (meter/sec)

$$f_m(\rho_n) = \sqrt{2/\pi}\int_0^{\rho_n}\left(\frac{1}{\sigma_z}\right) \exp(-H^2/2\sigma_z^2)\,dx$$

f_w = fraction of the time washout occurs

$$S_{\ell m}(\rho_n) = \frac{2.032}{\sigma_z u_\ell} \exp(-H^2/2\sigma_z^2)$$

σ_z = vertical dispersion coefficient, a function of stability class (m) and downwind distance (ρ_n)

The equations for the emission rate from a windblown source are quite complex and will not be given here.

B.2.6. STRAM

Reference: Haleu, et. al. (1977).

Abstract: STRAM (Source-Transport-Receptor Analysis Model) is a trajectory model using a Gaussian crosswind pollutant distribution designed to estimate ground-level concentrations of pollutants over source-receptor distances of up to approximately 1000 km. STRAM is designed to treat SO_2 emissions from several elevated point sources and the conversion of SO_2 to sulfate aerosol.

Equations:

(1) Unlimited mixing height case:

$$C_i = \frac{\Omega_i(x)}{2\pi\sigma_y\sigma_z u} \exp(-y^2/2\sigma_y^2)\left\{\exp\left[-\frac{(z-h)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2\sigma_z^2}\right]\right\}$$

$$\frac{d\Omega_i}{dx} = R_i - \frac{\lambda_i\Omega_i}{u} - \sqrt{2/\pi}\left(\frac{\Omega_i v_{di}}{\sigma_z u}\right) \exp(-h^2/2\sigma_z^2)$$

$\Omega_i = Q_{oi}$ = the emission rate of the ith source at $x = 0$.

(2) For a limited mixing Height (L):

$$C_i = \frac{\Omega_i(x)}{\sqrt{2\pi}\, uL\sigma_y} \exp(-y^2/2\sigma_y^2)$$

$$\frac{d\Omega_i}{dx} = R_i - \frac{\lambda_i \Omega_i}{u} - \frac{\Omega_i v_{di}}{uL}$$

$\Omega_i = Q_{oi}$ at $x = 0$.

Where C_i = ground level concentration of species i.

Ω_i = total mass of species i in the plume passing a downwind plane per unit time

$$R_i = \int_0^{\infty} \int_{-\infty}^{\infty} r_i(x,y,z)\,dy\,dz$$

r_i = rate of gain (or loss) of species i by chemical reaction

λ_i = washout coefficient for species i

v_{di} = dry deposition velocity for species i.

B.2.7. APRAC-1A

Reference: Ludwig and Mancuso (1972) and Ludwig and Dabbert (1972).

Abstract: APRAC is a model which computes hourly average carbon monoxide concentrations for any urban location. The model calculates contributions from dispersion on various scales: extraurban, mainly from sources upwind of the city of interest; intraurban, from freeway, arterial, and feeder street sources; and local, from dispersion within a street canyon. APRAC requires an extensive traffic inventory for the city of interest.

Equations:

Extraurban - $\chi_e = \dfrac{5.15 \times 10^{-11}\ F}{uL}$; F = annual fuel consumption within 22.5° sector extending from 32 km to 1000 km upwind of receptor.

Intraurban - $\chi_{ij} = \dfrac{0.8Q_i}{ua_{ij}} \left(\dfrac{x_{i+1}^{1-b_{ij}} - x_i^{1-b_{ij}}}{1-b_{ij}} \right)$ until this expression equals

the "box model value" $\dfrac{Q_i}{uL}\left(x_{i+1} - x_i\right)$

Thereafter the box model formula is used.

i = upwind area segment label

j = stability class label

a_{ij} and b_{ij} from $(\sigma_z)_{ij} = a_{ij}\, x^{b_{ij}}$ for x within segment i

Street Canyon - Lee side $\chi_L = \dfrac{KQ_s}{(u+0.5)\ \left[(x^2 + z^2)^{\frac{1}{2}} + L_o\right]}$

Windward side $\chi_W = \dfrac{KQ_s\ (B-z)}{(u+0.5)\ SB}$

Intermediate wind direction $\chi_I = \frac{1}{2}(\chi_L + \chi_W)$ (less than ±30° from street direction).

In which

x = horizontal distance from traffic lane

z = height above pavement

K = constant ≈7

L_o = vehicle size ≈2 meters

u = rooftop wind speed

Q_s = CO emission rate/meter

S = street width

B = average building height ≈38.8 meters

B.2.8. HIWAY

Reference: Zimmerman and Thompson (1975).

Abstract: HIWAY is a Gaussian plume model that computes the hourly concentrations of non-reactive pollutants downwind of roadways. It is applicable for uniform wind conditions and level terrain. Although best suited for at-grade highways, it can also be applied to depressed highways (cut sections).

Equations:

$\chi = \dfrac{q}{u} \displaystyle\int_0^D f\,d\ell$ integral along length of line segment, evaluated using trapezoidal rule.

q = CO emission rate/unit length

for stable conditions or if mixing height $L \geq 5000$ m

$$f = \frac{1}{2\pi\sigma_y\sigma_z}\, g_1 g_2,$$

for neutral or unstable conditions, with $\sigma_z \leq 1.6\ L$

$$f = \frac{1}{2\pi\sigma_y\sigma_z}\, g_1 g_3\,,$$

for neutral or unstable conditions, with $\sigma_z > 1.6L$

$$f = \frac{1}{\sqrt{2\pi}\ \sigma_y L}\, g_1$$

with

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = 2$$

$$g_3 = 2\sum_{n=-\infty}^{+\infty} \exp\left[-\frac{1}{2}\left(\frac{2nL}{\sigma_z}\right)^2\right]$$

B.2.9. DIFKIN

Reference: Martinez, et.al. (1973).

Abstract: The DIFKIN (Diffusion/Kinetics) model is a numerical/dynamic (trajectory) model for photochemical smog simulation. It determines the trajectory of an air parcel across an emission grid network and calculates pollutant concentrations as functions of time. The model obtains concentrations and fluxes at up to ten mesh points between ground level and the top of the mixing layer.

Equations:

DIFKIN numerically solves the vertical diffusion equation

$$\frac{\partial c_\ell}{\partial t} = \frac{\partial}{\partial z}\left(K_V \frac{\partial c_\ell}{\partial z}\right) + R_\ell \quad \text{for } \ell = 1, 2, \ldots, p$$

Along a trajectory determined from surface wind measurements, subject to the following initial and boundary conditions:

A. Initial Conditions

$C_\ell (z, t_{\text{initial}}) = f_\ell(z)$ = initial concentration distribution for species ℓ,

B. Boundary Conditions

(1) $z = 0$ (at ground level)

$$-K_V \frac{\partial c_\ell}{\partial z} = q_\ell(t)$$ (perfect reflection plus addition of emissions from ground level flux)

(2) $z = L(t)$ (at mixing height)

$$-K_V \frac{\partial c_\ell}{\partial z} = 0$$ (perfect reflection)

where c_ℓ = mean concentration of species ℓ

R_ℓ = rate of production (or depletion) of species ℓ through chemical reaction

K_V = vertical eddy diffusivity, a function of height z.

$q_\ell(t)$ = ground-level flux of species ℓ

B.2.10. SAI

Reference: Reynolds (1973).

Abstract: The SAI model is a numerical/dynamic model for studying the dispersion of photochemical pollutants, employing a fixed grid coordinate system and a finite difference solution of the atmospheric diffusion equation. The model calculates an emission inventory based on extensive traffic input data as well as stationary source emissions. It requires extensive meteorological data including both spatial and temporal variations and uses a kinetic mechanism for photochemical smog involving fifteen chemical reactions and ten chemical species.

Equations:

SAI numerically solves the advection-diffusion equation:

$$\frac{\partial}{\partial t}(\Delta H c_\ell) + \frac{\partial}{\partial x}(u \Delta H c_\ell) + \frac{\partial}{\partial y}(v \Delta H c_\ell) + \frac{\partial}{\partial \rho}(W c_\ell)$$

$$= \frac{\partial}{\partial x}\left(K_H \Delta H \frac{\partial c_\ell}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_H \Delta H \frac{\partial c_\ell}{\partial y}\right)$$

$$+ \frac{\partial}{\partial \rho}\left(\frac{K_V}{\Delta H} \frac{\partial c_\ell}{\partial \rho}\right) + R_\ell \Delta H + S_\ell \Delta H, \quad \ell = 1, 2, \ldots, p$$

where $\Delta H = H(x,y,t) - h(x,y)$ = elevation difference between the mixing height and ground level,

$$W = w - \rho \frac{\partial(\Delta H)}{\partial t}, \text{ and}$$

$$\rho = \frac{z - h(x,y)}{H(x,y,t) - h(x,y)}.$$

subject to the following:

A. Initial Conditions

$c_\ell(x,y,\rho,t_{\text{initial}}) = f_\ell(x,y,\rho)$ = initial concentration distribution fo species ℓ,

B. Boundary Conditions

(1) $\rho = 0$ (at ground level)

$$-\frac{K_V}{\Delta H} \frac{\partial c_\ell}{\partial \rho} = q_\ell(x,y,t)$$ (perfect reflection plus addition of emissions from ground level flux)

(2) $\rho = 1$ (at mixing height)

$$W c_\ell - \frac{K_V}{\Delta H} \frac{\partial c_\ell}{\partial \rho} = W g_\ell \text{ if } W \leq 0$$ (material from outside of region entrained if mixing height is increasing)

$$-\frac{K_V}{\Delta H} \frac{\partial c_\ell}{\partial \rho} = 0 \quad \text{if } W > 0$$ (perfect reflection with no entrainment otherwise)

(3) $x = x_E$ or x_W (along the east or west vertical boundaries)

$$u c_\ell - K_H \frac{\partial c_\ell}{\partial x} = u a_\ell \quad \text{if } \vec{U} \cdot \hat{n} \leq 0$$ (transport wind into region; material advected in from outside)

$$- K_H \frac{\partial c_\ell}{\partial x} = 0 \text{ if } \vec{U} \cdot \vec{n} > 0 \text{ (transport wind out of region)}$$

(4) $y = y_N$ or y_S (along the north or south vertical boundaries)

Similar to (3), except involving v, the y- component of the wind.

where

$\vec{U}$ = horizontal wind vector

$\vec{n}$ = outwardly directed unit vector perpendicular to the vertical boundary

c_ℓ = mean concentration of species ℓ

p = number of species

u,v,w = components of wind in x, y, z directions

K_H, K_V = horizontal and vertical eddy diffusivities

S_ℓ = emission rate of species ℓ from elevated source

R_ℓ = production rate of species ℓ by chemical reaction

q_ℓ = ground-level flux of species ℓ

g_ℓ = concentration of species ℓ above region

ℓ = concentration of species ℓ outside region

x_N, x_S, x_E, x_W = northern, southern, eastern, western boundaries of region

h(x,y) = terrain elevation

H(x,y,t) = elevation of inversion base.

GLOSSARY OF SYMBOLS

A,B	Regression coefficients used in calibration procedures.
h	Stack height
$H_{\ell mou}$	Effective stack height = (stack height) + (plume rise)
k	Wind sector index
k_n	Wind sector index corresponding to the sector containing the n-th source
ℓ	Wind speed class index
L	Mixing height (L_m if a function of stability)
m	Stability class index
n	Point and area source index
N	Total number of point and area sources
Q	Emission rate
Q_n	Emission rate for the n-th source
$T_{1/2}$	Pollutant half-life
u_ℓ	Representative horizontal wind speed for the ℓ-th wind speed class
u,v	Components of horizontal wind speed
w	Vertical wind speed
x	Downwind distance or distance in x-direction
y	Crosswind distance or distance in y-direction
z	Vertical distance
ρ	Downwind distance
σ_y, σ_z	Crosswind, vertical dispersion coefficients (subscripted with m if a function of stability)
$\phi_{k_n \ell m}$, $\phi_{k\ell m}$	Meteorological joint frequency function for wind in subcardinal direction k_n, k
χ	Pollutant concentration

logical and other data are available in the appropriate format.

The user has already classified the application and in the process has determined that sulfur dioxide transformation and removal are not important enough to select any other pollutant characteristics branch than number one. As a consequence, no check need be made at this point to determine whether or not SCIM incorporates treatments of these elements. Had the application index begun with number three, for example, indicating that some physical removal process is important, the user would have been required at this point to determine whether SCIM incorporates a treatment, however simplified, of that process. SCIM provides estimates of various percentile one-hour concentrations at each receptor, including the maximum expected value, and therefore does estimate precisely the quantity of interest. If the application had involved the estimation of the maximum 24-hour SO_2 concentration, SCIM would not have been found applicable, because it does not estimate this quantity directly, even though the necessary program modifications to do this calculation may be straightforward or even though the necessary calculations could easily be done by hand.

As a result of these checks and determinations, SCIM is found to be applicable to the application of interest. The "Applicable" box on Part A is checked to indicate this determination.

The description above also implies that SCIM is a simulation model and, in view of the guidelines for model classification in Section 4.3, the appropriate classification is:

Semiempirical/Sequential (Steady-State).

Step 5 simply involves referring to Table 4.1 to identify RAM as a suggested reference model for application 1243.

The next step (step 6) is to review the importance ratings of the application elements for application index number 1243 and to determine if modifications to these ratings are necessary to more accurately define the relative importance of the elements in the situation of real interest. Expert advice may be necessary in this step. It is assumed here that the importance ratings as given in Tables 4.2 - 4.13 are appropriate with the exception of those for composition of emissions and chemistry and reaction mechanism, which are modified from LOW to IRRELEVANT for purposes of this example. Notice that the rating for physical removal has not been changed from LOW to IRRELEVANT even though no physical removal process is considered important enough to affect the application classification. The distinction between LOW and IRRELEVANT is that, as explained in Section 4.4, the treatments of IRRELEVANT elements are not taken into account at all in the evaluation, while the treatments of LOW elements may be considered in certain cases. It is assumed for this example that the involvement of sulfur dioxide in atmospheric chemical reactions in and around Sample City [illegible]dered so unimportant that it should play no role at all in evaluating simulation models. Therefore, the elements "composition of emissions" and "chemistry and reaction mechanism" are in fact irrelevant. In contrast, it is assumed that dry deposition of sulfur dioxide, while not important enough to affect the application classification, nevertheless does occur and is not insignificant enough to be totally irrelevant. Thus, the importance rating of physical removal is kept at LOW. Both initial and modified importance ratings for each element are inserted in Part B of the Evaluation Form.

The next step (step 7) is the determination of the treatment by SCIM of all application elements not rated IRRELEVANT. Operating equations used by SCIM are reproduced on the reverse side of Part A of the evaluation form. Using these equations and the material in the references as sources, descriptions of the treatments by SCIM, together with the corresponding reference model treatments obtained from Tables B.2- B.13 and the importance ratings for each element, are entered on Part C of the evaluation form. The treatments by SCIM were determined in accordance with the guidelines given in Section 5, supplemented by the discussions presented in Appendix A.

After both the study model and reference model treatments of a given element have been entered on the Evaluation Form - Part C, the comparison of these two treatments may be made using the guidelines in Section 6.2.1. The level of detail involved in each treatment is examined with reference to the relative ranking of treatments in Tables 5.1-5.15. The result of each comparison consists of the single adjective from the set BETTER, COMPARABLE, WORSE which most accurately describes the treatment used by the study model in comparison with that used by the reference model. This result is then entered in the place provided in each section of Part C.

The various treatments by SCIM and RAM of most application elements are clearly COMPARABLE, and are virtually identical in several cases. The exceptions are the elements horizontal wind field and background, boundary and initial conditions. The two treatments of horizontal wind field are basically COMPARABLE. However, SCIM does not employ a randomization procedure for wind direction and RAM does, with the result that SCIM only allows 36 different wind directions while RAM allows 360. Thus, SCIM <u>may</u> be somewhat WORSE in its treatment of the horizontal wind field. In cases of doubt, both results are indicated on the form; the primary evaluation as usual, followed by a secondary evaluation in parentheses (see the entries on Part C). The same situation arises for background, boundary and initial conditions. The two treatments are basically COMPARABLE, but SCIM may be a little WORSE because of its less detailed treatment of the upper boundary condition. On the other hand, SCIM allows a background value to be input. Both comparisons are indicated on Part C of the Evaluation Form.

In the cases of emission rate and temporal correlations, it is ne[illegible]y to judge the importance of area source emissions in Sample City before [illegible]

APPENDIX C
APPLICATIONS TO SPECIFIC MODELS

APPENDIX C APPLICATIONS TO SPECIFIC MODELS

This appendix contains examples of the application of the methodology presented in this workbook to several specific atmospheric dispersion models. Each subsection deals with a different study model and illustrates the nature of the information required about a study model, the factors involved in making individual element-by-element comparisons with a reference model, and the process of arriving at a final technical evaluation. Each subsection consists of a body of text in which the reasons for obtaining the various element-by-element comparisons and the final technical evaluation are explained. In the first example, the entire procedure is illustrated. In subsequent examples, it is assumed that the first five steps in the comparison need little additional explanation and that the Application Classification Form and the Evaluation Form - Part A have been completed. In each example, the application for which the study model is considered has been chosen so that the study model is in fact applicable in order to illustrate the methodology. A complete set of forms for each example, filled out in accordance with the discussion presented in the text, is located at the end of each subsection. The user should refer to these completed forms while reading the text.

CONTENTS OF APPENDIX C

C.1 EXAMPLE 1: SCIM/1243

In this example, the application of interest involves estimating the maximum expected one-hour sulfur dioxide concentration in Sample City, a moderately sized urban area located in gently rolling terrain far from any large bodies of water. Each step in the entire methodology is illustrated. While reading the text, the user should refer to the completed forms at the end of the sect

The first step involves the classification of the application as explained in Section 3. With regard to pollutant characteristics, sulfur dioxide is a primary pollutant not subject to significant removal processes within the time scale of the application. The size of the region of interest is of the order of 50 km or less, and the residence time of a pollutant emitted within this region is less than 5-8 hours for typical wind speeds. As indicated in Table 3.1, the appropriate pollutant characteristics index number under these circumstances is one.

The averaging time is short (under 24 hours); the appropriate averaging time index number is two, as discussed in Section 3.4.

The Sample City emission inventory is assumed to contain both point and area sources and the appropriate source characteristics index number is therefore four, as explained in Section 3.5.

Finally, since the terrain in which Sample City is located is simple and the size of the region of interest is less than 100 km, the appropriate transport characteristics index number is three, as explained in Section 3.6.

The completed Application Classification Form for this example can be found at the end of this section. As indicated, the appropriate application index is 1243.

At this time, the basic information sections of the Evaluation Form - Part A are also completed by listing the reference documentation and preparing a short abstract describing SCIM's mode of operation.

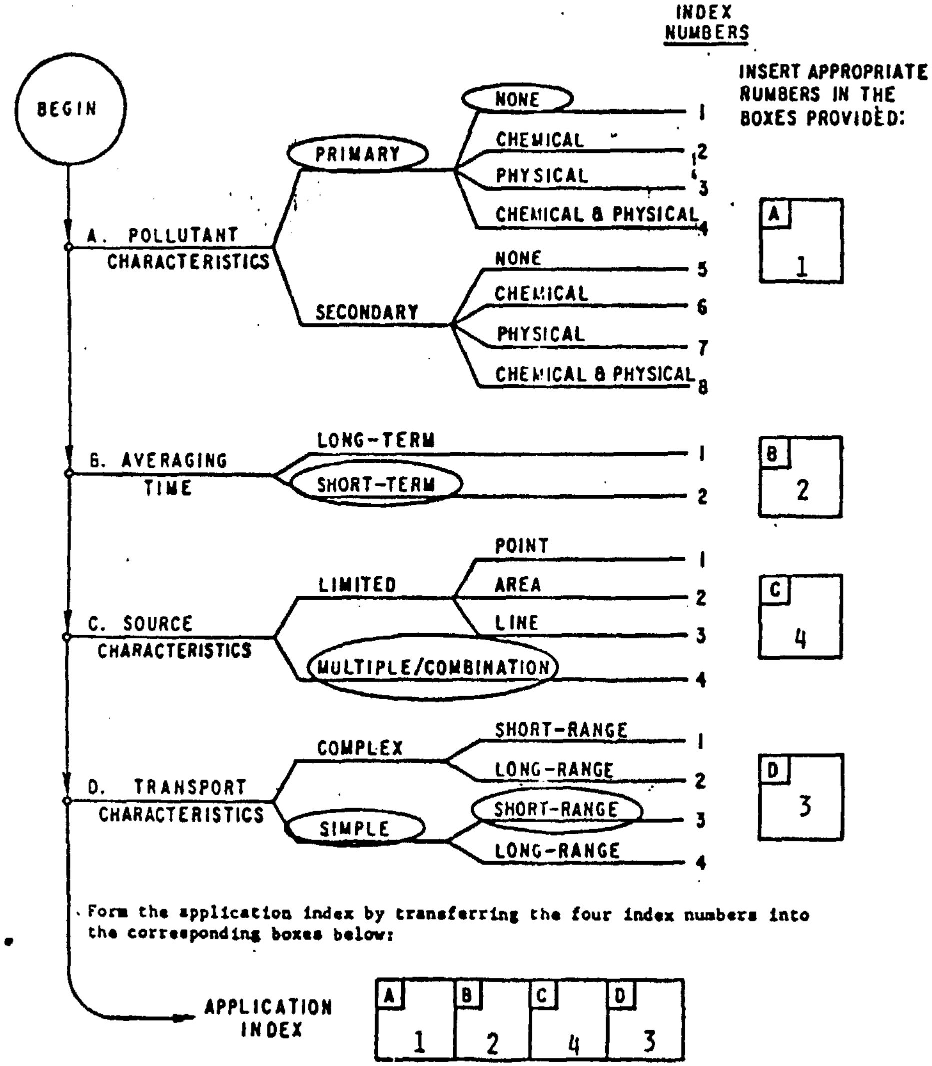
This completes step 1.

The next step in the comparison involves the documentation of the study model equations. The references listed on the front of the Evaluation Form - Part A are used to determine the working equations shown on the reverse side of the form to complete step 2.

These references also indicate that SCIM selects a sample of one-hour periods from the total number in some period of record, typically one year. The sample is obtained by taking every n-th hour where n is an integer specified by the user. Having selected the sample, SCIM applies a steady-state Gaussian model separately to each hour in the sample and estimates from these results both the long term average concentration and the frequency distribution of one-hour concentrations. With this information, SCIM may be classified and its compatibility with the application of real interest checked (steps 3 and 4 in the comparison).

It is assumed, in this example, that the Sample City emission inventory is structured in a manner compatible with SCIM input requirements, specifically that all required source information is available, that area sources are defined in a suitable manner, that the number of point and area sources is with limitations, and so on. It is also assumed that the necessary meteoro

APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

APPLICATION INDEX

A	B	C	D
1	2	4	3

the comparisons because SCIM and RAM differ in the level of detail with which the temporal variation of area source emissions are described. The comparisons actually made in the example assume that area source contributions are not significant enough to justify rating the SCIM treatment BETTER. If these contributions were more important in the application, the additional detail in the SCIM treatment might justify a BETTER rating.

The synthesis of these individual comparisons into a final technical evaluation (step 9) is documented on the Evaluation Form - Part D. The guidelines in Section 6.2.2 are used to arrive at this final evaluation. In the example, there are no CRITICAL elements. Therefore, the initial evaluation is based on the comparisons for the three HIGH-rated elements. All of these comparisons are COMPARABLE, resulting in an initial comparative rating of COMPARABLE. Of the elements rated MEDIUM, all five have COMPARABLE treatments; therefore no change in the initial rating is indicated. Even if the secondary evaluations for horizontal wind field and background, boundary and initial conditions were used, they would not carry sufficient weight to alter the evaluation. Thus, the technical evaluation of SCIM for Application 1243 is that SCIM is COMPARABLE to the reference model, RAM. This evaluation is further supported by the distribution of comparisons for the LOW elements, although these would not be considered here, because the rating based upon HIGH and MEDIUM elements is unambiguous.

EVALUATION FORM

Part A: Abstract and References

Study Model: Sampled Chronological Input Model (SCIM)

References: Koch, R.C. and G.H. Stadsklev, *A User's Manual for the Sampled Chronological Input Model (SCIM)*, GEOMET Report No. E-261, prepared for U.S. EPA under Contract No. 68-02-0281. (December 1974).

Koch, R.C. and S.D. Thayer, *Validation and Sensitivity Analysis of the Gaussian Plume Multiple - Source Urban Diffusion Model*, NTIS PB 206951, National Technical Information Service, Springfield, Va. 22151. (November 1971).

Abstract: The Sampled Chronological Input Model (SCIM) is a Gaussian plume-based model designed to estimate mean long-term pollutant concentrations and the frequency distribution and maximum of one-hour pollutant concentrations in an urban area.

Classification: Semiempirical/Sequential (Steady-State)

Application Index: 1243

Reference Model: RAM

Application Description: Maximum 1-hour SO_2 concentration in an urban area.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A (reverse): Equations

Study Model: SCIM

Equations:

Point sources:

$$\chi_n = \frac{Q_n}{2\pi u\sigma_y\sigma_z} g_z \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left(-\frac{kx}{u}\right)$$

$$\text{with } g_z(x,z;H) = \exp\left[-\frac{1}{2}\left(\frac{H-z}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{H+z}{\sigma_z}\right)^2\right]$$

Area sources:

$$\chi_A = \frac{1}{2\pi}\int_o^{x_d} \frac{\bar{q}(x)}{u\sigma_z} g_z(x,z;H) \exp\left(-\frac{kx}{u}\right) dx$$

with $\bar{q}(x) \cong q(x,o)$, $q(r,\theta)$ = emission rate per unit area at position (r,θ) from receptor

(Narrow plume approximation)

Integral evaluated using trapezoidal rule.

Total estimated concentration $\chi_{tot} = \chi_A + \sum_{n=1}^{N} \chi_n$

N = number of point sources

Vertical dispersion coefficient:

$$\sigma_z = ax^b \qquad x \leq x_1$$

$$\sigma_z = L \qquad x \geq x_2$$

$$\sigma_z = \frac{L}{2}\left(\frac{x+x_2-2x_1}{x_2-x_1}\right) \qquad x_1 < x < x_2$$

$$x_1 = \left(\frac{L}{2a}\right)^{1/b} \quad \text{and} \quad x_2 = \left(\frac{L}{a}\right)^{1/b}$$

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1243

Application Element	Importance Rating Initial	Importance Rating Modified[a]
Source-Receptor Relationship	M	M
Emission Rate	M	M
Composition of Emissions	L	I ✓
Plume Behavior	H	H
Horizontal Wind Field	M	M
Vertical Wind Field	L	L
Horizontal Dispersion	H	H
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	L
Background, Boundary, Initial Conditions	M	M
Temporal Correlations	M	M

[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Source-Receptor Relationship	Application Element: Emission Rate
Reference Model: RAM Treatment: Arbitrary location and release height for each point source. Flat terrain. Area sources defined as square cells (or multiples) in a rectangular array; up to three effective release heights (for u=5m/sec) user-specified. Arbitrary receptor locations - all at the same height above (or at) ground. Precise downwind, crosswind distances for each source-receptor pair. Sides of area sources must lie along grid boundary directions.	Reference Model: RAM Treatment: Arbitrary constant emission rate for each point and area source. Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for area source with given effective release height. Includes only those areas intersected by the upwind ray.
Study Model: SCIM Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Arbitrary location and emission height for point sources. Flat terrain. Arbitrary location and height for receptors. Area sources defined as square cells in up to three concentric arrays with user-defined grid sizes. Up to five user-defined release heights for area sources. Precise downwind and crosswind distance for each source-receptor pair.	Study Model: SCIM Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Arbitrary constant emission rate for each point source. Arbitrary average emission rate for each area source; area source emissions assumed functions of average emission rate, temperature and time of day. Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for area source with given effective release height; includes only those areas intersected by the upwind ray.

Rule 2, Continued

EVALUATION FORM

Part C : Treatment of Elements

Application Index: 1243

Application Element: Plume Behavior

Reference Model: RAM

Treatment:

Uses Briggs' (1971, 1972), downwind distance dependent plume rise for point sources.

If plume height exceeds mixing height, ground level concentrations assumed zero.

No plume rise calculated for area sources; assumed to be included in release height.

Fumigation, downwash not treated.

Study Model: SCIM

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment:

Two step procedure using Briggs'(1969) for point sources.

Not treated explicitly for area sources-assumed included in input release heights.

If stack height +50% of plume rise exceeds mixing height, source is excluded.

Fumigation, downwash not treated.

Application Element: Horizontal Wind Field

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Constant, uniform wind speed and direction assumed for each of a sequence of hours.

Arbitrary wind speeds and direction values to 10° input by user; directions randomized by addition of $(n-4)^{0}$ with n = random integer from zero to nine.

Wind speed is modified to correspond to value at release height, modification dependent only on stability class.

Study Model: SCIM

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE (WORSE)

Treatment: Semiempirical/Sequential (Steady-State).

Constant, uniform wind speed within each of sequence of one-hour periods.

Arbitrary wind speeds and directions to 10° input by user.

Wind speed modified (power law) to correspond to value at release height, modification procedure depends only on stability (unstable, neutral, stable).

EVALUATION FORM

Part C : Treatment of Elements

Application Index: 1243

Application Element: Vertical Wind Field

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Assumed equal to zero (implicit).

Study Model: SCIM

Importance Rating: LOW

Comparative Evaluation: COMPARABLE

Treatment: Semiempirical/Sequential (Steady-State).

Assumed equal to zero (implicit).

Application Element: Horizontal Dispersion

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Gaussian plume function assumed for point sources.

Atmospheric stability divided into six (Pasquill-Gifford) classes, determined hourly.

Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user option.

Surface roughness not treated explicitly

One hour averaging time used.

Area sources: Narrow plume approximation.

Study Model: SCIM

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment: Semiempirical/Sequential (Steady-State).

Gaussian plume function for point sources.

Atmospheric stability divided into four classes (urban) or five classes (rural), determined hourly.

Dispersion coefficients: McElroy-Pooler (1968) for urban area, Pasquill-Gifford (Turner, 1969) for rural areas.

Surface roughness not treated explicitly.

One-hour averaging time.

Area Sources: Narrow plume approximation.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Vertical Dispersion Reference Model: RAM Treatment: Semiempirical/Sequential (Steady-State). Gaussian plume function assumed. Atmospheric stability divided into six (Pasquill-Gifford) classes, determined hourly. Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user's option. Surface roughness not treated explicitly.	**Application Element:** Physical Removal Reference Model: RAM Treatment: Semiempirical/Sequential (Steady-State). Exponential decay - first order (linear). Single, constant user-specified decay constant.
Study Model: SCIM Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Semiempirical/Sequential (Steady-State). Gaussian plume function. Atmospheric stability divided into four classes (urban) or five classes (rural), determined hourly. Dispersion coefficients: McElroy-Pooler (1968) (urban), or Pasquill-Gifford (Turner, 1969) (rural). Surface roughness not treated explicitly.	Study Model: SCIM Importance Rating: LOW Comparative Evaluation: COMPARABLE Treatment: Exponential decay. Single, constant user-supplied decay constant.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Background, Boundary, Initial Conditions Reference Model: RAM Treatment: Background not treated explicitly. Both upper and lower boundaries - perfect reflection. 1) Neutral and unstable conditions: method of multiple images treated by summation of infinite series until $\sigma_z = 1.6\times$(mixing height); uniform mixing assumed thereafter; 2) Stable conditions: mixing height assumed to have no effect. Mixing height for a given hour obtained interpolation of radiosonde data.	**Application Element:** Temporal Correlations Reference Model: RAM Treatment: Sequential. User supplies hourly values of wind speed, wind direction, mixing height, and other meteorological variables required for determination of stability class and plume rise. (Correlations automatic.) Emission rates constant, not correlated with other parameters.
Study Model: SCIM Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE (WORSE) Treatment: Background - Single Constant Value Lower boundary - perfect reflection. Upper boundary - implicit treatment; no effect until σ_z=0.5 (mixing height), maximum σ_z value = mixing height, linear interpolation on σ_z in transition region; transition distances determined using $\sigma_z = ax^b$. Mixing height interpolated from radiosonde data.	Study Model: SCIM Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Sequential. User supplies hourly values of wind speed, direction, mixing height and other variables required for stability determination. (Correlations automatic.) Point source emissions constant, not correlated with other parameters. Area source emissions an empirical function of ambient temperature and hour of the day. (Correlations automatic.)

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element:	Application Element:
Reference Model:	Reference Model:
Treatment: Two IRRELEVANT elements: • Composition of Emissions • Chemistry and Reaction Mechanism	Treatment:
Study Model:	Study Model:
Importance Rating:	Importance Rating:
Comparative Evaluation:	Comparative Evaluation:
Treatment:	Treatment:

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1243 Reference Model: RAM Study Model SCIM

Importance Rating of Application Elements	Number of Treatments Total	BETTER	COMPARABLE	WORSE	Comparative Rating of Study Model
CRITICAL	0	-	-	-	-
HIGH	3	0	3	0	COMPARABLE
MEDIUM	5	0	5 (3)	0 (2)	COMPARABLE
LOW[a]	2	0	2	0	
IRRELEVANT	2	XXX	XXX	XXX	
Total	12 (Should equal 12)				

TECHNICAL EVALUATION COMPARABLE

---

[a] Used only in ambiguous cases.

C.2 EXAMPLE 2: AQDM/1143

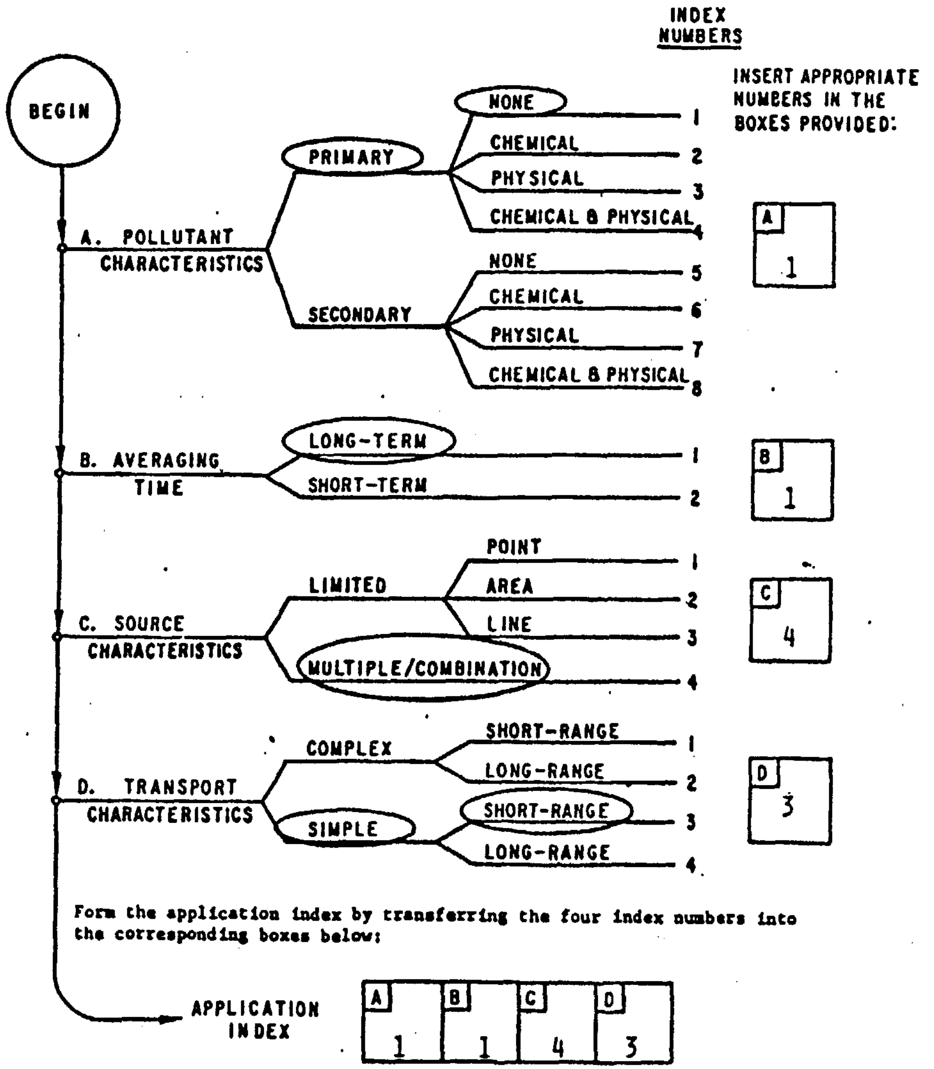
The application of interest involves the estimation of long-term sulfur dioxide concentrations in Sample City, a moderately sized urban area located in gently rolling terrain, the same urban area used in Example 1, Appendix C.1. The appropriate application index is 1143 and the suggested reference model is CDM. The completed Application Classification Form and Evaluation Form for this example may be found at the end of this section.

It is assumed that the user can classify AQDM, determine that AQDM is applicable, review and modify the importance ratings, determine the equations used by AQDM, and determine the treatments of the application elements by both AQDM and CDM. The classification and applicability checks are straightforward. The importance rating modifications are the same as in Example 1, specifically, that the elements composition of emissions and chemistry and reaction mechanism are rated IRRELEVANT due to the non-involvement of sulfur dioxide in atmospheric chemistry over the distances and times of interest. The determination of the equations and of the treatments are straightforward. The results are presented on the Evaluation Form-Part A(reverse) and C, respectively.

AQDM and CDM are similar in most respects and most comparisons result in COMPARABLE ratings. The two exceptions are emission rate and horizontal wind field, for both of which AQDM is rated WORSE. The AQDM treatment of emission rate is rated WORSE primarily because of the use of a single effective point source approximation for area sources instead of the more detailed numerical integration used by CDM, and secondarily because CDM allows a day/night variation in emission rates whereas AQDM allows no variation. The AQDM treatment of the horizontal wind field is rated WORSE, because CDM uses a wind speed which is corrected for emission height while AQDM does not incorporate any such variation.

With only one element rated of HIGH importance, the initial rating is the same as the rating for that element; in this case, the initial rating is COMPARABLE. The MEDIUM-rated elements, however, definitely show a bias toward a rating of WORSE. In this case, taking into account the relatively low number of HIGH-rated elements, the relatively high proportion of MEDIUM-rated elements for which AQDM uses a WORSE treatment, and the absence of any elements that are treated BETTER by AQDM, a change in the comparative rating of AQDM from COMPARABLE to WORSE is justified. Furthermore, the distribution of comparisons for the LOW-rated elements supports this conclusion, although little weight should be given to the LOW-rated elements. Therefore, the appropriate technical evaluation for AQDM in application 1143 is WORSE.

APPLICATION CLASSIFICATION FORM



A 1

B 1

C 4

D 3

Form the application index by transferring the four index numbers into the corresponding boxes below:

A	B	C	D
1	1	4	3

EVALUATION FORM

Part A: Abstract and References

Study Model: Air Quality Display Model (AQDM)

References: TRW Systems Group. "Air Quality Display Model." Prepared for National Air Pollution Control Administration under Contract No. PH-22-68-60 (NTIS PB 189194), DHEW, U.S. Public Health Service, Washington, D.C., November 1969.

Abstract: The Air Quality Display Model (AQDM) is a climatological steady state Gaussian plume model that estimates annual arithmetic average sulfur dioxide and particulate concentrations at ground level. A statistical model based on Larsen (1969) is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Classification: Semiempirical/Climatological (Steady-State)

Application Index: 1143 **Reference Model:** CDM

Application Description: Urban, long-term, conservative pollutants, simple terrain.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A(reverse): Equations

Study Model: AQDM

Equations:

Point sources only.

$$\chi = \sum_{n=1}^{n} \sum_{\ell=1}^{6} \sum_{m=1}^{5} \phi_{k_n \ell m} \chi_{n\ell m}$$

N = Number of sources.

with

$$\chi_{n\ell m} = \frac{16}{2\pi x} \frac{2Q_n}{2\pi u_\ell \sigma_z} \left(\frac{C-y}{C}\right) \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{for } x \leq x_L$$

$$\chi_{n\ell m} = \frac{16}{2\pi x} \frac{Q_n}{u\ell L} \left(\frac{C-y}{C}\right) \quad \text{for } x \geq 2x_L$$

linear interpolation for $x_L < x < 2x_L$

x_L is defined by $\sigma_z(x_L) = 0.47L$

y = crosswind distance between receptor and sector k centerline

C = sector width at receptor location

$\sigma_z(x) = ax^b + c$; a, b, c = functions of stability class (m)
a, b, c for neutral conditions split into
$x > 1000$m case and $x \leq 1000$m case.

Calibration: $\chi_{calibrated} = A + B\left(\chi_{background} + \chi_{uncalibrated}\right)$
with $\chi_{uncalibrated}$ given by the first equation above.

Larsen (1971) statistical transformation of averaging times used for 1 - 24 hour averages.

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1143

Application Element	Importance Rating Initial	Importance Rating Modified[a]
Source-Receptor Relationship	M	M
Emission Rate	M	M
Composition of Emissions	L	I ✓
Plume Behavior	M	M
Horizontal Wind Field	M	M
Vertical Wind Field	L	L
Horizontal Dispersion	M	M
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	L
Background, Boundary, Initial Conditions	M	M
Temporal Correlations	L	L

[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

Rule 9_ Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Source-Receptor Relationship	**Application Element:** Emission Rate
Reference Model: CDM	**Reference Model:** CDM
Treatment: Arbitrary location for each point source. Area sources specified as integral multiples of basic grid cell size, located on user-defined grid; sides lie along grid boundary directions. Receptor location arbitrary. Arbitrary release heights for point and area sources. Precise separation for each source-receptor pair. Receptors are at ground level. No terrain differences between source/receptor.	**Treatment:** Single arbitrary emission rate for each point and area source. Area integrations are done numerically one 22.5° sector at a time; sampling at discrete intervals on a polar grid centered on the receptor. Day/night variations in emissions, same variation assumed for all sources.
Study Model: AQDM	**Study Model:** AQDM
Importance Rating: MEDIUM	**Importance Rating:** MEDIUM
Comparative Evaluation: COMPARABLE	**Comparative Evaluation:** WORSE
Treatment: Arbitrary location for each point source. Arbitrary location and size for each area source. Up to 225 receptors located on uniform rectangular grid. Up to 12 user-specified receptor locations. Arbitrary release height for each point, area source. Precise downwind and crosswind distance for each source-receptor pair. Receptors at ground level. No terrain differences between source and receptor.	**Treatment:** Point sources: single rate for each source. Area sources: single rate for each source. Each source treated by effective single source approximation. No temporal variation allowed.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Plume Behavior	**Application Element:** Horizontal Wind Field
Reference Model: CDM Treatment: Briggs' 2/3 (1971) neutral/unstable formula used. If stack height + plume rise is greater than mixing height, ground level concentrations assumed equal to zero. Alternative to Briggs - input value of plume rise times wind speed for each point source. No plume rise calculated for area sources. Does not treat fumigation or downwash.	Reference Model: CDM Treatment: Climatological approach. 16 wind directions. 6 wind speed classes. Wind speed corrected for release height based on power law variation, exponents from DeMarrais (1959). Constant, uniform (steady-state) wind assumed.
Study Model: AQDM Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Holland (1953) formula, with adjustment for stability. No plume rise calculated for area sources. Does not treat fumigation or downwash. If stack height plus plume rise is greater than mixing height, ground level concentration assumed equal to zero.	Study Model: AQDM Importance Rating: MEDIUM Comparative Evaluation: WORSE Treatment: Climatological approach. 16 wind directions. 6 wind speed classes. No variation in windspeed with height. Constant, uniform (steady-state) wind assumed.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Vertical Wind Field	**Application Element:** Horizontal Dispersion
Reference Model: CDM Treatment: Assumed equal to zero.	Reference Model: CDM Treatment: Semiempirical/Climatological (Steady-State). Uniform distribution within each of 16 sectors (narrow-plume approximation). Averaging time = 1 month to 1 year. Surface roughness not treated explicitly.
Study Model: AQDM Importance Rating: LOW Comparative Evaluation: COMPARABLE Treatment: Assumed equal to zero.	Study Model: AQDM Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Climatological approach. Linear interpolation between 22.5° sector centerlines; center value calculated by sector averaging procedure (narrow plume approximation). Averaging time = 1 month - 1 year. Surface roughness not treated explicitly.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Vertical Dispersion

Reference Model: CDM

Treatment:

Semiempirical/climatological (Steady-State)
Gaussian plume function assumed.
5 stability classes as defined by Turner (1964).
Neutral stability split into day/night cases, giving six classes in all.
Dispersion coefficients taken from Turner (1970).
Area sources - stability class is decreased by 1 category from input values to account for urban effects.
Neutral dispersion coefficients are used for all neutral and stable classes.
No provision for variations in surface roughness.

Study Model: AQDM

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment:

Semi-empirical/Gaussian plume.
5 stability classes (Turner, 1964).
Neutral stability split internally into 60% day, 40% night.
Dispersion coefficients from Pasquill (1961) and Gifford (1961).
Neutral dispersion coefficients used for all neutral and stable classes.
No provision for variations in surface roughness.

Application Element: Physical Removal

Reference Model: CDM

Treatment:

Dry deposition only.
Effective source treatment using exponential decay (First-order process).
Single constant user-supplied halflife used.

Study Model: AQDM

Importance Rating: LOW

Comparative Evaluation: WORSE

Treatment:

Not treated explicitly.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Background, Boundary, Initial Conditions

Reference Model: CDM

Treatment:

Input single constant background value for each pollutant.
Lower boundary (ground): assumes perfect reflection; uses single image source.
Upper boundary (mixing height): no effect until vertical dispersion coefficient equals 0.8 of mixing height, uniform vertical mixing assumed beyond this point.

Study Model: AQDM

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment:

Input single constant background value for each pollutant.
Lower boundary (ground): perfect reflection; single image source.
Upper boundary (mixing ht): no effect until $\sigma_z \geq .47H$ (occurs at $x = x_L$); for $x > 2x_L$, uniform mixing; in between, linear interpolation transition region used.

Application Element: Temporal Correlations

Reference Model: CDM

Treatment:

Wind speed, direction, stability correlated via wind rose.
Mixing height is adjusted according to stability class:
- Class A - 1.5 x afternoon climatological value,
- Class D (night) - average of morning and afternoon climatological values,
- Class E - morning climatological value.

Emission rates: day-night variation allowed; all sources assumed to vary by same factor.
Non-sequential (climatological) limited correlation.

Study Model: AQDM

Importance Rating: LOW

Comparative Evaluation: COMPARABLE

Treatment:

Wind speed, direction, stability correlated via wind rose.
Emission rate - not correlated with any other factor.
Non-sequential (climatological) limited correlation.
Mixing height adjusted according to stability class:
- Class A - 1.5 x afternoon climatological value,
- Class D (night, internally divided) average of 100 meters and afternoon climatological value,
- Class E - assumes 100 meters.

EVALUATION FORM

Part C : Treatment of Elements

Application Index: 1143

Application Element:
Reference Model:
Treatment:

Two IRRELEVANT elements:

- Composition of Emissions
- Chemistry and Reaction Mechanism

Study Model:
Importance Rating:
Comparative Evaluation:
Treatment:

Application Element:
Reference Model:
Treatment:

Study Model:
Importance Rating:
Comparative Evaluation:
Treatment:

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1143 Reference Model: CDM Study Model AQDM

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL	0	—	—	—	—
HIGH	1	0	1	0	COMPARABLE
MEDIUM	6	0	4	2	WORSE
LOW [a]	3	0	2	1	
IRRELEVANT	2	XXX	XXX	XXX	

Total 12 (Should equal 12)

TECHNICAL EVALUATION WORSE

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[a] Used only in ambiguous cases.

C.3. EXAMPLE 3: PTDIS/1213

The application of interest involves the estimation of ground level centerline sulfur dioxide concentrations at various distances downwind of a power plant located in relatively flat terrain. The appropriate application index is 1213 and the suggested reference model is CRSTER (Single Source). Both CRSTER and RAM are suggested as reference models for application 1213 in Table 4.1. In accordance with footnote j of that table, CRSTER has been chosen, since the application of interest involves only a single power plant. PTDIS is classified as a Semiempirical/Steady-State model and is determined to be applicable. Part A of the Evaluation Form summarizes the general information regarding this example.

The importance ratings are given on Part B of the Evaluation Form; in this example three modifications have been made. Due to the physical and chemical characteristics of sulfur dioxide and the short range of the application the elements physical removal processes, chemistry and reaction mechanism, and composition of emissions have been rated IRRELEVANT.

The reverse side of Part A of the Evaluation Form gives the equations used used by PTDIS and Part C gives the treatments, importance ratings, and comparison results for all elements not rated IRRELEVANT. As can be seen, the treatments are very similar in all cases and in all cases a comparative rating of COMPARABLE is appropriate. For source-receptor relationship and horizontal wind field, some confusion may arise regarding the appropriate rating, the possible source of confusion being the specification in the application description on Part A that centerline ground level concentrations are desired. PTDIS is designed specifically for this application, whereas CRSTER (Single-Source) is designed to estimate concentrations at receptors on a polar grid with a 10° increment between successive radial directions. In addition, CRSTER accepts real meteorological data in which the wind direction is assumed given to the nearest 10° and randomizes this direction by the addition of an integer chosen from the values -4° to +5°. Thus CRSTER may not provide centerline concentration estimates; it was never intended to do so explicitly. CRSTER would in fact be found not applicable in this case were it the study model and PTDIS the reference model. This difference in objectives does not invalidate the use of CRSTER as a basis for comparison but implies that those aspects of source-receptor relationship and horizontal wind field which have treatments which differ simply because of the different objectives of the two models should not be considered in making the comparisons.

The Evaluation Form - Part D summarizes the individual comparison results and shows that the technical evaluation of PTDIS for application 1213 is obviously COMPARABLE.

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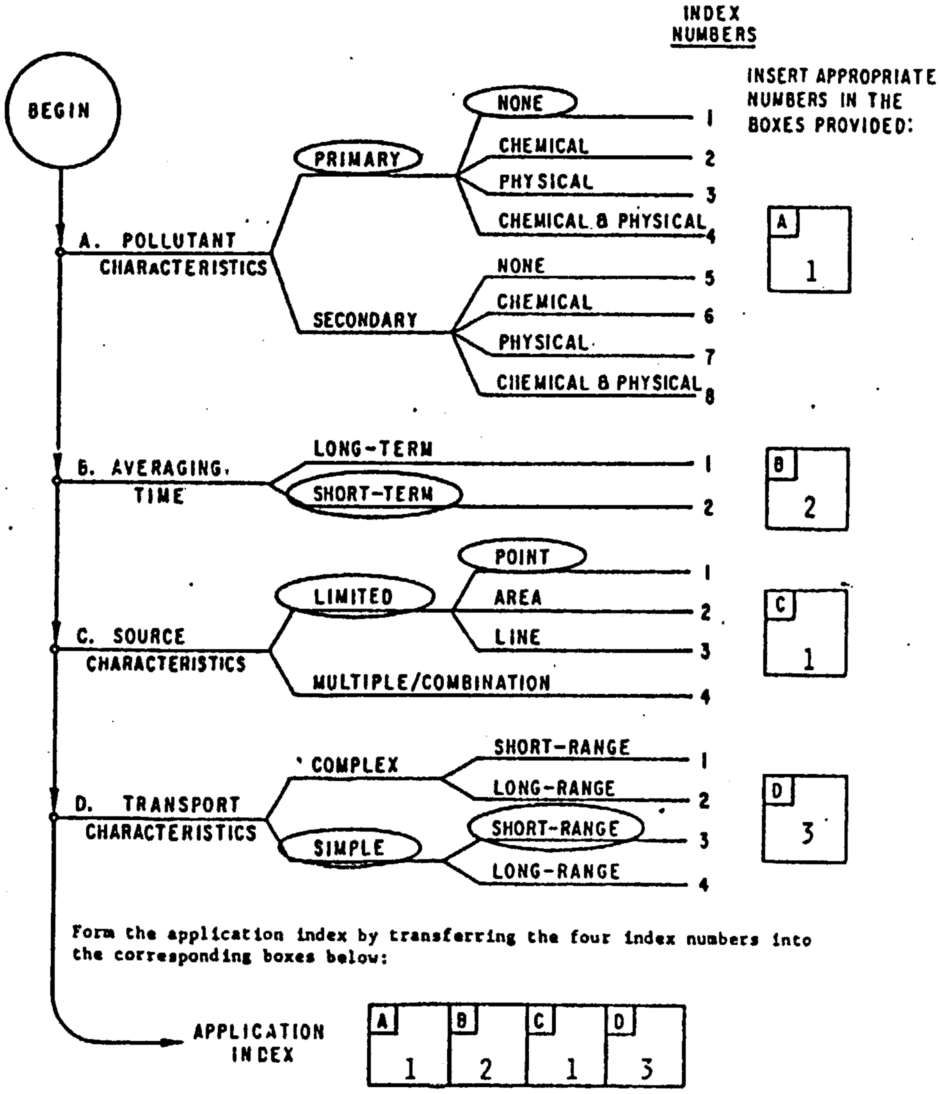
APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

APPLICATION INDEX: A 1 B 2 C 1 D 3

EVALUATION FORM

Part A: Abstract and References

Study Model: PTDIS

References: Environmental Protection Agency, *User's Network for Applied Modeling of Air Pollution (UNAMAP)*, NTIS PB 229771, National Technical Information Service, Springfield, Va. (1974).

Turner, D.B., *Workbook of Atmospheric Dispersion Estimates*, NTIS PB 191482, National Technical Information Service, Springfield, Va.

Abstract: PTDIS is a steady-state Gaussian plume model that estimates short-term center-line concentrations directly downwind of a point source at distances specified by the user for a single user-specified set of meteorological conditions. The effect of limiting vertical dispersion by a mixing height can be included and gradual plume rise to the point of final rise is also considered. An option allows the calculation of isopleth half-widths for specific concentrations at each downwind distance.

Classification: Semempirical/Steady-State

Application Index: 1213

Reference Model: Single Source (CRSTER)

Application Description: Single elevated point source, flat terrain, sulfur dioxide, downwind centerline ground level concentrations only.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A(reverse): Equations

Study Model: PTDIS

Equations:

$$\chi(x;0,0;H) = \frac{Q}{2\pi u \sigma_y \sigma_z} g_1 \; g_3$$

with $g_1 = 1$

and $$g_3 = \sum_{n=-\infty}^{+\infty} \left[\exp\left[-\frac{1}{2}\left(\frac{2nL-H}{\sigma_z}\right)^2 \right] + \exp\left[-\frac{1}{2}\left(\frac{2nL+H}{\sigma_z}\right)^2 \right] \right]$$

$\chi = 0$ if $H > L$

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1213

Application Element	Importance Rating Initial	Importance Rating Modified[a]
Source-Receptor Relationship	H	H
Emission Rate	H	H
Composition of Emissions	L	I ✓
Plume Behavior	H	H
Horizontal Wind Field	H	H
Vertical Wind Field	L	L
Horizontal Dispersion	H	H
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	I ✓
Background, Boundary, Initial Conditions	M	M
Temporal Correlations	M	M

---

[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

: : :

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Source-Receptor Relationship	Application Element: Emission Rate
Reference Model: Single Source (CRSTER) Treatment: Up to 19 sources all assumed to be located at same position. Receptor locations restricted to 36 azimuths (every 10°) and five user-specified radial distances. Arbitrary stack height for each source. Unique stack height for each source. Unique topographic elevation for each receptor: must be less than each stack height. Receptors must be at ground level. Precise downwind/crosswind distance for each source receptor pair.	Reference Model: Single Source (CRSTER) Treatment: Single arbitrary value for each source. Monthly variation allowed.
Study Model: PTDIS Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Single stack of arbitrary height. Up to 50 receptors, all at ground level, directly underneath plume centerline, at arbitrary user-specified downwind distances. Flat terrain assumed.	Study Model: PTDIS Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Single arbitrary constant value.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Plume Behavior	Application Element: Horizontal Wind Field
Reference Model: Single Source (CRSTER) Treatment: Briggs' (1971, 1972) final plume rise formulas; plume rise not treated as a function of downwind distance. If plume height exceeds mixing height, concentrations further downwind assumed equal to zero. Does not treat either fumigation or downwash.	Reference Model: Single Source (CRSTER) Treatment: Semiempirical/Sequential (Steady-state) Constant, uniform wind speed and direction assumed for each of a sequence of hours. Wind speeds (arbitrary) and directions (nearest 10°) input by user; directions randomized by addition of (n-4)° with n = random integer from 0 to 9. Wind speed corrected for release height with corrections dependent only on stability class.
Study Model: PTDIS Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Briggs (1971, 1972) plume rise formulae. Alternatively, one user-supplied plume rise value can be used. Does not treat fumigation or downwash. If plume height exceeds mixing height, ground level concentration assumed equal to zero.	Study Model: PTDIS Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Semiempirical/Steady-state) Wind directions implicit along source-receptor direction. Uses user-defined wind speed. No variation in wind speed with height. Constant, uniform (steady-state) wind assumed.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Vertical Wind Field	**Application Element:** Horizontal Dispersion
Reference Model: Single Source (CRSTER) Treatment: Assumed equal to zero (implicit).	Reference Model: Single Source (CRSTER) Treatment: Semiempirical/Sequential (Steady-State). Gaussian plume function assumed. Atmospheric stability divided into seven classes (Pasquill-Gifford); class 7 - extremely stable - elevated plume assumed not to touch ground. Dispersion coefficients from Turner (1969). Surface roughness not treated explicitly. 1-hour averaging time.
Study Model: PTDIS Importance Rating: LOW Comparative Evaluation: COMPARABLE Treatment: Assumed equal to zero (implicit).	Study Model: PTDIS Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Semiempirical/Steady-State. Gaussian plume function assumed. Calculations for a single user-specified (Pasquill-Gifford) stability class. Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness, averaging time or travel time. Averaging time unknown, approximately 10 - 60 minutes.

Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Vertical Dispersion	**Application Element:** Background, Boundary, Initial Conditions
Reference Model: Single Source (CRSTER) Treatment: Semiempirical/Sequential (Steady-State). Gaussian plume function assumed. Atmospheric stability divided into seven (Pasquill-Gifford) classes; class 7 - extremely stable - elevated plume does not touch ground. Dispersion coefficients from Turner (1969). Surface roughness not treated explicitly.	Reference Model: Single Source (CRSTER) Treatment: Background not treated explicitly. Lower boundary: perfect reflection in horizontal plane at receptor height. Upper boundary: perfect reflection; method of multiple images treated by summation of series until vertical dispersion coefficient = 1.6x (mixing height); uniform vertical mixing thereafter. Mixing height for a given hour obtained by interpolation of radiosonde data.
Study Model: PTDIS Importance Rating: HIGH Comparative Evaluation: COMPARABLE Treatment: Semiempirical/Steady-State. Gaussian plume function assumed. Calculations done for user-specified (Pasquill-Gifford) stability class. Dispersion coefficients from Turner (1969). Surface roughness not treated explicitly.	Study Model: PTDIS Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Background not treated explicitly. Lower boundary: perfect reflection. Upper boundary: (neutral and unstable conditions) user-input mixing height used; perfect reflection assumed. Upper boundary: (stable conditions) - concept of mixing height not employed; no upper boundary considered - given meteorological conditions implicitly assumed to extend higher than plume at all distances. Multiple reflections numerically accounted for by summation of series.

Rule

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Temporal Correlations

Reference Model: Single Source (CRSTER)

Treatment:
Sequential; correlations automatic for meteorological parameters.

User supplies hourly values of wind speed, wind direction, mixing height, and other meteorological variables required for determining stability class and plume rise.

Monthly emission variation allows limited emission/meteorology correlations.

Study Model: PTDIS

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment:

User supplies appropriate values of all input variables for the hour in question; correlations automatic.

Application Element:

Reference Model:

Treatment:

3 IRRELEVANT Elements:

- Composition of Emissions
- Chemistry and Reaction Mechanism
- Physical Removal

Study Model:

Importance Rating:

Comparative Evaluation:

Treatment:

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1213 Reference Model: Single Source (CRSTER) Study Model PTDIS

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL	0	-	-	-	-
HIGH	6	0	6	0	COMPARABLE
MEDIUM	2	0	2	0	COMPARABLE
LOW[a]	1	0	1	0	
IRRELEVANT	3	XXX	XXX	XXX	

Total 12 (Should equal 12)

TECHNICAL EVALUATION COMPARABLE

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[a] Used only in ambiguous cases.

C.4. EXAMPLE 4: PTMAX /1213

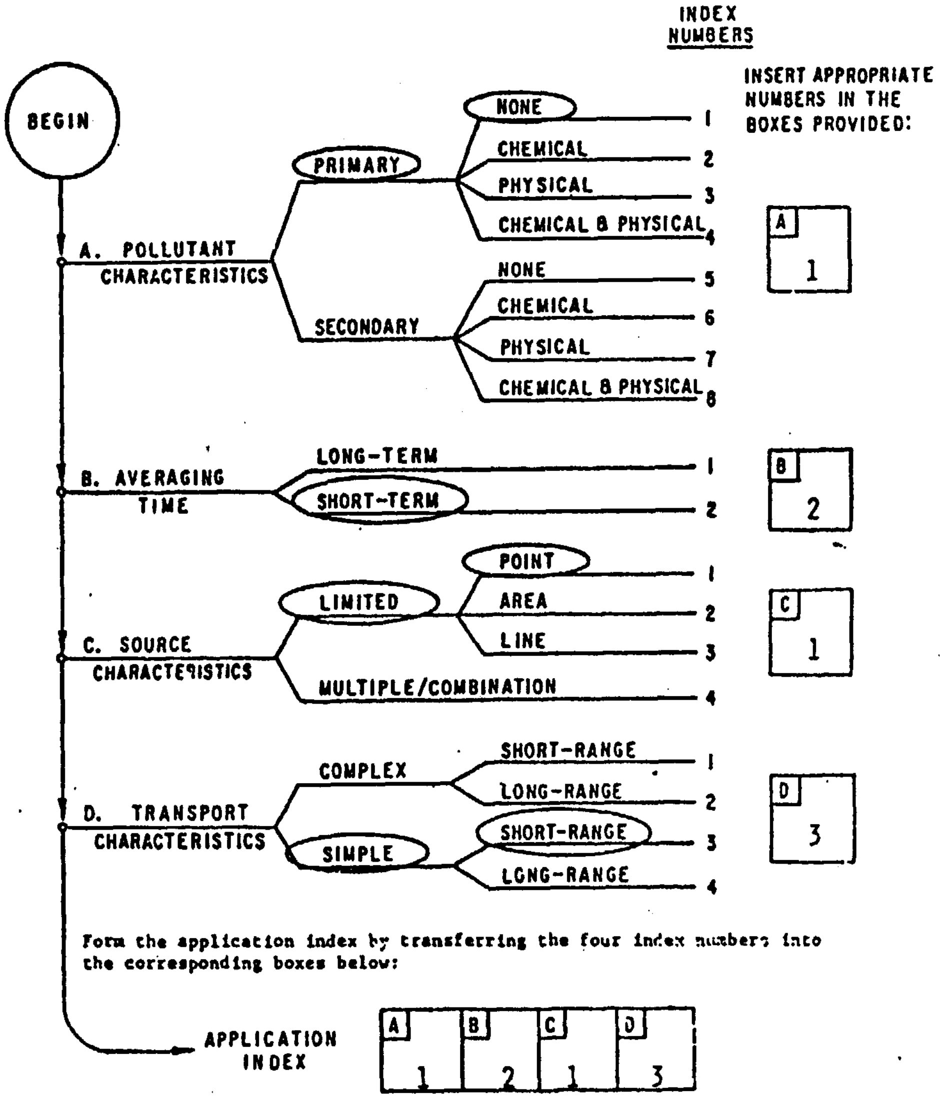
The application of interest involves the estimation of maximum ground level concentrations of sulfur dioxide downwind of a single power plant located in relatively flat terrain, as well as the downwind distance to the maximum, for a variety of conditions. The appropriate application index is 1213 and the suggested reference model is Single Source (CRSTER). CRSTER is used instead of RAM because the application involves a single point source, as explained in footnote j to Table 4.1. PTMAX is classified as a Semiempirical/ Steady-State model and is determined to be applicable. Part A of the Evaluation Form summarizes the general information for this example.

The importance ratings are given on the Evaluation Form - Part B; in this example four modifications have been made. Due to the physical and chemical characteristics of sulfur dioxide and the short range of the application the elements physical removal processes, chemistry and reaction mechansim, and composition of emissions have been rated IRRELEVANT. In addition, due to the desire on the part of the user to estimate <u>maximum</u> downwind concentrations under a variety of conditions, the importance rating of background, boundary and initial conditions has been modified from MEDIUM to HIGH. This modification reflects the need for treating the effects of limited mixing due to a low-lying inversion, a situation which may result in relatively high ground level concentrations.

The reverse side of Part A of the Evaluation Form gives the equations used by PTMAX and Part C gives the treatments, importance ratings, and comparison results for all elements not rated IRRELEVANT. As can be seen, the treatments are very similar in all cases and in all but one case a rating of COMPARABLE is appropriate. The one element which PTMAX does not treat in a manner comparable to that used by CRSTER is background, boundary and initial conditions, for which the treatment by PTMAX is rated WORSE. As in the previous example, PTMAX is rated COMPARABLE to CRSTER for source-receptor relationship and horizontal wind field in spite of obvious differences in the treatments of these elements, because the differences relate to aspects of each element which are not relevant to the real application of interest.

Part D of the Evaluation Form summarizes the individual comparison results. The initial technical evaluation for PTMAX is WORSE due to the worse treatment of background, boundary and initial conditions. Specifically, the treatment used by PTMAX of the effects of the upper boundary is worse than that used by CRSTER. Since the user is particularly interested in maximum concentrations, which may result in part from a low-lying upper boundary, this single WORSE comparison is considered sufficient justification for a WORSE initial comparison. Furthermore, due to the small number of MEDIUM- and LOW-rated elements [illegible]e is no justification for modifying this initial rating. Thus, the appr[illegible] technical evaluation for PTMAX in application 1213 is WORSE.

APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

EVALUATION FORM

Part A: Abstract and References

Study Model: PTMAX

References: Environmental Protection Agency, *User's Network for Applied Modeling of Air Pollution (UNAMAP)*, NTIS PB 229771, National Technical Information Service, Springfield, Va. (1974).

Turner, D.B., *Workbook of Atmospheric Dispersion Estimates*, NTIS PB 191482, National Technical Information Service, Springfield, Va. (1969).

Abstract: PTMAX is a steady-state Gaussian plume model that performs an analysis of the maximum short-term concentrations from a single point source as a function of stability and wind speed. The final plume height is used for each computation. A separate analysis must be made for each individual stack; the model cannot give the maximum concentrations from a combination of stacks.

Classification: Semiempirical/Steady-State

Application Index: 1213

Reference Model: Single Source (CRSTER)

Application Description: Maximum ground level sulfur dioxide concentrations from a single power plant in relatively flat terrain.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A(reverse): Equations

Study Model: PTMAX

Equations:

$$X(x,0,0;H) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1213

Application Element	Importance Rating	
	Initial	Modified[a]
Source-Receptor Relationship	H	H
Emission Rate	H	H
Composition of Emissions	L	I ✓
Plume Behavior	H	H
Horizontal Wind Field	H	H
Vertical Wind Field	L	L
Horizontal Dispersion	H	H
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	I ✓
Background, Boundary, Initial Conditions	M	H ✓
Temporal Correlations	M	M

---

[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

Rule 9 Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Source-Receptor Relationship

Reference Model: Single Source (CRSTER)

Treatment: Up to 19 sources all assumed to be located at same position.

Receptor locations restricted to 36 azimuths (Every 10°) and five user-specified radial distances.

Arbitrary stack height for each source.

Unique topographic elevation for each receptor; must be less than stack heights.

Receptors must be at ground level.
Precise downwind/crosswind distance for each source receptor pair.

Study Model: PTMAX

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment:

Single stack of arbitrary height.

Determines downwind distance of maximum ground level concentration.

Flat terrain assumed.

Application Element: Emission Rate

Reference Model: Single Source (CRSTER)

Treatment:

Single arbitrary value for each source.

Monthly variation allowed.

Study Model: PTMAX

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment:

Single arbitrary constant value.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Plume Behavior

Reference Model: Single Source (CRSTER)

Treatment: Briggs' (1971, 1972) final plume rise; not treated as a function of downwind distance.

If plume height exceeds mixing height, concentrations further downwind assumed equal to zero.

Does not treat either fumigation or downwash.

Study Model: PTMAX

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment: Two step procedure using Briggs' (1971, 1972) final plume rise formulae.

Does not treat fumigation or downwash.

Application Element: Horizontal Wind Field

Reference Model: Single Source (CRSTER)

Treatment: Semiempirical/Sequential (Steady-State).

Constant, uniform wind speed and direction assumed for each of a sequence of hours.

Wind speeds (arbitrary) and directions (nearest 10°) input by user; directions randomized by addition of (n-4)° with n=random integer from zero to nine.

Wind speed corrected for release height, correction using power law variation with exponents dependent on stability class.

Study Model: PTMAX

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment: Semiempirical/Steady-State.

Wind directions implicit along source-receptor direction.

No variation in wind speed with height.

Constant, uniform (steady-state) wind assumed.

Uses fixed, internally defined set of wind speed values ranging from 0.5 to 20 m/sec.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Vertical Wind Field **Reference Model:** Single Source (CRSTER) **Treatment:** Assumed equal to zero (implicit).	**Application Element:** Horizontal Dispersion **Reference Model:** Single Source (CRSTER) **Treatment:** Semiempirical/Sequential (Steady-State). Gaussian plume function assumed. Atmospheric stability divided into seven classes (Pasquill-Gifford); Class 7 - extremely stable - elevated plume assumed not to touch ground. Dispersion coefficients from Turner (1969). Surface roughness not treated explicitly. One-hour averaging time.
Study Model: PTMAX **Importance Rating:** LOW **Comparative Evaluation:** COMPARABLE **Treatment:** Assumed equal to zero (implicit).	**Study Model:** PTMAX **Importance Rating:** LOW **Comparative Evaluation:** COMPARABLE **Treatment:** Semiempirical/Steady-State. Gaussian plume function assumed. Calculations for each of six Pasquill-Gifford stability classes. Dispersion coefficients from Turner (1969); no adjustments made for variations in surface roughness, averaging time or travel time. Averaging time unknown, approximately 10-60 minutes.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Vertical Dispersion **Reference Model:** Single Source (CRSTER) **Treatment:** Semiempirical/Sequential (Steady-State). Gaussian plume function assumed. Atmospheric stability divided into seven (Pasquill-Gifford) classes; Class 7 - extremely stable - elevated plume does not touch ground. Dispersion coefficients from Turner (1969). Surface roughness not treated explicitly.	**Application Element:** Background, Boundary, Initial Conditions **Reference Model:** Single Source (CRSTER) **Treatment:** Background not treated explicitly. Lower boundary: perfect reflection in horizontal plane at receptor height. Upper boundary: Perfect reflection: method of multiple images treated by summation of series until vertical dispersion coefficient = 1.6x (mixing height); uniform vertical mixing thereafter. Mixing height for a given hour obtained by interpolation of radiosonde data.
Study Model: PTMAX **Importance Rating:** HIGH **Comparative Evaluation:** COMPARABLE **Treatment:** Semiempirical/Steady-State. Gaussian plume function assumed. Calculations done for six Pasquill-Gifford stability classes. Dispersion coefficients from Turner (1969). Surface roughness not treated explicitly.	**Study Model:** PTMAX **Importance Rating:** HIGH **Comparative Evaluation:** WORSE **Treatment:** Background not treated explicitly. Lower boundary: perfect reflection at ground level. Upper boundary: mixing height assumed high enough to have no effect.

Rule 9 Continued

Rule 9 Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Temporal Correlations

Reference Model: Single Source (CRSTER)

Treatment: Sequential; correlations automatic for meteorological parameters.

User supplies hourly values of wind speed, wind direction, mixing height, and other meteorological variables required for determining stability class and plume rise.

Monthly emission variation allows limited emission-meteorology correlations.

Study Model: PTMAX

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment:

Correlations automatic - user supplies appropriate data for situation of interest.

Application Element:

Reference Model:

Treatment:

Three IRRELEVANT Elements:

- Composition of emissions
- Chemistry and Reaction Mechanism
- Physical Removal

Study Model:

Importance Rating:

Comparative Evaluation:

Treatment:

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1213 Reference Model: Single Source (CRSTER) Study Model PTMAX

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL	0	-	-	-	-
HIGH	7	0	6	1	WORSE
MEDIUM	1	0	1	0	WORSE
LOW[a]	1	0	1	0	
IRRELEVANT	3	XXX	XXX	XXX	

Total 12 (Should equal 12)

TECHNICAL EVALUATION WORSE

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[a] Used only in ambiguous cases.

C.5. EXAMPLE 5: PTMTP/1213

The application of interest involves the estimation of total one and 24-hour ground level sulfur dioxide concentrations from a few (less than 10-20) nearby power plants located in gently rolling rural terrain. The application index is 1213 and in this example the suggested reference model is RAM, since the application involves several sources at different locations. PTMTP is classified as a Semiempirical/Sequential (Steady-State) model, and is determined to be applicable.

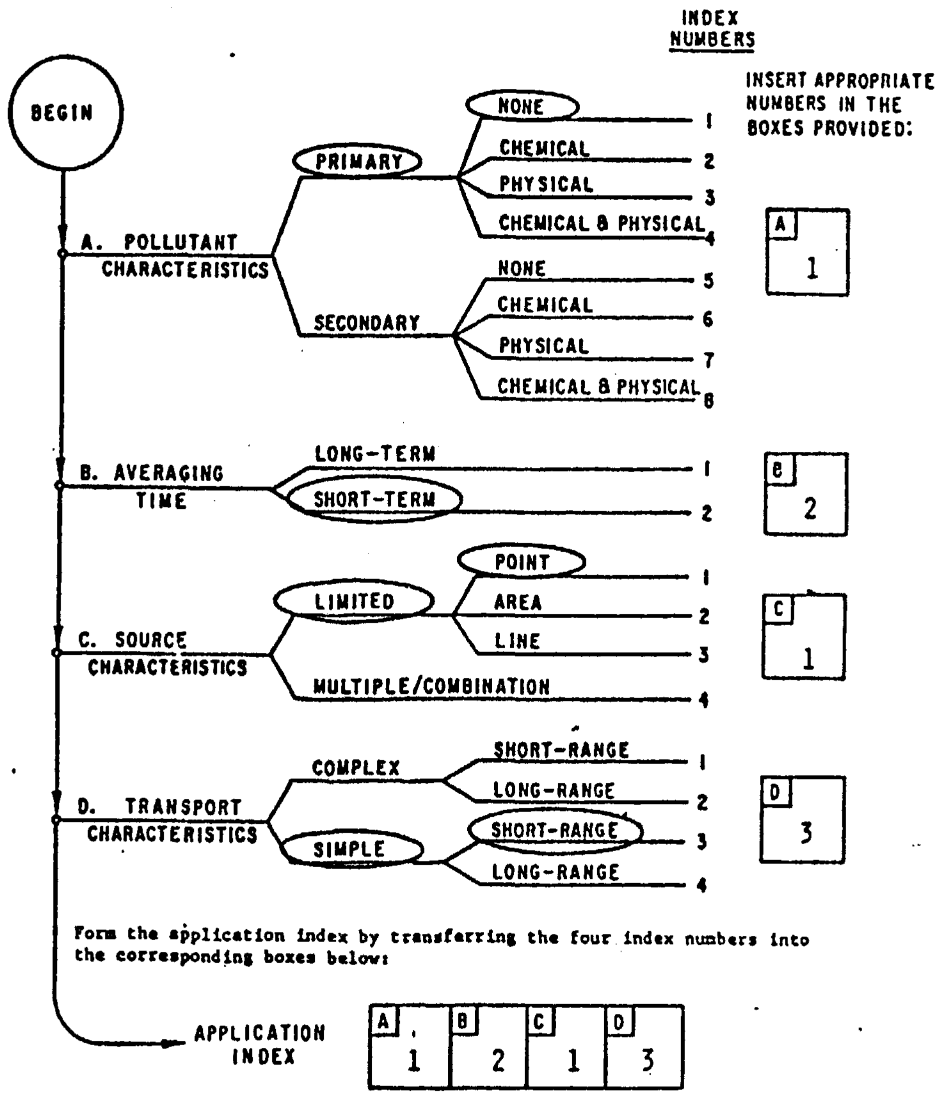
The importance ratings, shown on Part B of the Evaluation Form, incorporate the modification of composition of emissions, chemistry and reaction mechanism, and physical removal processes from LOW to IRRELEVANT. No other modifications are made.

The reverse side of Part A of the Evaluation Form gives the equations used by PTMTP and Part C gives the treatments, importance ratings, and comparisons results. As can be seen, the treatments by PTMTP are all quite similar to those used by RAM and are rated COMPARABLE in all cases. The treatments by RAM of those aspects of source-receptor relationship, emission rate, and other elements that involve consideration of area sources are not given in Part D in this example, because area sources are not involved in this application. These treatments by RAM are irrelevant and are not considered in making the comparisons. A question may arise with regard to horizontal wind field, because PTMTP does not adjust the input wind speed for the source release heights in estimating the contribution of each as does RAM. However, PTMTP does not require that the wind speed near the surface be input, and the user is free to input values appropriate for an average release height for the sources involved. PTMTP does not distinguish between different heights and uses the input wind speed for all sources. This difference between RAM and PTMTP is not considered significant enough to rate PTMTP worse.

The results of the element-by-element comparisons are summarized in Part D of the Evaluation Form and clearly indicate that PTMTP should be rated COMPARABLE to RAM for this application.

: : :

APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

EVALUATION FORM

Part A: Abstract and References

Study Model: PTMTP

References:

Environmental Protection Agency. *User's Network for Applied Modeling of Air Pollution (UNAMAP)*, NTIS PB 229771, National Technical Information Service, Springfield, Va. (1974).

Turner, D.B., *Workbook of Atmospheric Dispersion Estimates*, NTIS PB 191482, National Technical Information Service, Springfield, Va. (1969).

Abstract: PTMTP is a steady-state, Gaussian plume model that estimates for a number of arbitrarily located receptor points at or above ground-level, the concentration from a number of point sources. Plume rise is determined for each source. Downwind and crosswind distances are determined for each source-receptor pair. Concentrations at a receptor from various sources are assumed additive. Hour by hour calculations are made based on hourly meteorological data; both hourly concentrations and averages over any averaging time from one to 24 hours can be obtained.

Classification: Semiempirical/Sequential (Steady-State)

Application Index: 1213

Reference Model: RAM

Application Description: Short term (one and 24 hour) ground level concentrations of sulfur dioxide from several power plants, relatively flat terrain, short range, rural area.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A(reverse): Equations

Study Model: PTMTP

Equations:

$$\chi(x,y,z) = \sum_{n=1}^{N} \chi_n(x,y,z;H_n)$$

with

$$\chi_n(x,y,z;H_n) = \frac{Q_n}{2\pi u \sigma_y \sigma_z} g_1 g_3$$

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{k=-\infty}^{+\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H_n+2kL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H_n+2kL}{\sigma_z}\right)^2\right]\right\}$$

$\chi_n = 0$ if $H_n > L$.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Source-Receptor Relationship	Application Element: Emission Rate
Reference Model: RAM	Reference Model: RAM
Treatment: Arbitrary location and release height for each point source. Flat terrain. Arbitrary receptor locations - all at the same height above (or at) ground. Precise downwind, crosswind distances for each source-receptor pair.	Treatment: Arbitrary constant emission rate for each point source.
Study Model: PTMTP	Study Model: PTMTP
Importance Rating: HIGH	Importance Rating: HIGH
Comparative Evaluation: COMPARABLE	Comparative Evaluation: COMPARABLE
Treatment: Point sources only. Arbitrary location and release height for each of up to 25 point sources. Flat terrain assumed. Arbitrary location and height for each of up to 30 receptors. Precise downwind, crosswind distances evaluated for each source, receptor pair.	Treatment: Single constant emission rate for each point source.

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1213

Application Element	Importance Rating Initial	Importance Rating Modified[a]
Source-Receptor Relationship	H	H
Emission Rate	H	H
Composition of Emissions	L	I ✓
Plume Behavior	H	H
Horizontal Wind Field	H	H
Vertical Wind Field	L	L
Horizontal Dispersion	H	H
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	I ✓
Background, Boundary, Initial Conditions	M	M
Temporal Correlations	M	M

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[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

Rule 9 Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Vertical Wind Field

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Assumed equal to zero (implicit).

Study Model: PTMTP

Importance Rating: LOW

Comparative Evaluation: COMPARABLE

Treatment: Semiempirical/Sequential (Steady-State).

Assumed equal to zero (implicit).

Application Element: Horizontal Dispersion

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Gaussian plume function assumed.

Atmospheric stability divided into six (Pasquill-Gifford) classes, determined hourly.

Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user's option.

Surface roughness not treated explicitly.

One hour averaging time used.

Study Model: PTMTP

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment: Semiempirical/Sequential (Steady-State).

Gaussian plume function assumed.

Atmospheric stability divided into six (Pasquill-Gifford) classes, supplied hourly.

Dispersion coefficients from Turner (1969).

Surface roughness not treated explicitly.

One hour averaging time.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Plume Behavior

Reference Model: RAM

Treatment: Two step procedure.

Uses Briggs' (1971, 1972) downwind distance dependent plume rise formulae for point sources.

If plume height exceeds mixing height, ground level concentrations assumed zero.

Fumigation, downwash not treated.

Study Model: PTMTP

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment: Two step procedure.

Uses Briggs' 2/3 (1971, 1972) downwind distance dependent plume rise formulae.

Does not treat fumigation or downwash.

If plume height exceeds mixing height, concentration further downwind assumed zero.

Application Element: Horizontal Wind Field

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Constant, uniform wind speed and direction assumed for each of a sequence of hours.

Arbitrary wind speeds and direction values to 10° input by user; directions randomized by addition of (n-4)° with n=random integer from zero to nine.

Wind speed is modified to correspond to value at release height, modification dependent only on stability class.

Study Model: PTMTP

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE (WORSE)

Treatment: Semiempirical/Sequential (Steady-State).

Uses sequence of up to 24 user-supplied hourly values of wind speed (arbitrary) and direction (nearest degree).

Constant, uniform wind speed and direction for each hour; no variation of wind speed, direction with height; no correction made for release height.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Temporal Correlations

Reference Model: RAM

Treatment: Sequential

User supplies hourly values of wind speed, wind direction, mixing height, and other meteorological variables required for determination of stability class and plume rise. (Correlations automatic.)

Emission rates constant, not correlated with other parameters.

Application Element:

Reference Model:

Treatment:

Three IRRELEVANT elements:

- Composition of Emissions
- Chemistry and Reaction Mechanism
- Physical Removal Processes

Study Model: PTMTP

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment: Sequential.

User supplies hourly values of wind speed, wind direction, stability class, mixing height.

Correlations among these parameters are automatically treated.

Emission rates constant.

Study Model:

Importance Rating:

Comparative Evaluation:

Treatment:

Rule Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1213

Application Element: Vertical Dispersion

Reference Model: RAM

Treatment: Semiempirical/Sequential (Steady-State).

Gaussian plume function assumed.

Atmospheric stability divided into six (Pasquill-Gifford) classes, determined hourly.

Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user's option.

Surface roughness not treated explicitly.

Application Element: Background, Boundary, Initial Conditions

Reference Model: RAM

Treatment: Background not treated explicitly.

Both upper and lower boundaries - perfect reflection.

1) Neutral and unstable conditions: method of multiple images treated by summation of infinite series until σ_z = 1.6× (mixing height); uniform mixing assumed thereafter;

2) Stable conditions: mixing height assumed to have no effect.

Mixing height for a given hour obtained by interpolation of radiosonde data.

Study Model: PTMTP

Importance Rating: HIGH

Comparative Evaluation: COMPARABLE

Treatment: Semiempirical/Sequential (Steady-State).

Gaussian plume function assumed.

Atmosperic stability divided into six (Pasquill-Gifford) classes, supplied hourly.

Dispersion coefficients from Turner (1969).

Surface roughness not treated explicitly.

One hour averaging time.

Study Model: PTMTP

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment: Background not treated explicitly.

Both upper and lower boundaries - perfect reflection assumed.

Multiple reflections treated by summation of series.

Uses user-supplied hourly mixing height.

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1213 Reference Model: RAM Study Model PTMTP

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL	0	-	-	-	-
HIGH	6	0	6(5)	0(1)	COMPARABLE
MEDIUM	2	0	2	0	COMPARABLE
LOW[a]	1	0	1	0	
IRRELEVANT	3	XXX	XXX	XXX	

Total 12 (Should equal 12)

TECHNICAL EVALUATION COMPARABLE

---

[a] Used only in ambiguous cases.

C.6 EXAMPLE 6: HANNA-GIFFORD/1243

In this example, the application of interest involves the estimation of one and twenty-four hour total suspended particulate concentrations from near ground-level area sources within an urban area located in relatively flat terrain. The application index is 1243 and the suggested reference model is RAM.

There are two forms of the Hanna-Gifford model which have been discussed in the modeling literature. One form is that used in this example, and the other form is used in Example 7, Appendix C.7. The user may examine the equations presented on the reverse side of Part A of the Evaluation Form in these two examples to see the differences between the two versions of the model.

The Hanna-Gifford model is not available as a computer program accompanied by a comprehensive user's manual. Rather, the model has been presented and discussed in a series of literature publications, three of which are cited on Part A of the Evaluation Form. Consequently, different users may implement the methods of Hanna and Gifford in different ways and the results obtained may not be strictly said to have arisen from the same algorithm. In this example it is assumed that the equations are applied separately to each of a sequence of twenty-four hours. The reference model, RAM, works in the same manner.

The Hanna-Gifford model is classified Semiempirical/Sequential (Steady-State) and is determined to be applicable to the situation to be modeled.

The importance ratings shown on Part B incorporate three modifications. Chemistry and reaction mechanism has been designated as IRRELEVANT. The importance of plume behavior has been changed from MEDIUM to LOW on the assumption that the particular area sources in question do not give rise to significant plume rise. Also, since the sources are near ground-level, there is no need to consider downwash and fumigation. Finally, the importance rating of horizontal dispersion has been changed from HIGH to MEDIUM due to the fact that only area sources are of interest in this case. The modified rating corresponds to the rating for horizontal dispersion in application number 1223, which involves area sources only.

Part C gives the treatments, importance ratings, and comparison results. It should be noted that the treatments by RAM, the reference model, of the various aspects of each element that deal with point sources have been omitted. These treatments are irrelevant in this particular application and are not considered in making the evaluation.

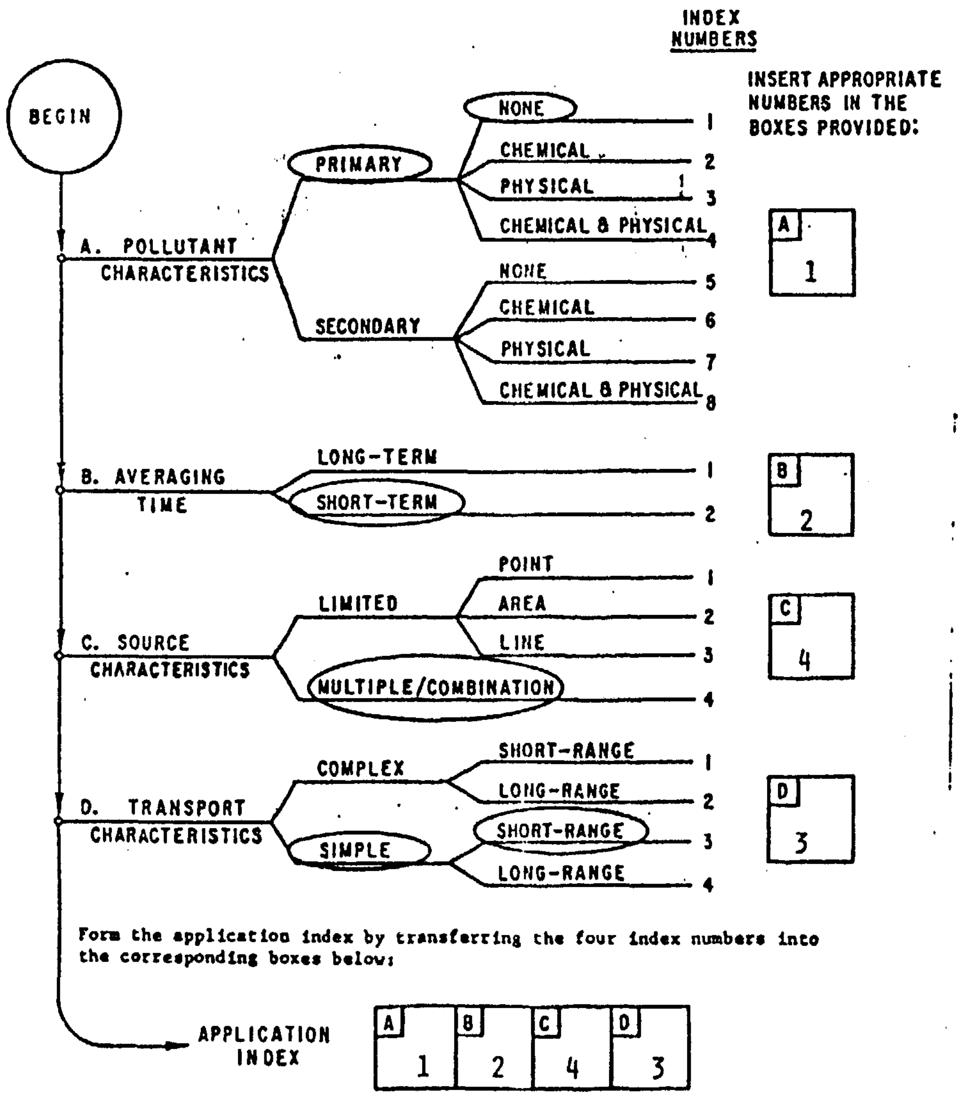
Both RAM and the Hanna-Gifford model make use of similar methods for estimating total area source contributions and this similarity is reflected in the treatments of many of the application elements. Significant differences in the models occur, however, as a result of differences in the implementation of these similar methods. Nevertheless, the initial comparative evaluation of the Hanna-Gifford model is COMPARABLE, based on comparable treatments of the three HIGH-rated elements. It should be noted that for one of the high elements, source-receptor relationship, the Hanna-Gifford model was rated COMPARABLE even though it assumes ground level emissions while RAM allows the user to specify non-zero effective emission heights. In the application of interest this difference is unimportant, because the emissions are known to be released near the ground. In other applications, in which it is known that some or all such emissions effectively occur above ground level, this difference may be significant enough to justify a WORSE rating. This type of decision can only be made by a person familiar with the actual situation of interest.

The two MEDIUM-rated elements whose treatments by the Hanna-Gifford model are rated WORSE are horizontal wind field and background, boundary and initial conditions. The treatment of horizontal wind field by the Hanna-Gifford model is rated WORSE, because only sixteen possible wind directions are used whereas RAM accepts wind directions to the nearest 10° and randomizes these so that the wind direction may correspond to any of 360 different values. The treatment of background, boundary and initial conditions is rated WORSE, because the Hanna-Gifford model does not treat the effects of the upper boundary. A secondary comparison of COMPARABLE is indicated, because for ground level sources, the effects of the upper boundary may not be felt for a substantial distance downwind, depending on the depth of the mixed layer and the wind speed.

The substantial number of MEDIUM-rated elements that are treated WORSE by Hanna-Gifford together with the relatively small number of HIGH-rated elements and the absence of any HIGH or MEDIUM-rated elements that are treated BETTER provides adequate justification for modifying the comparative evaluation from COMPARABLE to WORSE in this application. The treatments of the LOW-rated elements support this modification although little weight is attached to them. The appropriate technical evaluation of the Hanna-Gifford model in application 1243 is therefore WORSE.

Rule 932, Continued

APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

APPLICATION INDEX

A	B	C	D
1	2	4	3

EVALUATION FORM

Part A: Abstract and References

Study Model: Hanna-Gifford

References:

Hanna, S.R., "A Simple Method of Calculating Dispersion from Urban Area Sources." *J. Air Pollution Control Assn.*, Vol. 21, No. 12, pp. 774-777, December 1971.

Gifford, F.A., and S.R. Hanna, "Modeling Urban Air Pollution." *Atmospheric Environment*, Vol. 7, pp. 131-136, 1973.

Gifford, F.A. and S.R. Hanna, "Urban Air Pollution Modeling." Paper No. ME-320, Proc. 2nd International Clean Air Congress, Washington, D.C., pp. 1146-1151 (December 1970).

Abstract: The Hanna-Gifford model is an area source model based upon the assumption of a Gaussian pollutant distribution in the vertical and using the narrow-plume approximation (homogeneous emissions in the crosswind direction) in the horizontal direction.

Classification: Semiempirical/Sequential (Steady-State)

Application Index: 1243 **Reference Model:** RAM

Application Description: One and twenty-four hour concentrations of total suspended particulate matter from area sources in an urban area for a given period, flat terrain.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A(reverse): Equations

Study Model: Hanna-Gifford

Equations:

$$\chi = \sqrt{\frac{2}{\pi}}\ \frac{1}{u} \int_0^\infty \frac{q(x)}{\sigma_z}\, dx$$ Narrow plume approximation, ground level sources.

$$\chi = \sqrt{\frac{2}{\pi}}\ \frac{1}{u}\ \frac{(\Delta x/2)^{1-b}}{a(1-b)} \left[Q_o + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b} \right] \right]$$

$$\sigma_z(x) = ax^b$$

N = number of upwind grid squares.

Δx = width of a grid square.

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1243

Application Element	Importance Rating	
	Initial	Modified[a]
Source-Receptor Relationship	M	M
Emission Rate	M	M
Composition of Emissions	L	L
Plume Behavior	H	L ✓
Horizontal Wind Field	M	M
Vertical Wind Field	L	L
Horizontal Dispersion	H	M ✓
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	L
Background, Boundary, Initial Conditions	M	M
Temporal Correlations	M	M

[a] With the exception of the designation of IRRELEVANT elements, it is expected that <u>at most</u> one CRITICAL designation and possibly one other modification may be made.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Source-Receptor Relationship

Reference Model: RAM

Treatment:

Area sources defined as square cells (or multiples) in a rectangular array; up to three effective release heights (for u = 5m/sec) user-specified; sides lie along grid boundary directions.

Arbitrary receptor locations - all at the same height above (or at) ground.

Flat terrain assumed.

Downwind distance calculated for points along rays which intersect area sources.

Study Model: Hanna-Gifford

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment:

Area sources only, square cells in a rectangular array.

Receptors and sources both at ground level.

Each receptor assumed located at center of a grid square.

Flat terrain assumed.

Application Element: Emission Rate

Reference Model: RAM

Treatment:

Arbitrary constant emission rate for each area source.

Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for area source with given effective release height.

Includes only those areas intersected by the upwind ray.

Study Model: Hanna-Gifford

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment:

Arbitrary constant emission rate for each area source.

Area source contributions obtained by analytic integration along upwind distance of narrow-plume approximation formulae for area source at ground level oriented perpendicular to upwind direction.

Includes only grid squares directly upwind of receptor.

Rule C Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Composition of Emissions

Reference Model: RAM

Treatment:

Single representative pollutant only; no treatment of size distribution.

Study Model: Hanna-Gifford

Importance Rating: LOW

Comparative Evaluation: COMPARABLE

Treatment:

Single representative pollutant only.

No treatment of size distribution.

Application Element: Plume Behavior

Reference Model: RAM

Treatment:

No plume rise calculated for area sources; assumed to be included in release height.

Fumigation, downwash not treated.

Study Model: Hanna-Gifford

Importance Rating: LOW

Comparative Evaluation: WORSE

Treatment:

Not treated explicitly; effective release height assumed zero.

Fumigation, downwash not treated.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Horizontal Wind Field	Application Element: Vertical Wind Field
Reference Model: RAM	Reference Model: RAM
Treatment: Semiempirical/Sequential (Steady-State).	Treatment: Semiempirical/Sequential (Steady-State)
Constant, uniform wind speed and direction assumed for each of a sequence of hours.	Assumed equal to zero (implicit).
Arbitrary wind speeds and direction values to 10° input by user; directions randomized by addition of (n - 4)° with n = random integer from zero to nine.	
Wind speed is modified to correspond to value at release height, modification dependent only on stability class.	
Study Model: Hanna-Gifford	Study Model: Hanna-Gifford
Importance Rating: MEDIUM	Importance Rating: LOW
Comparative Evaluation: WORSE	Comparative Evaluation: COMPARABLE
Treatment: Semiempirical/Sequential (Steady-State).	Treatment: Semiempirical/Sequential (Steady-State).
Constant, uniform wind speed, direction assumed for each of a sequence of hours.	Assumed equal to zero (implicit).
Wind speed arbitrary; wind direction restricted to one of 16 equally spaced directions.	

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Horizontal Dispersion	Application Element: Vertical Dispersion
Reference Model: RAM	Reference Model: RAM
Treatment: Semiempirical/Sequential (Steady-State).	Treatment: Semiempirical/Sequential (Steady-State).
Narrow plume approximation for area sources; horizontal dispersion not treated explicitly.	Gaussian plume function assumed.
	Atmospheric stability divided into six (Pasquill-Gifford) classes, determined hourly.
	Dispersion coefficients from Turner (1969) or McElroy and Pooler (1968) at user's option.
	Surface roughness not treated explicitly.
Study Model: Hanna-Gifford	Study Model: Hanna-Gifford
Importance Rating: MEDIUM	Importance Rating: HIGH
Comparative Evaluation: COMPARABLE	Comparative Evaluation: COMPARABLE
Treatment: Semiempirical/Sequential (Steady-State).	Treatment: Semiempirical/Sequential (Steady-State).
Narrow plume approximation; horizontal dispersion not treated explicitly.	Gaussian plume function assumed.
	Atmospheric stability divided into classes (Smith 1968).
	Dispersion coefficient $\sigma_z = ax^b$ with a,b from Smith (1968) or Briggs (1973).
	Surface roughness not treated explicitly.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Physical Removal

Reference Model: RAM

Treatment:

Exponential decay - first order (linear) processes.

Single, constant user - specified decay constant.

Application Element: Background, Boundary, Initial Conditions

Reference Model: RAM

Treatment: Background not treated explicitly.

Both upper and lower boundaries perfect reflection.

1) Neutral and unstable conditions: method of multiple images treated by summation of infinite series until σ_z = 1.6×(mixing height); uniform mixing assumed thereafter;
2) Stable conditions: mixing height assumed to have no effect.

Mixing height for given hour obtained by interpolation of radiosonde data.

Study Model: Hanna-Gifford

Importance Rating: LOW

Comparative Evaluation: WORSE

Treatment:

Not treated explicitly.

Study Model: Hanna-Gifford

Importance Rating: MEDIUM

Comparative Evaluation: WORSE (COMPARABLE)

Treatment:

Background: single additive constant.

Lower boundary: perfect reflection.

Upper boundary: assumed high enough to have no effect; atmospheric stability assumed constant to above the the plume height.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1243

Application Element: Temporal Correlations

Reference Model: RAM

Treatment: Sequential.

User supplies hourly values of wind speed, wind direction, mixing height, and other meteorological variables required for determination of stability class and plume rise. (Correlations automatic.)

Emission rates constant, not correlated with other parameters.

Application Element:

Reference Model:

Treatment:

One IRRELEVANT element:

- Chemistry and Reaction Mechanism

Study Model: Hanna-Gifford

Importance Rating: MEDIUM

Comparative Evaluation: COMPARABLE

Treatment: Sequential.

Hourly values of wind speed, direction, stability supplied by user. (Correlations automatic.)

Emission rates constant; not correlated with other parameters.

Study Model:

Importance Rating:

Comparative Evaluation:

Treatment:

Rule

Continued

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1243 Reference Model: RAM Study Model Hanna-Gifford

Importance Rating of Application Elements	Number of Treatments Total	 BETTER	 COMPARABLE	 WORSE	Comparative Rating of Study Model
CRITICAL	0	-	-	-	-
HIGH	1	0	1	0	COMPARABLE
MEDIUM	6	0	4 (5)	2 (1)	WORSE
LOW	4	0	2	2	
IRRELEVANT	1	XXX	XXX	XXX	
Total	12 (Should equal 12)				

TECHNICAL EVALUATION WORSE

C.7 EXAMPLE 7: HANNA-GIFFORD/1143

The application of interest involves the estimation of long-term ground-level total suspended particulate concentrations arising from near ground-level area sources in an urban area located in relatively flat terrain. The application index is 1143 and the suggested reference model is CDM.

As explained in Example 6, Appendix C.6, two forms of the Hanna-Gifford model have been discussed in the references given on Part A of the Evaluation Form. One was used in Example 6 and the other is used in this example. Also, as pointed out in Example 6, the Hanna-Gifford model has been presented in a series of literature publications rather than in a user's manual accompanied by a computer code. As a result, the implementation of the Hanna-Gifford model in a specific application may depend to some extent on the user. In this example the procedure used by Hanna (1971) is considered.

The Hanna-Gifford model is classified Semiempirical/Climatological (Steady-State). The climatological classification seems most appropriate, since a climatological average wind speed is used in the equation, even though this form of the model does not appear to exactly correspond to the definition of a climatological model used in this workbook. In fact however, the equation used in this example may be derived from a climatological version of the other form of the model given certain assumptions regarding the nature of the stability-wind rose used. The Hanna-Gifford model is determined to be applicable to the situation to be modeled.

Two modifications have been made in the importance ratings. Chemistry and reaction mechanism has been rated IRRELEVANT, and the importance rating of plume behavior has been changed from MEDIUM to LOW due to the assumed nature of the area sources in question, as in the previous example.

The working equations are given on the reverse side of Part A and the treatments, importance ratings, and comparisons are given on Part C of the Evaluation Form. The treatments by the reference model (CDM) of point-source related aspects of each element have been omitted as they are irrelevant in this application.

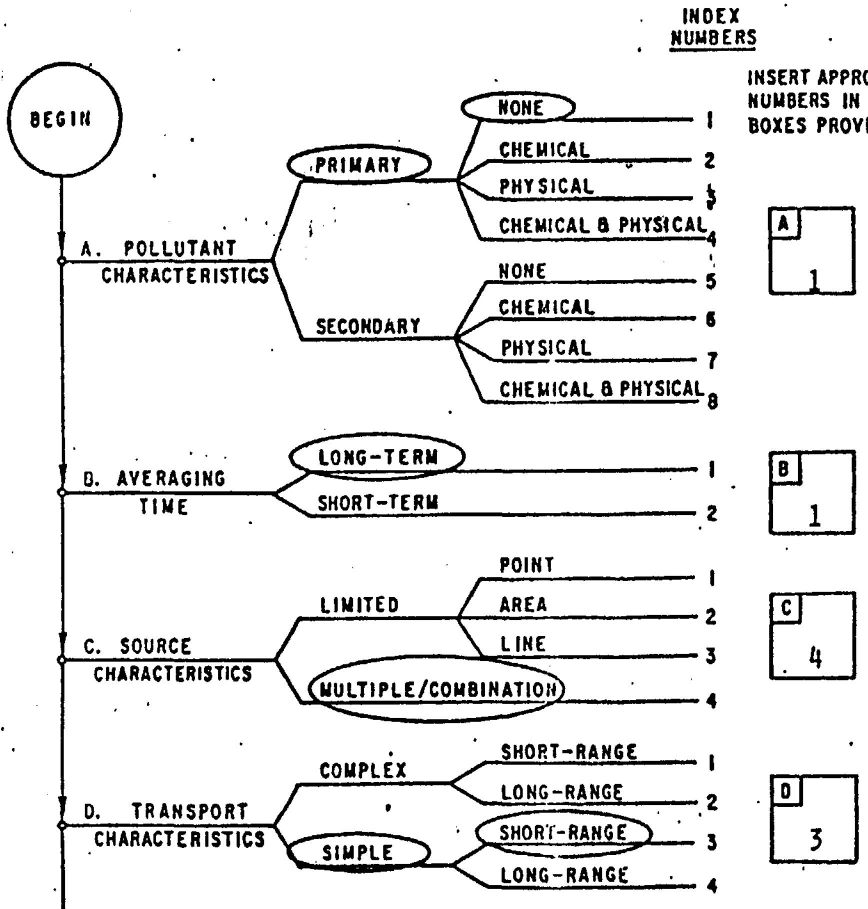
Only one element, vertical dispersion, is rated as being of HIGH importance in this application and the treatment by this form of the Hanna-Gifford model is considered WORSE than that used by CDM, because only one stability class (neutral) is considered. Had the model been implemented in a slightly different way, this particular aspect of the treatment could have easily been modified. A secondary comparison of COMPARABLE is indicated, because neutral stability is indeed expected to occur more frequently than any other in an urban area. A user familiar with the specific area to be mod [illegible]s in the best position to judge the adequacy of this treatment in that area. Other aspects of the two treatments of vertical dispersion are comparable.

The treatments of the MEDIUM-rated elements show a definite bias toward a WORSE rating. The treatments of emission rate and horizontal dispersion are rated definitely COMPARABLE, and the treatment of source-receptor relationship is rated COMPARABLE although with a secondary rating of WORSE due to the treatment of only the one grid square containing the receptor. The validity of this procedure is related to the spatial variability of the emission rates for nearby grid squares, which in turn depends in part on the size of the grid square used. The treatment of horizontal wind field is rated WORSE, as is the treatment of background, boundary and initial conditions although for this element on a secondary rating of COMPARABLE is indicated. The uncertainty in the comparison for background, boundary and initial conditions arises because, although the Hanna-Gifford model does not treat effects due to the upper boundary, these effects may not be important for ground level sources at short to moderate range, depending on the depth of the mixing layer. Of the two uncertain ratings, the one for background, boundary and initial conditions is considered the greater, and the distributions of treatments for MEDIUM-rated elements which deserve the most consideration are 0,3,2 and 0,2,3.

The results for the MEDIUM-rated elements clearly support the initial rating of WORSE and the LOW-rated elements also support this rating. The appropriate technical evaluation for this form of the Hanna-Gifford model is therefore WORSE in this application.

Rule 932, Continued

APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

APPLICATION INDEX

A	B	C	D
1	1	4	3

EVALUATION FORM

Part A: Abstract and References

Study Model: Hanna-Gifford

References:

Hanna, S.R., "A Simple Method of Calculating Dispersion from Urban Area Sources." *J. Air Pollution Control Assn.*, Vol. 21, No. 12, pp. 774-777, December 1971.

Gifford, F.A., and S.R. Hanna, "Modeling Urban Air Pollution." *Atmospheric Environment*, Vol. 7, pp. 131-136, 1973.

Gifford, F.A., and S.R. Hanna, "Urban Air Pollution Modeling." Paper No. ME-320, Proc. 2nd International Clean Air Congress, Washington, D.C., pp. 1146-1151 (December, 1970).

Abstract: The Hanna-Gifford model is an area source model based upon the assumption of a Gaussian pollutant distribution in the vertical and using the narrow-plume approximation (homogeneous emissions in the crosswind direction) in the horizontal direction.

Classification: Semiempirical/Climatological (Steady-State)

Application Index: 1143

Reference Model: CDM

Application Description: Long-term ground-level total suspended particulate concentrations from near ground-level area sources in an urban area.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A(reverse): Equations

Study Model: Hanna-Gifford

Equations:

$$X = C \frac{Q_o}{u}$$

with

X = ground level concentration in a given grid square.

Q_o = emission rate per unit area in the same square.

u = average wind speed over the period of interest.

$$C = \sqrt{\frac{2}{\pi}} \left(\frac{2N+1}{2} \Delta x \right)^{1-b} \frac{1}{a(1-b)}$$

with

$N = 4$

Δx = grid spacing (meters)

$a = 0.15$ meters^{1-b}

$b = 0.75$

(a and b correspond to parameters in the representation of the vertical dispersion coefficient:

$$\sigma_z = ax^b.$$

The values are those recommended by M.E. Smith (1968) for neutral stability.)

EVALUATION FORM

Part B: Importance Ratings

Application Index: 1143

Application Element	Importance Rating	
	Initial	Modified[a]
Source-Receptor Relationship	M	M
Emission Rate	M	M
Composition of Emissions	L	L
Plume Behavior	M	L ✓
Horizontal Wind Field	M	M
Vertical Wind Field	L	L
Horizontal Dispersion	M	M
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	L	I ✓
Physical Removal Processes	L	L
Background, Boundary, Initial Conditions	M	M
Temporal Correlations	L	L

[a] With the exception of the designation of IRRELEVANT elements, it is expected that <u>at most</u> one CRITICAL designation and possibly one other modification may be made.

Rule 9' continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Source-Receptor Relationship	Application Element: Emission Rate
Reference Model: CDM	Reference Model: CDM
Treatment: Area sources integral multiples of basic grid square. Receptor location arbitrary. Arbitrary release heights for area sources. Precise separation for each source-receptor pair. Receptors are at ground level. No terrain differences between source/receptor. Sides of area sources lie along grid boundary directions.	Treatment: Arbitrary emission rate for each area source. Area integrations are done numerically one 22.5° sector at a time; sampling at discrete points defined by specific radial and angular intervals on a polar grid centered on the receptor. Day/night variations in emissions, same variation assumed for all sources; no other temporal variation.
Study Model: Hanna-Gifford	Study Model: Hanna-Gifford
Importance Rating: MEDIUM	Importance Rating: MEDIUM
Comparative Evaluation: COMPARABLE (WORSE)	Comparative Evaluation: COMPARABLE
Treatment: Single square, ground-level area source over which emissions are approximately uniform, considered for each receptor. Arbitrary grid size, user-specified. Ground-level receptors, located arbitrarily within source area. Flat terrain assumed. Area sources square cells in user-specified grid.	Treatment: Single constant emission rate for the source area. Area source contribution obtained by analytic integration along upwind direction of narrow-plume approximation formulae for ground-level source.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Composition of Emissions	Application Element: Plume Behavior
Reference Model: CDM	Reference Model: CDM
Treatment: Treats up to two independent pollutants.	Treatment: No plume rise calculated for area sources. Does not treat fumigation or downwash.
Study Model: Hanna-Gifford	Study Model: Hanna-Gifford
Importance Rating: LOW	Importance Rating: LOW
Comparative Evaluation: COMPARABLE	Comparative Evaluation: COMPARABLE
Treatment: Independent pollutants, treated one at a time.	Treatment: Not treated explicitly; effective release height assumed zero. Does not treat downwash or fumigation.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Horizontal Wind Field	Application Element: Vertical Wind Field
Reference Model: CDM Treatment: Climatological. 16 wind directions. 6 wind speed classes. Wind speed corrected for release height based on power law variation; exponents from DeMarrais (1959). Stability class dependent. Constant, uniform (steady-state) wind assumed.	Reference Model: CDM Treatment: Assumed equal to zero (implicit).
Study Model: Hanna-Gifford Importance Rating: MEDIUM Comparative Evaluation: WORSE Treatment: Climatological Only average wind speed in area of interest is considered. No variation of wind speed with height.	Study Model: Hanna-Gifford Importance Rating: LOW Comparative Evaluation: COMPARABLE Treatment: Assumed equal to zero (implicit).

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Horizontal Dispersion	Application Element: Vertical Dispersion
Reference Model: CDM Treatment: Semiempirical/Climatological (Steady-State). Uniform distribution within each of 16 sectors (sector averaging). Averaging time = one month to one year. Atmospheric stability and surface roughness not treated explicitly.	Reference Model: CDM Treatment: Semiempirical/Climatological (Steady-State). Gaussian plume function assumed. Five stability classes as defined by Turner (1964), neutral stability split into day/night cases. Dispersion coefficients taken from Turner (1970). Area sources - stability class is decreased by one category from input values to account for urban effects. Neutral dispersion coefficients are used for all neutral and stable classes. Surface roughness not treated explicitly.
Study Model: Hanna-Gifford Importance Rating: MEDIUM Comparative Evaluation: COMPARABLE Treatment: Semiempirical/Climatological (Steady-State). Narrow-plume approximation; horizontal dispersion not treated explicitly.	Study Model: Hanna-Gifford Importance Rating: HIGH Comparative Evaluation: WORSE (COMPARABLE) Treatment: Semiempirical/Climatological (Steady-State) Gaussian plume function assumed. Single atmospheric stability (neutral) considered. Dispersion coefficient $\sigma_z = ax^b$; a, b from Smith (1968). Surface roughness not treated explicitly.

Rule Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Physical Removal **Reference Model:** CDM **Treatment:** Treats only first-order (linear) processes. Single, constant user-supplied halflife used - exponential decay.	**Application Element:** Background, Boundary, Initial Conditions **Reference Model:** CDM **Treatment:** Input single constant background value for each pollutant. Lower boundary (ground): Perfect reflection. Upper boundary (mixing height): Perfect reflection. No effect until vertical dispersion coefficient equals 0.8 of mixing height, uniform vertical mixing assumed beyond this point.
Study Model: Hanna-Gifford **Importance Rating:** LOW **Comparative Evaluation:** WORSE **Treatment:** Not treated explicitly.	**Study Model:** Hanna-Gifford **Importance Rating:** MEDIUM **Comparative Evaluation:** WORSE (COMPARABLE) **Treatment:** Background: single additive constant. Lower boundary: perfect reflection. Upper boundary: Assumed high enough to have no effect; atmospheric stability assumed constant to above the plume height.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 1143

Application Element: Temporal Correlations **Reference Model:** CDM **Treatment:** Wind speed, direction, stability correlated via wind rose; mixing height is adjusted according to stability class: Class A - 1.5 x afternoon climatological value; Class D (night) - average of morning and afternoon climatological values; Class E - morning climatological value. Emission rates: day-night variation allowed; all sources assumed to vary by same factor. Non-sequential (climatological) limited correlation.	**Application Element:** **Reference Model:** **Treatment:** One IRRELEVANT element: o Chemistry and reaction mechanism.
Study Model: Hanna-Gifford **Importance Rating:** LOW **Comparative Evaluation:** WORSE **Treatment:** Correlations not treated explicitly.	**Study Model:** **Importance Rating:** **Comparative Evaluation:** **Treatment:**

EVALUATION FORM

Part D: Technical Comparison

Application Index: 1143 Reference Model: CDM Study Model Hanna-Gifford

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL	0	-	-	-	-
HIGH	1	0	0 (1)	1 (0)	WORSE
MEDIUM	5	0	3 (4-2)	2 (1-3)	WORSE
LOW	5	0	3	2	
IRRELEVANT	1	XXX	XXX	XXX	

Total 12 (Should equal 12)

TECHNICAL EVALUATION WORSE

C.8. EXAMPLE 8: APPENDIX J/6243

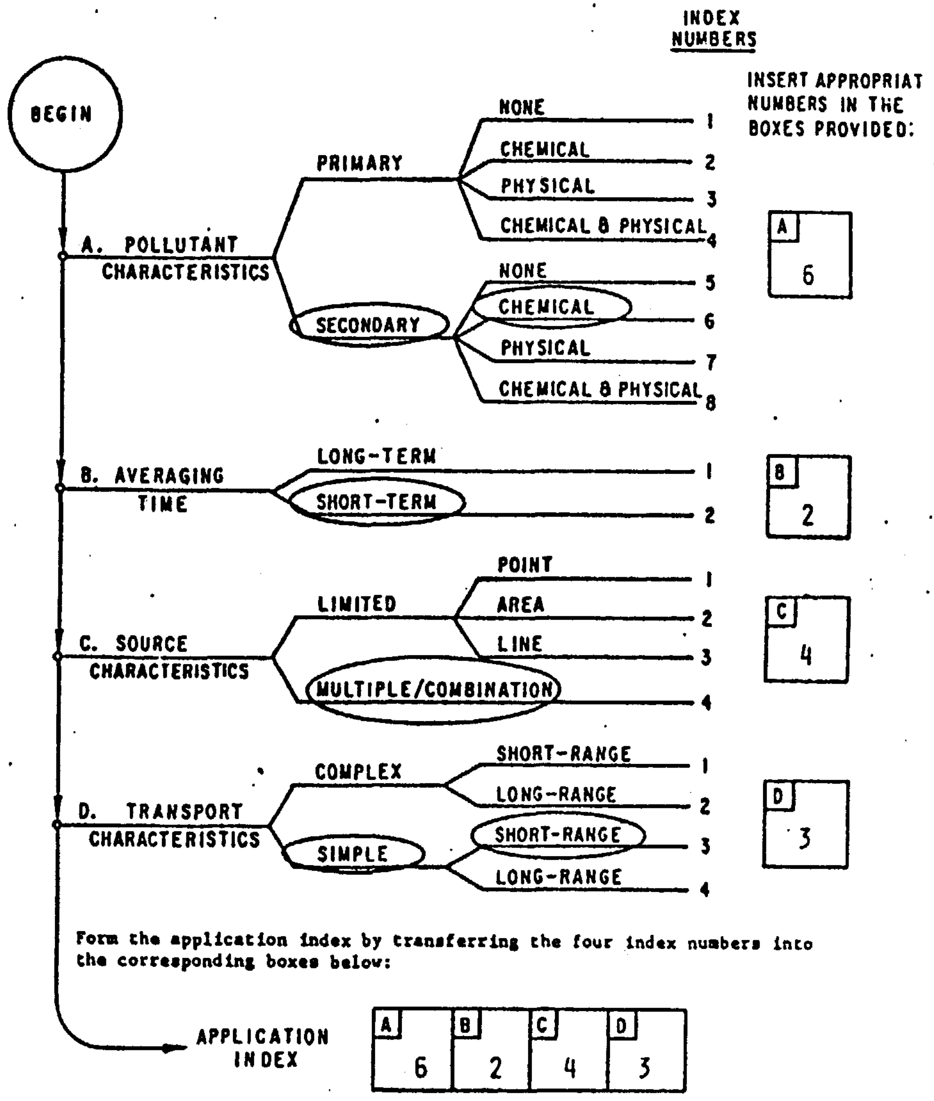
In this example, the application involves the estimation of the percent reduction of hydrocarbon emissions required in order to achieve the National Ambient Air Quality Standard for photochemical oxidant in Sample City, a moderately sized urban area located in gently rolling terrain. The appropriate Application Index is 6243 and the suggested reference model is the SAI urban photochemical model.

The study model in this example is Appendix J. Appendix J consists of a single graph of percent hydrocarbon reduction against maximum measured one-hour photochemical oxidant concentration. Given the appropriate oxidant measurement from Sample City, the required percent reduction may be read directly from the graph. The curve is based on a simple rollback model in combination with an empirical "upper limit curve," which represents the upper envelope of a plot of maximum daily one-hour oxidant levels against 6-9 AM non-methane hydrocarbon levels, the data being accumulated from several U.S. cities. The upper limit curve provides an approximate relationship between oxidant levels and precursor (hydrocarbon) levels under worst case conditions. The appropriate classification of Appendix J is therefore Rollback/Statistical.

The equations are documented and Appendix J is determined to be applicable and the "applicable" box of Part A of the Evaluation Form is checked. Then, in accordance with the instructions in Section 2, the guidelines in Section 7 are consulted immediately following Step 4 of the procedure, the classification of the study model as a Rollback/Statistical model. It is assumed that an element-by-element examination of the approximations inherent in Appendix J compared to the SAI model is desired. Therefore, Parts B, C, and D of the Evaluation Form are filled out in the same manner as if two simulation models were being compared.

With only one exception, the element-by-element comparisons of Appendix J with the SAI model indicate that Appendix J is WORSE. The single element in which they are rated COMPARABLE is physical removal, which is not treated by the version of the SAI model used as a reference model in this workbook. The technical evaluation of Appendix J is clearly WORSE. This should be interpreted as meaning that the approximations that must be made to reduce the SAI working equations to the Appendix J curve are determined to be not justified in this application.

APPLICATION CLASSIFICATION FORM



Form the application index by transferring the four index numbers into the corresponding boxes below:

EVALUATION FORM

Part A: Abstract and References

Study Model: Appendix J

References: Federal Register 36 No. 158, August 14, 1971.

Air Quality Criteria for Nitrogen Oxides, AP-84, Environmental Protection Agency, Washington, (January 1971).

Abstract: Appendix J is a method for estimating the percent reduction of hydrocarbon emissions within an urban area required in order to achieve the National Ambient Air Quality Standard for photochemical oxidant in that area. The method is based on the use of simple rollback together with an empirical relationship between the maximum observed oxidant concentration and measured non-methane hydrocarbon concentractions.

Classification: Rollback/Statistical

Application Index: 6243 **Reference Model:** SAI

Application Description: Estimate percent reduction in hydrocarbon emissions in given urban area required to meet photochemical oxidant standard.

Model Applicability: Applicable ☒ Not Applicable ☐

EVALUATION FORM

Part A (reverse): Equations

Study Model: Appendix J

Equations:

$$\text{Percent hydrocarbon emission reduction} = \frac{X_{max} - X_{std}}{X_{max}} \times 100$$

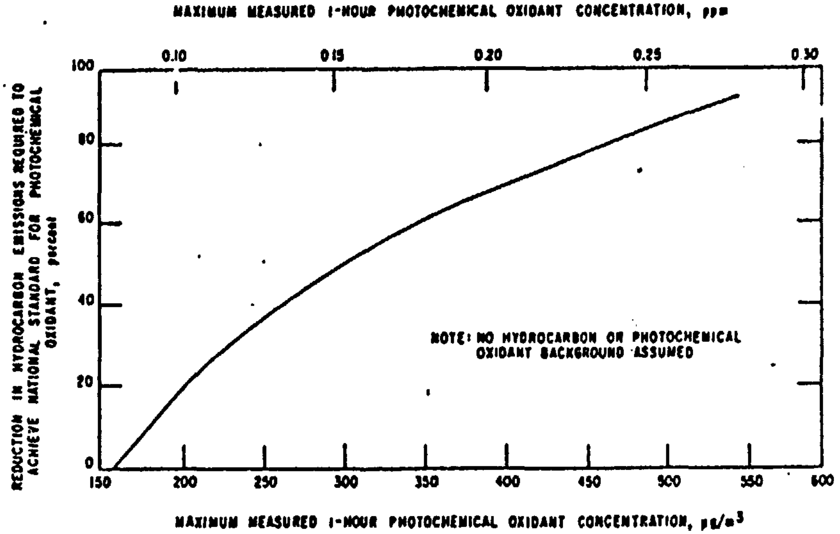
(Assumes zero background hydrocarbon concentration).

X_{max} = nonmethane hydrocarbon concentration associated with the observed maximum oxidant level.

X_{std} = nonmethane hydrocarbon concentration (0.24 ppmC) associated with the photochemical oxidant national ambient air quality standard (0.08 ppm over a 1-hour period).

The hydrocarbon concentration for a given oxidant concentration is determined using the empirical "upper limit curve," the upper envelope curve of a plot of maximum daily oxidant level against observed 6-9 AM hydrocarbon level, the data being accumulated from several U.S. cities.

The result is the Appendix J curve:



EVALUATION FORM

Part B: Importance Ratings

Application Index: 6243

Application Element	Importance Rating Initial	Importance Rating Modified[a]
Source-Receptor Relationship	H	H
Emission Rate	H	H
Composition of Emissions	H	H
Plume Behavior	H	M ✓
Horizontal Wind Field	H	H
Vertical Wind Field	L	L
Horizontal Dispersion	H	H
Vertical Dispersion	H	H
Chemistry and Reaction Mechanism	H	H
Physical Removal Processes	L	L
Background, Boundary, Initial Conditions	H	H
Temporal Correlations	H	H

[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

Rule C Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Source-Receptor Relationship

Reference Model: SAI

Treatment: All sources except power plants aggregated to square grid cells in 25 X 25 array; location of power plant specified only by grid cell; grid cell size arbitrary.

Arbitrary release height for power plant; other emissions treated as upward fluxes at ground level; topographic elevation arbitrary.

Receptors at ground level and in each of up to five vertical cells; horizontal location arbitrary.

Areas oriented by fixed grid boundaries.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment:

Receptors at ground level.

Other aspects not treated explicitly.

Application Element: Emission Rate

Reference Model: SAI

Treatment: Point source (power plant) emissions distributed homogeneously throughout entire vertical column above grid square containing the source; emission rates supplied by user.

Other emissions treated as upward pollutant fluxes at ground surface.

Sequence of hourly average rates for mobile sources.

Stationary source rates assumed constant.

Rates for mobile sources determined from user-supplied emission factors and traffic data.

Rates for stationary sources input by user.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment:

Does not treat variations within study area explicitly.

Accounts for change in total emissions in region of interest between baseline and prediction periods.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Composition of Emissions

Reference Model: SAI

Treatment: Treats emissions of reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2, and CO.

User inputs mobile source emissions of hydrocarbons, NO_x, and CO.

Mobile source NO_x emissions assumed to be 99% NO_2; converted internally to NO.

Mobile source hydrocarbon emissions split internally into 67.4% (mole fraction) reactive fraction and 32.6% unreactive fraction.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment:

Non-methane hydrocarbon emissions only.

Application Element: Composition of Emissions - (Contd.)

Reference Model: SAI

Treatment:

User inputs stationary source (both point and area) emissions of reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2, and CO.

Study Model:

Importance Rating:

Comparative Evaluation:

Treatment:

Rule Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Plume Behavior

Reference Model: SAI

Treatment:

Uses Briggs' formulae (1971) for point sources only to determine if plume from a power plant penetrates inversion.

If plume height exceeds mixing height, emissions from source are not treated.

Does not treat either fumigation or downwash.

Plume rise not treated explicitly for sources other than power plants.

Study Model: Appendix J

Importance Rating: MEDIUM

Comparative Evaluation: WORSE

Treatment:

Not treated explicitly.

Application Element: Horizontal Wind Field

Reference Model: SAI

Treatment: Numerical/Dynamic.

Fixed grid model.

Wind speed and direction specified for each of a sequence of hours at points on a horizontal grid, interpolated from surface measurements.

Arbitrary wind speed, direction values allowed.

Wind speed, direction independent of height.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment: Rollback/Statistical.

Not treated explicitly.

Rule 932 Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Vertical Wind Field

Reference Model: SAI

Treatment: Numerical/Dynamic.

Vertical wind speed specified for each of a sequence of hours at points on a three-dimensional grid.

Values assumed linearly increasing functions of height, values near surface determined from horizontal wind speed, directions using mass consistency requirement.

Study Model: Appendix J

Importance Rating: LOW

Comparative Evaluation: WORSE

Treatment: Rollback/Statistical.

Not treated explicitly.

Application Element: Horizontal Dispersion

Reference Model: SAI

Treatment: Numerical/Dynamic.

Numerical solution of advection-diffusion equation in three dimensions.

Horizontal eddy diffusivity value assumed uniform and constant and is fixed in the computer code.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment: Rollback/Statistical.

Not treated explicitly.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Vertical Dispersion

Reference Model: SAI

Treatment: Numerical/Dynamic,

Numerical solution of advection-diffusion equation in three dimensions.

Vertical eddy diffusivity an empirical function of wind speed and height above ground.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment: Rollback/Statistical.

Not treated explicitly.

Application Element: Chemistry and Reaction Mechanism

Reference Model: SAI

Treatment: Photochemical Smog System.

Fifteen reactions involving 10 species (NO, NO_2, O_3, Hc, O, OH, HO_2, RO_2, NO_3, HNO_2).

Lumping approximation for 2 species (Hc, RO_2).

Steady-state approximation for 6 species (NO_3, O, RO_2, OH, HO_2, HNO_2).

NO_2 photolysis rate calculated internally as a function of time.

No adjustments made for the effects of incomplete turbulent mixing below the resolution of the grid.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment: Photochemical oxidant estimation only.

Two species only: non-methane hydrocarbon and photochemical oxidant.

Empirical relation (the "upper limit curve") used to describe relation between hydrocarbon concentrations under worst case conditions.

Rule 9. Continued

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Physical Removal

Reference Model: SAI

Treatment:

Not treated explicitly.

Study Model: Appendix J

Importance Rating: LOW

Comparative Evaluation: COMPARABLE

Treatment:

Not treated explicitly.

Application Element: Background, Boundary, Initial Conditions

Reference Model: SAI

Treatment: Numerical/Dynamic.

Background (see treatment of fluxes at vertical sides).

Upper: Perfect reflection for pollutants within region of interest (turbulent diffusive flux = 0).

Allows for entrainment of pollutants from above mixing layer.

Lower: Implicit perfect reflection; no adjustment made to emission fluxes to account for removal.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment: Rollback/Statistical.

Background levels of non-methane hydrocarbon and photochemical oxidant both assumed zero.

Boundary, initial conditions not treated explicitly.

EVALUATION FORM

Part C: Treatment of Elements

Application Index: 6243

Application Element: Background, Boundary, Initial Conditions (Contd.)

Reference Model: SAI

Treatment: Numerical/Dynamic.

Vertical: Treated as a function of position and elevation; total flux normal to side of region required to be continuous across boundary.

Initial: Mean initial concentrations of six species (reactive HC, NO, O_3, NO_2, CO, unreactive HC) specified for each grid cell.

Study Model:

Importance Rating:

Comparative Evaluation:

Treatment:

XXX

Application Element: Temporal Correlations

Reference Model: SAI

Treatment: Sequential up to 24 hours.

Correlations automatic.

Parameters updated every hour: mobile source emission for each ground-level grid square, point source (power plant) emissions, wind speed and direction, mixing height at every vertical column of grids, vertical eddy diffusivity at every vertical interface of grid cells, incoming fluxes at boundaries, NO_2 photolysis rate constant.

Update based on user input values.

Study Model: Appendix J

Importance Rating: HIGH

Comparative Evaluation: WORSE

Treatment:

Not treated explicitly.

Total emissions allowed to change between baseline and forecast periods.

Rule 932, Continued

EVALUATION FORM

Part D: Technical Comparison

Application Index: 6243 Reference Model: SAI Study Model Appendix J

Importance Rating of Application Elements	Number of Treatments Total	BETTER	COMPARABLE	WORSE	Comparative Rating of Study Model
CRITICAL	0	-	-	-	-
HIGH	9	0	0	9	WORSE
MEDIUM	1	0	0	1	WORSE
LOW	2	0	1	1	
IRRELEVANT	0	XXX	XXX	XXX	

Total 12 (Should equal 12)

TECHNICAL EVALUATION WORSE

APPENDIX D
APPLICATION CLASSIFICATION AND
MODEL EVALUATION FORMS

APPENDIX D. APPLICATION CLASSIFICATION AND MODEL EVALUATION FORMS

Included in this appendix is an outline of the steps in the model evaluation methodology presented in this workbook together with a copy of each form required by the procedure.

The following page, entitled, WORKBOOK SECTION AND FORM FOR EACH STEP IN COMPARISON, lists the nine steps in the comparison procedure. It refers the reader to the workbook section containing instructions for each step and identifies which form to use for documenting the results.

The first step classifies the application and the results are recorded on the APPLICATION CLASSIFICATION FORM. Some basic information about the study model is also recorded on the EVALUATION FORM - Part A.

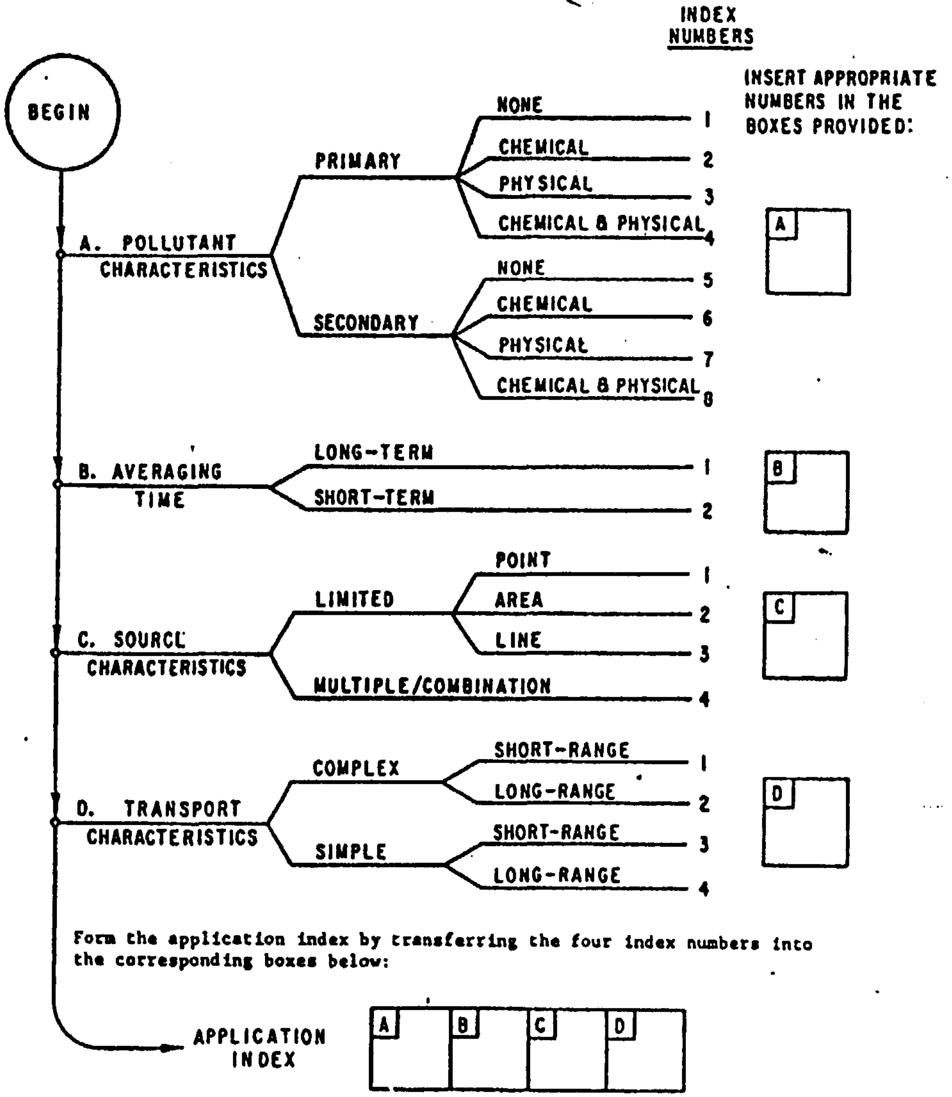
The results of steps 2 - 5 are also documented on the EVALUATION FORM - Part A. These steps involve documenting the study model equations (reverse side of form), checking the study model compatibility, classifying the study model, and identifying the reference model.

In step 6, the importance rating of the application elements are reviewed and modified if necessary. The EVALUATION FORM - Part B is used to record both the initial and modified importance ratings.

The treatment of the application elements by both models are described on the EVALUATION FORM - Part C and then compared. Results of the element-by-element comparisons are recorded on the form to complete steps 7 and 8.

In the last step of the procedure, the comparisons of individual elements are combined with the importance ratings to arrive at a technical evaluation of the study model. EVALUATION FORM - Part D provides a convenient framework for making this overall comparison.

APPLICATION CLASSIFICATION



INSERT APPROPRIATE NUMBERS IN THE BOXES PROVIDED:

Form the application index by transferring the four index numbers into the corresponding boxes below:

WORKBOOK SECTION AND FORM FOR EACH STEP IN COMPARISON

Step		Workbook Sections	Form in Appendix D
Number	Action		
1	Classify application	3	Application Classification Form
	Record study model information	2.3	Evaluation Form A
2	Document study model equations	2.3	Reverse side of Evaluation Form A
3	Check study model compatibility	4.2	Evaluation Form A
4	Classify study model type[a]	4.3	Evaluation Form A
5	Identify reference model	4.4	Evaluation Form A
6	Review importance ratings	4.5	Evaluation Form B
7	Determine treatments of elements	5	Evaluation Form C
8	Compare treatments on element-by-element basis	6.2.1	Evaluation Form C
9	Synthesize individual comparisons into overall comparison	6.2.2	Evaluation Form D

[a] If the study model has been classified as a rollback/statistical model, the user should proceed directly to Section 7 wherein such models are discussed.

EVALUATION FORM

Part A: Abstract and References

Study Model:

References:

Abstract:

Classification:

Application Index:

Reference Model:

Application Description:

Model Applicability: Applicable ☐ Not Applicable ☐

EVALUATION FORM

Part B: Importance Ratings

Application Index:

Application Element	Importance Rating	
	Initial	Modified[a]
Source-Receptor Relationship		
Emission Rate		
Composition of Emissions		
Plume Behavior		
Horizontal Wind Field		
Vertical Wind Field		
Horizontal Dispersion		
Vertical Dispersion		
Chemistry and Reaction Mechanism		
Physical Removal Processes		
Background, Boundary, Initial Conditions		
Temporal Correlations		

[a] With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

EVALUATION FORM

Part A (reverse): Equations

Study Model:

Equations:

EVALUATION FORM

Part C: Treatment of Elements

Application Index:__________

Application Element:
Reference Model:
Treatment:

Study Model:
Importance Rating:
Comparative Evaluation:
Treatment:

Application Element:
Reference Model:
Treatment:

Study Model:
Importance Rating:
Comparative Evaluation:
Treatment:

EVALUATION FORM

Part D: Technical Comparison

Application Index:____________________ Reference Model:____________________ Study Model:____________________

Importance Rating of Application Elements	Number of Treatments				Comparative Rating of Study Model
	Total	BETTER	COMPARABLE	WORSE	
CRITICAL					____________
HIGH					____________
MEDIUM					____________
LOW					
IRRELEVANT	____	XXX	XXX	XXX	

Total (Should equal 12)

TECHNICAL EVALUATION ____________

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO EPA-450/2-78-028b	2. OAQPS No. 1.2-097A	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Workbook for the Comparison of Air Quality Models - Appendices		5. REPORT DATE May 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO OAQPS No. 1.2-097A
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air and Waste Management Office of Air Quality Planning and Standards Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED EPA/OAQPS Guideline
		14. SPONSORING AGENCY CODE 200/04
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

The document consists of appendices to the Workbook for the Comparison of Air Quality Models. Appendix A presents guidance on emissions, plume dispersion, chemistry and reaction mechanisms, and physical removal processes. Appendix B provides background information on some suggested reference models. Examples of the application of the workbook methodology are presented in Appendix C.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Atmospheric Models Air Pollution Abatement Mathematical Models Atmospheric Diffusion	Implementation Air Pollution Planning Gaussian Plume Models Diffusion Modeling	13B

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS (This Report) None	21. NO. OF PAGES 280
	20. SECURITY CLASS (This page) None	22. PRICE

EPA Form 2220-1 (9-73)

Pima County Code
Title 17. Air Quality Control
Chapter 12. Permits and Permit Revisions
Article V. Open Burning Permits

17.12.480

Open burning permits.

A. In addition to the definitions contained in A.R.S. § 49-501, in this Section:

1. "Agricultural burning" means burning of vegetative materials related to the production and harvesting of crops and raising of animals for the purpose of marketing for profit, or providing a livelihood, but not including the burning of household waste or prohibited materials. Burning may be conducted in fields, piles, ditch banks, fence rows, or canal laterals for purposes such as weed control, disease and pest prevention, or site preparation.

2. "Air curtain destructor" means an incineration device designed and used to secure, by means of a fan-generated air curtain, controlled combustion of only wood waste and slash materials in an earthen trench or refractory-lined pit or bin.

3. "Approved waste burner" means an incinerator constructed of fire resistant material with a cover or screen that is closed when in use, and has openings in the sides or top no greater than one inch in diameter.

4. "Class I area" means any one of the Arizona mandatory federal Class I areas defined in A.R.S. § 49-401.01.

5. "Construction burning" means burning wood or vegetative material from land clearing, site preparation, or fabrication, erection, installation, demolition, or modification of any buildings or other land improvements, but does not include burning household waste or prohibited material.

6. "Dangerous material" means any substance or combination of substances that is capable of causing bodily harm or property loss unless neutralized, consumed, or otherwise disposed of in a controlled and safe manner.

7. "Emission reduction techniques" means methods for controlling emissions from open outdoor fires to minimize the amount of emissions output per unit of area burned.

8. "Flue," as used in this Section, means any duct or passage for air or combustion gases, such as a stack or chimney.

9. "Household waste" means any solid waste including garbage, rubbish, and sanitary waste from a septic tank that is generated from households including single and multiple family residences, hotels and motels, bunkhouses, ranger stations, crew quarters, campgrounds, picnic grounds, and day-use recreation areas, but does not include construction debris, landscaping rubble, demolition debris or prohibited materials.

10. "Independent authority to permit fires" means the authority of a county to permit fires by a rule adopted under Arizona Revised Statutes, Title 49, Chapter 3, Article 3, and includes only Maricopa, Pima, and Pinal counties.

11. "Open outdoor fire or open burning" means the combustion of material of any type, outdoors and in the open, where the products of combustion are not directed through a flue. Open outdoor fires include agricultural, residential, prescribed, and construction burning, and fires using air curtain destructors.

12. "Prescribed burning" means the controlled application of fire to wildland fuels that are in either a natural or modified state, under certain burn and smoke management prescription conditions that have been specified by the land manager in charge of or assisting the burn, to attain planned resource management objectives. Prescribed burning does not include a fire set or permitted by a public officer to provide instruction in fire fighting methods, or construction or residential burning.

13. "Prohibited materials" means nonpaper garbage from the processing, storage, service, or consumption of food; chemically treated wood; lead-painted wood; linoleum flooring, and composite counter-tops; tires; explosives or ammunition; oleanders; asphalt shingles; tar paper; plastic and rubber products, including bottles for household chemicals; plastic grocery and retail bags; waste petroleum products, such as waste crankcase oil, transmission oil, and oil filters; transformer oils; asbestos; batteries; anti-freeze; aerosol spray cans; electrical wire insulation; thermal insulation; polyester products; hazardous waste products such as paints, pesticides, cleaners and solvents, stains and varnishes, and other flammable liquids; plastic pesticide bags and containers; and hazardous material containers including those that contained lead, cadmium, mercury, or arsenic compounds.

14. "Residential burning" means open burning of vegetative materials conducted by or for the occupants of residential dwellings, but does not include burning household waste or prohibited material.

B. Unlawful open burning. Notwithstanding any other rule in this Chapter, a person shall not ignite, cause to be ignited, permit to be ignited, allow, or maintain any open outdoor fire in a county without independent authority to permit fires except as provided in A.R.S. § 49-501 and this Section.

C. Open outdoor fires exempt from a permit. The following fires do not require an open burning permit from the control officer or a delegated authority:

1. Fires used only for:
   a. Cooking of food,
   b. Providing warmth for human beings,
   c. Recreational purposes,
   d. Branding of animals,
   e. Orchard heaters for the purpose of frost protection in farming or nursery operations, and
   f. The proper disposal of flags under 4 U.S.C. 1, § 8.
2. Any fire set or permitted by any public officer in the performance of official duty, if the fire is set or permission given for the following purpose:
   a. Control of an active wildfire; or
   b. Instruction in the method of fighting fires, except that the person setting these fires must comply with the reporting requirements of subsection (D)(3)(f).
3. Fire set by or permitted by the control officer of Department of Agriculture for the purpose of disease and pest prevention in an organized, area-wide control of an epidemic or infestation affecting livestock or crops.
4. Prescribed burns set by or assisted by the federal government or any of its departments, agencies, or agents, or the state or any of its agencies, departments, or political subdivisions.

D. Open outdoor fires requiring a permit.

1. The following open outdoor fires are allowed with an open burning permit from the control officer or a delegated authority:
  a. Construction burning;
  b. Agricultural burning;
  c. Residential burning;
  d. Prescribed burns conducted on private lands without the assistance of a federal or state land manager as defined under;
  e. Any fire set or permitted by a public officer in the performance of official duty, if the fire is set or permission given for the purpose of weed abatement, or the prevention of a fire hazard, unless the fire is exempt from the permit requirement under subsection (C)(3);
  f. Open outdoor fires of dangerous material under subsection (E);
  g. Open outdoor fires of household waste under subsection (F); and
  h. Open outdoor fires that use an air curtain destructor, as defined in 17.12.480 (A)(2).

2. A person conducting an open outdoor fire in a county with independent authority to permit fires shall obtain a permit from the control officer or a delegated authority unless exempted under subsection (C). Permits may be issued for a period not to exceed one year. A person shall obtain a permit by completing an PDEQ-approved application form.

3. Open outdoor fire permits issued under this Section shall include:
  a. A list of the materials that the permittee may burn under the permit;
  b. A means of contacting the permittee authorized by the permit to set an open fire in the event that an order to extinguish the open outdoor fire is issued by the control officer or the delegated authority;
  c. A requirement that burns be conducted during the following periods, unless otherwise waived or directed by the control officer on a specific day basis:
    i. Year-round: ignite fire no earlier than one hour after sunrise; and
    ii. Year-round: extinguish fire no later than two hours before sunset;
  d. A requirement that the permittee conduct all open burning only during atmospheric conditions that:
    i. Prevent dispersion of smoke into populated areas;
    ii. Prevent visibility impairment on traveled roads or at airports that result in a safety hazard;
    iii. Do not create a public nuisance or adversely affect public safety;
    iv. Do not cause an adverse impact to visibility in a Class I area; and
    v. Do not cause uncontrollable spreading of the fire;
  e. A list of the types of emission reduction techniques that the permittee shall use to minimize fire emissions;
  f. A reporting requirement that the permittee shall meet by providing the following information in a format provided by the control officer for each date open burning occurred, on either a daily basis on the day of the fire, or an annual basis in a report to the control officer or delegated authority due on February 1 for the previous calendar year:
    i. The date of each burn;
    ii. The type and quantity of fuel burned for each date open burning occurred;
    iii. The fire type, such as pile or pit, for each date open burning occurred; and

iv. For each date open burning occurred, the legal location, to the nearest section, or latitude and longitude, to the nearest degree minute, or street address for residential burns;

g. A requirement that the person conducting the open burn notify the local fire-fighting agency or private fire protection service provider, if the service provider is a delegated authority, before burning. If neither is in existence, the person conducting the burn shall notify the state forester;

h. A requirement that the permittee start each open outdoor fire using items that do not cause the production of black smoke;

i. A requirement that the permittee attend the fire at all times until it is completely extinguished;

j. A requirement that the permittee provide fire extinguishing equipment on-site for the duration of the burn;

k. A requirement that the permittee ensure that a burning pit, burning pile, or approved waste burner be at least 50 feet from any structure;

l. A requirement that the permittee have a copy of the burn permit on-site during open burning;

m. A requirement that the permittee not conduct open burning when an air stagnation advisory, as issued by the National Weather Service, is in effect in the area of the burn or during periods when smoke can be expected to accumulate to the extent that it will significantly impair visibility in Class I areas;

n. A requirement that the permittee not conduct open burning when any stage air pollution episode is declared by ADEQ or PDEQ;

o. A statement that the control officer, or any other public officer, may order that the burn be extinguished or prohibit burning during periods of inadequate smoke dispersion, excessive visibility impairment, or extreme fire danger; and

p. A list of the activities prohibited and the criminal penalties provided under A.R.S. § 13-1706.

4. The control officer or a delegated authority shall not issue an open burning permit under this Section:

a. That would allow burning prohibited materials other than under a permit for the burning of dangerous materials;

b. If the applicant has applied for a permit under this Section to burn a dangerous material which is also hazardous waste under 40 CFR 261, but does not have a permit to burn hazardous waste under 40 CFR 264, or is not an interim status facility allowed to burn hazardous waste under 40 CFR 265; or

c. If the burning would occur at a solid waste facility in violation of 40 CFR 258.24 and the control officer has not issued a variance under A.R.S. § 49-763.01.

E. Open outdoor fires of dangerous material. A fire set for the disposal of a dangerous material is allowed by the provisions of this Section, when the material is too dangerous to store and transport, and the control officer has issued a permit for the fire. A permit issued under this subsection shall contain all provisions in subsection (D)(3) except for subsections (D)(3)(e) and (D)(3)(f). The control officer shall permit fires for the disposal of dangerous materials only when no safe alternative method of disposal exists, and burning the materials does not result in the emission of hazardous or toxic substances either directly or as a product of combustion in amounts that will endanger health or safety.

F. Open outdoor fires of household waste. An open outdoor fire for the disposal of household waste is allowed by provisions of this Section when permitted in writing by the control officer or a delegated authority. A permit issued under this subsection shall contain all provisions in subsection (D)(3) except for subsections (D)(3)(e) and (D)(3)(f). The permittee shall conduct open outdoor fires of household waste in an approved waste burner and shall either:

1. Burn household waste generated on-site on farms or ranches of 40 acres or more where no household waste collection or disposal service is available; or
2. Burn household waste generated on-site where no household waste collection and disposal service is available and where the nearest other dwelling unit is at least 500 feet away.

G. The control officer shall hold an annual public meeting for interested parties to review operations of the open outdoor fire program and discuss emission reduction techniques.

H. Nothing in this Section is intended to permit any practice that is a violation of any statute, ordinance, rule, or regulation.

I. The term of any open burning permit shall be as specified by the control officer, subject to the following limitations:

1. The term of a temporary open burning permit shall not exceed three consecutive or nonconsecutive days within a thirty-day period; and
2. The term of an extended open burning permit shall expire as specified on the original application, and shall in no case exceed ninety days. (Ord. 2004-97 § 3 (part), 2004; Ord. 1993-128 § 3 (part), 1993)

ORDINANCE NUMBER 2019-7

AN ORDINANCE OF THE BOARD OF SUPERVISORS OF PIMA COUNTY, ARIZONA, RELATING TO AIR QUALITY; AMENDING THE PIMA COUNTY CODE TITLE 17, BY ADDING SECTION 17.16.125.

THE BOARD OF SUPERVISORS OF PIMA COUNTY, ARIZONA, FINDS THAT:

1. The Pima County Board of Supervisors as the governing body for the Pima County Air Quality Control District adopts air quality ordinances under the statutory authority of Arizona Revised Statutes Title 49, Chapter 3, Article 3.
2. The Pima County Air Quality Control District operates within the Pima County Department of Environmental Quality.
3. The intention of this ordinance is to adopt and implement visible emissions and stabilization requirements in order to ensure continued particulate matter, specifically particulate matter at or less than 10 micrometers (PM_{10}) emissions reductions in the Ajo PM_{10} Planning Area.

IT IS ORDAINED BY THE BOARD OF SUPERVISORS OF PIMA COUNTY, ARIZONA, AS FOLLOWS:

Section 1: Title 17 is amended to add Section 17.16.125.

Chapter 17.16 - EMISSION LIMITING STANDARDS

. . .

Article III. - Emissions from Existing and New Nonpoint Sources

. . .

17.16.125 - Inactive mineral tailings impoundment and slag storage area within the Ajo PM_{10} Planning Area.

A. Applicability. This Section applies to the owner or operator of the inactive mineral tailings impoundment and slag storage area within the Ajo PM_{10} Planning Area.

B. Definitions. The following definitions apply for the purposes of this Section:

1. "Affected area" means the Ajo PM_{10} Planning Area.
2. "Ajo PM_{10} Planning Area" means the area designated in 40 C.F.R. §81.303, adopted as of June 30, 2017 with no future editions or amendments.
3. "Chemical or organic soil stabilizer" means hygroscopic material, solution of water and chemical surfactant foam, non-toxic chemical stabilizer or any other chemical or organic

dust palliative that is not prohibited by the U. S. Environmental Protection Agency, the Arizona Department of Environmental Quality, the Pima County Department of Environmental Quality or any applicable law, rule, or regulation, as a treatment material for reducing PM_{10} emissions.

4. "Coarse" with respect to copper smelter slag material means no less than 3/8 inches in diameter.
5. "Copper smelter slag" means the waste material consisting primarily of iron sulfides separated from copper matte during the smelting and refining of copper ore concentrates.
6. "Crushed rock" means crushed stone or angular rock of a size 2 inches or greater in diameter.
7. "Department" means the Pima County Department of Environmental Quality.
8. "Gravel" means a loose aggregation of rock fragments of low silt content (5% or less) and less than 2 inches in diameter.
9. "High wind event" means an hourly average wind speed of 25 miles per hour or more or an instantaneous wind gust of 40 miles per hour or more as measured in the affected area by a meteorological monitoring station.
10. "Inactive" with respect to the mineral tailings impoundment and slag storage area means that activities in support of ongoing mining operations or for any commercial purpose no longer occur.
11. "Meteorological monitoring station" means one of the following:
    a. A Pima County Department of Environmental Quality meteorological monitoring station;
    b. A station operated by the National Weather Service;
    c. A Remote Automated Weather Station operated by the United States Forest Service, or United States Bureau of Land Management;
    d. An Automated Weather Observing System or Automated Surface Observing System station, located at an airport, and either operated or certified by the Federal Aviation Administration; or
    e. Any other meteorological equipment or wind instrument that is installed, calibrated, operated, and maintained by the owner or operator in accordance with the requirements for SLAMS/SPM (non-NCore) instruments in *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements Version 2.0 (Final)*, publication number EPA-454/B-08-002, March 2008, and no future editions or amendments, and manufacturer's specifications, as applicable.
12. "Mineral tailings impoundment" means the earth-fill embankment dams used to store byproducts of prior mining operations that separated mineral ore from other unused material.
13. "Opacity" means the degree to which emissions reduce the transmission of light and obscure the view of an object in the background.
14. "Particulate matter" means any airborne finely divided solid or liquid material with an aerodynamic diameter smaller than one hundred micrometers.
15. "PM_{10}" means particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometers as measured by a reference method contained within 40 C.F.R.

Part 50, Appendix J or by an equivalent method designated in accordance with 40 C.F.R. Part 53, both sections adopted as of June 30, 2017 with no future editions or amendments.

16. "Slag storage area" means the area used to store copper smelter slag.

17 "Vegetative cover" means rooted vegetation or unattached vegetative debris lying on the surface that is not susceptible to movement by wind.

C. Control Measures.

1. The owner or operator shall implement and maintain at least one of the following reasonably available control measures to reduce PM_{10} emissions from the inactive mineral tailings impoundment to ensure compliance with subsection D.1 below:
   a. Application of crushed rock or gravel;
   b. Application of chemical or organic soil stabilizers;
   c. Application of water;
   d. Establishment of vegetative cover; or
   e. Any other equivalent methods or techniques approved by the Department and EPA Region IX.
2. The owner or operator shall implement and maintain at least one of the following reasonably available control measures to reduce PM_{10} emissions from the inactive slag storage area:
   a. Application of a cap consisting of coarse copper smelter slag material; or
   b. Any other equivalent methods or techniques approved by the Department and EPA Region IX.
3. To prevent trespass in the inactive mineral tailings impoundment and slag storage area, the owner or operator shall install and maintain the following:
   a. No trespassing signs; and
   b. Physical barriers such as fences, gates, posts, shrubs, trees, or other measures to effectively restrict access from the general public.

D. Opacity Standard.

1. The owner or operator shall not cause or allow visible emissions to exceed twenty percent opacity from the mineral tailings impoundment. Opacity shall be determined in accordance with subsection E.1 below.
2. The opacity standard in subsection D.1 above shall not apply during high wind events if the owner or operator has implemented and maintained reasonably available control measures required in subsections C.1 and C.3 above for the mineral tailings impoundment, as documented by subsection F.1.a below.

E. Monitoring.

1. To demonstrate compliance with subsections C.1 and D.1 above, the owner or operator shall conduct weekly visible emission observations of the mineral tailings impoundment.
   a. All observations shall be conducted in accordance with 40 C.F.R. Part 60, Appendix A, Reference Method 9.
   b. As an alternative to subsection E.1.a, the owner or operator may elect to conduct observation in accordance with ASTM D7520-16. If so, the owner or operator must

have standard operating procedures in place to ensure that equipment is operated and maintained in accordance with manufacturer's specifications per Section 8.1 of ASTM D7520-16.

2. To demonstrate compliance with subsection C.2 above, the owner or operator shall conduct monthly inspections of the slag storage area to assess the effectiveness of control measures. Inspection reports shall, at a minimum, include identification of inspector; inspection date and time; findings of inspection, and any corrective action or preventive measures to be taken.
3. To demonstrate compliance with subsection C.3 above, the owner or operator shall conduct monthly inspections of trespassing signs and physical constraints. Inspection reports shall, at a minimum, include identification of inspector; inspection date and time; findings of inspection, and any corrective action or preventive measures to be taken.

F. Recordkeeping.

1. The owner or operator shall maintain and make available to the Department or EPA Region IX the following records upon request:
    a. Records of reasonably available control measures implemented and maintained as required by subsection C above;
    b. Records of visible emission observations required by subsection E.1 above;
    c. Records of inspections required by subsections E.2 and E.3 above;
    d. Records of observer EPA Reference Method 9 or ASTM D7520-16 certifications;
    e. Records of the owner or operator's installation, calibration, certification, operation, and maintenance of any meteorological equipment or wind instrument used for purposes of identifying high wind events; and
    f. Records of meteorological monitoring station data used for purposes of identifying high wind events.
2. If the owner or operator elects to conduct weekly visual observations in accordance with subsection E.1.b, the following records shall be maintained:
    a. ASTM D7520-16 certification documentation, data sheets, and all raw unaltered JPEGs used for opacity and certification determination, recorded in a form suitable and readily available for expeditious inspection and review.
    b. Standard operating procedures used to ensure that equipment is operated and maintained in accordance with manufacturer's specifications per Section 8.1 of ASTM D7520-16.
3. All records required by this section shall be maintained by the owner or operator for a minimum of 5 years.

G. Notification.

1. The owner or operator shall provide written notification to the Department at least 30 days prior to initiating weekly visual observations in accordance with subsection E.1. The notification shall identify proposed observation points/locations and provide justification for the selection of those points/locations.
2. The owner or operator shall provide written notification to the Department at least 30 days prior to using any meteorological monitoring station as described in subsection B.11.e.

H. Reporting.

1. The owner or operator shall report to the Department any visible emissions in excess of opacity limit established by subsection D.1. The report shall be in two parts as specified below:
    a. Notification by telephone or facsimile within 24 hours of the time the owner or operator first learned of the occurrence of excess opacity that includes all available information from subsection H.2.
    b. Detailed written notification by submission of an excess opacity report within 72 hours of the notification under subsection H.1.a.
2. The excess opacity report shall contain the following information:
    a. The approximate location at the mineral tailing impoundment where the excess opacity occurred;
    b. The level of excess opacity as measured in accordance with subsection F;
    c. The time and duration or expected duration of the excess opacity;
    d. The nature and cause or suspected cause of the excess opacity;
    e. The steps that were or are being taken to limit the excess opacity; and
    f. Any corrective action or preventative measures taken.
3. In the case of continuous or recurring excess opacity events, the notification requirements of this subsection shall be satisfied if the owner or operator provides the required notification after excess opacity events are first detected and includes in the notification an estimate of the time the excess opacity events will continue. Excess opacity occurring after the estimated time period or changes in the nature of the excess opacity as originally reported shall require additional notification pursuant to subsections H.1 and H.2.

. . .

Section 2. This Ordinance is effective 30 days after the date of adoption.

PASSED AND ADOPTED by the Board of Supervisors, Pima County, Arizona, this 22nd day of January, 2019

JAN 22 2019

Richard Elías, Chairman of the Board of Supervisors

ATTEST:

Clerk of Board

APPROVED AS TO FORM:

12/10/18

Lesley M. Lukach
Deputy County Attorney

REVIEWED BY:

Ursula Nelson, Director
Department of Environmental Quality