Emission Factor Documentation for AP-42
Section 13.2.6

Abrasive Blasting

Final Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Factor and Inventory Group

EPA Contract 68-D2-0159
Work Assignment No. 4-02

MRI Project No. 4604-02

September 1997

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Research Triangle Park, NC 27711

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NOTICE

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PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment Nos. 2-01 and 4-02. Mr. Ron Myers was the requester of the work.

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TABLE OF CONTENTS

Page

1. INTRODUCTION 1-1

2. INDUSTRY AND PROCESS DESCRIPTION 2-1
   2.1 INDUSTRY CHARACTERIZATION 2-1
   2.2 PROCESS DESCRIPTION 2-1
      2.2.1 Types of Abrasives 2-1
      2.2.2 Blasting Methods 2-2
   2.3 DUST CONTROL TECHNIQUES 2-9
      2.3.1 Blast Enclosures 2-9
      2.3.2 Vacuum Blasters 2-9
      2.3.3 Drapes 2-9
      2.3.4 Water Curtains 2-9
      2.3.5 Wet Blasting 2-11
      2.3.6 Centrifugal Blasters 2-13
   2.4 REFERENCES FOR SECTION 2 2-13

3. GENERAL DATA REVIEW AND ANALYSIS 3-1
   3.1 LITERATURE SEARCH AND SCREENING 3-1
   3.2 DATA QUALITY RATING SYSTEM 3-1
   3.3 EMISSION FACTOR QUALITY RATING SYSTEM 3-2
   3.4 REFERENCES FOR SECTION 3 3-3

4. EMISSION FACTOR DEVELOPMENT 4-1
   4.1 REVIEW OF SPECIFIC DATA SETS 4-1
      4.1.1 Reference 1 4-2
      4.1.2 Reference 2 4-2
      4.1.3 Reference 3 4-2
      4.1.4 Reference 4 4-3
      4.1.5 Reference 5 4-3
      4.1.6 Reference 6 4-3
   4.2 RESULTS OF DATA ANALYSIS 4-3
   4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS 4-7
   4.4 REFERENCES FOR SECTION 4 4-11

5. PROPOSED AP-42 SECTION 13.2.6 5-1

LIST OF FIGURES

Figure		Page
2-1a.	Suction blast nozzle assembly	2-4
2-1b.	Suction-tape blasting machine	2-4
2-2.	Pressure-type blasting machine	2-5
2-3a.	Wet blasting machine	2-6
2-3b.	Adapter nozzle converting a dry blasting unit to a wet blasting unit	2-6
2-4.	Hydraulic blasting nozzle	2-6
2-5.	Schematic of vacuum blaster head	2-10
2-6.	Nozzle for air abrasive wet blast	2-11
2-7.	Water curtain device for abrasive blast nozzle	2-12

LIST OF TABLES

Table		Page
2-1.	MEDIA COMMONLY USED IN ABRASIVE BLASTING	2-2
2-2.	FLOW RATE OF SAND THROUGH A BLASTING NOZZLE AS A FUNCTION OF NOZZLE PRESSURE AND INTERNAL DIAMETER	2-8
2-3.	BULK DENSITY OF COMMON ABRASIVES	2-8
4-1.	REFERENCE DOCUMENTS REVIEWED DURING LITERATURE SEARCH	4-1
4-2.	SUMMARY OF TEST DATA FOR ABRASIVE BLASTING OPERATIONS	4-4
4-3.	SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR ABRASIVE BLASTING OPERATIONS	4-6
4-4.	SUMMARY OF PM TEST DATA FROM REFERENCE 1	4-8
4-5.	SUMMARY OF EMISSION FACTORS FOR PM METALS	4-9
4-6.	SUMMARY OF EMISSION FACTORS FOR PM-10 METALS	4-9
4-7.	SUMMARY OF EMISSION FACTORS FOR PM-2.5 METALS	4-10
4-7.	SUMMARY OF EMISSION FACTORS FOR PM-2.5 METALS	4-10
4-8.	CANDIDATE PM-10 AND PM-2.5 EMISSION FACTORS	4-10
4-9.	CANDIDATE TOTAL PM EMISSION FACTORS DIFFERENTIATED BY WIND SPEED	4-10
4-10.	CANDIDATE EMISSION FACTOR FOR GARNET BLASTING	4-11

1. INTRODUCTION

The document *Compilation of Air Pollutant Emission Factors* (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 are issued to add new emission source categories and to update existing emission factors. The EPA also routinely updates AP-42 in response to the needs of Federal, State, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of source activity. Emission factors reported in AP-42 are used to:

1. Estimate areawide emissions.
2. Estimate emissions for a specific facility.
3. Evaluate emissions relative to ambient air quality.

This report provides background information from test reports and other information to support preparation of a new AP-42 section for abrasive blasting. The information in the proposed AP-42 section is based on a review of the available literature for particulate phase air pollutants produced by abrasive blasting operations.

This report contains five sections. Following the introduction, Section 2 describes abrasive blasting equipment, practices, and allied processes. Section 3 describes data collection and rating procedures, and Section 4 describes the emission factor development. Section 5 presents the proposed AP-42 section.

2. INDUSTRY AND PROCESS DESCRIPTION

2.1 INDUSTRY CHARACTERIZATION[1]

Abrasive blasting is used for a variety of surface cleaning and texturing operations, mostly involving metallic target materials. Sand is the most widely used blasting abrasive. Other abrasive materials include coal slag, smelter slags, mineral abrasives, metallic abrasives, and synthetic abrasives. Industries that use abrasive blasting include the shipbuilding industry, automotive industry, and other industries that involve surface preparation and painting. The majority of shipyards no longer use sand for abrasive blasting because of concerns about silicosis, a condition caused by respiratory exposure to crystalline silica. In 1991, about 4.5 million tons of abrasives, including 2.5 million tons of sand, 1 million tons of coal slag, 500 thousand tons of smelter slag, and 500 thousand tons of other abrasives, were used for domestic abrasive blasting operations.

2.2 PROCESS DESCRIPTION[1-8]

The following sections briefly describe the types of abrasives, blasting methods, and dust control techniques commonly used in outdoor abrasive blasting.

2.2.1 Types of Abrasives[1-2]

Abrasive materials are generally classified as: sand, slag, metallic shot or grit, synthetic, or other. The cost and properties associated with the abrasive material dictate its application. The following discusses the general classes of common abrasives.

Silica sand is commonly used for abrasive blasting where reclaiming is not feasible, such as in unconfined abrasive blasting operations. Sand has a rather high breakdown rate, which can result in substantial dust generation. Worker exposure to free crystalline silica is of concern when silica sand is used for abrasive blasting.

Coal and smelter slags are commonly used for abrasive blasting at shipyards. Black Beauty™, which consists of crushed slag from coal-fired utility boilers, is a commonly used slag. Slags have the advantage of low silica content, but have been documented to release other contaminants, including hazardous air pollutants (HAP), into the air.

Metallic abrasives include cast iron shot, cast iron grit, and steel shot. Cast iron shot is hard and brittle and is produced by spraying molten cast iron into a water bath. Cast iron grit is produced by crushing oversized and irregular particles formed during the manufacture of cast iron shot. Steel shot is produced by blowing molten steel. Steel shot is not as hard as cast iron shot, but is much more durable. These materials typically are reclaimed and reused.

Synthetic abrasives, such as silicon carbide and aluminum oxide, are becoming popular substitutes for sand. These abrasives are more durable and create less dust than sand. These materials typically are reclaimed and reused.

Other abrasives include mineral abrasives (such as garnet, olivine, and staurolite), cut plastic, glass beads, crushed glass, and nutshells. As with metallic and synthetic abrasives, these other abrasives are generally used in operations where the material is reclaimed. Mineral abrasives are reported to create significantly less dust than sand and slag abrasives.

The type of abrasive used in a particular application is usually specific to the blasting method. Dry abrasive blasting is usually done with sand, aluminum oxide, silica carbide, metallic grit, or shot. Wet blasting is usually done with sand, glass beads, or any materials that will remain suspended in water. Table 2-1 lists common abrasive materials and their applications.

TABLE 2-1. MEDIA COMMONLY USED IN ABRASIVE BLASTING[2]

Type of medium	Sizes normally available	Applications
Glass beads	8 to 10 sizes from 30- to 440-mesh; also many special gradations	Decorative blending; light deburring; peening; general cleaning; texturing; noncontaminating
Aluminum oxide	10 to 12 sizes from 24- to 325-mesh	Fast cutting; matte finishes; descaling and cleaning of coarse and sharp textures
Garnet	6 to 8 sizes (wide-band screening) from 16- to 325-mesh	Noncritical cleaning and cutting; texturing; noncontaminating for brazing steel and stainless steel
Crushed glass	5 sizes (wide-band screening) from 30- to 400-mesh	Fast cutting; low cost; short life; abrasive; noncontaminating
Steel shot	12 or more sizes (close gradation) from 8- to 200-mesh	General-purpose rough cleaning (foundry operation, etc.); peening
Steel grit	12 or more sizes (close gradation) from 10- to 325-mesh	Rough cleaning; coarse textures; foundry welding applications; some texturing
Cut plastic	3 sizes (fine, medium, coarse); definite-size particles	Deflashing of thermoset plastics; cleaning; light deburring
Crushed nutshells	6 sizes (wide-band screening)	Deflashing of plastics; cleaning; very light deburring; fragile parts

2.2.2 Blasting Methods[2-8]

Abrasive blasting systems typically include three basic components: an abrasive container (i.e., blasting pot), a propelling device, and an abrasive blasting nozzle(s). The exact equipment used depends on the application.

The three propelling methods used in abrasive blasting systems are: centrifugal wheels, air pressure, or water pressure. Centrifugal wheel systems use centrifugal and inertial forces to mechanically propel the abrasive media.[3] Air blast systems use compressed air to propel the abrasive to the surface being cleaned.[4] Finally, the water blast method uses either compressed air or high pressure water.[5]

The compressed air suction, the compressed air pressure, and the wet abrasive blasting systems utilize the air blast method. Hydraulic blasting systems utilize the water blast method.

In compressed air suction systems, two rubber hoses are connected to a blasting gun. One hose is connected to the compressed-air supply and the other is connected to the bottom of the abrasive supply tank or “pot.” The gun (Figure 2-1a) consists of an air nozzle that discharges into a larger nozzle. The high velocity air jet (expanding into the larger nozzle) creates a partial vacuum in the chamber. This vacuum draws the abrasive into the outer nozzle and expels it through the discharge opening. Figure 2-1b shows a typical suction type blasting machine.

The compressed air pressure system consists of a pressure tank (pot) in which the abrasive is contained. The use of a pressure tank forces abrasive through the blast hose rather than siphoning it as described above. The compressed air line is connected to both the top and bottom of the pressure tank. This allows the abrasive to flow by gravity into the discharge hose without loss of pressure (see Figure 2-2).

Finally, wet abrasive blasting systems (Figure 2-3a) use a specially designed pressure tank. The mixture of abrasive and water is propelled by compressed air.   An alternate method uses a pressure tank and a modified abrasive blasting nozzle. This modified abrasive blasting nozzle is shown in Figure 2-3b.

Hydraulic blasting incorporates a nozzle similar to that described above for air suction systems, except that high pressure water is used as the propelling media instead of compressed air. A diagram of this type of nozzle is shown in Figure 2-4.

Pressure blast systems generally give a faster, more uniform finish than suction blast systems. They also produce high abrasive velocities with less air consumption than suction systems. Pressure blast systems can operate at pressures as low as 1 psig to blast delicate parts and up to 125 psig to handle the most demanding cleaning and finishing operations.[2]

Suction blast systems are generally selected for light-to-medium production requirements, limited space, and moderate budgets. These systems can blast continuously without stopping for abrasive changes and refills.[2]

The amount of sand used during blasting operations can be estimated using Table 2-2. By knowing the inside diameter of the nozzle (inches) and the air pressure supplied (psig), the sand flow rate is provided. For different abrasives and nozzle diameters, Equation 2-1 can be used.[2]

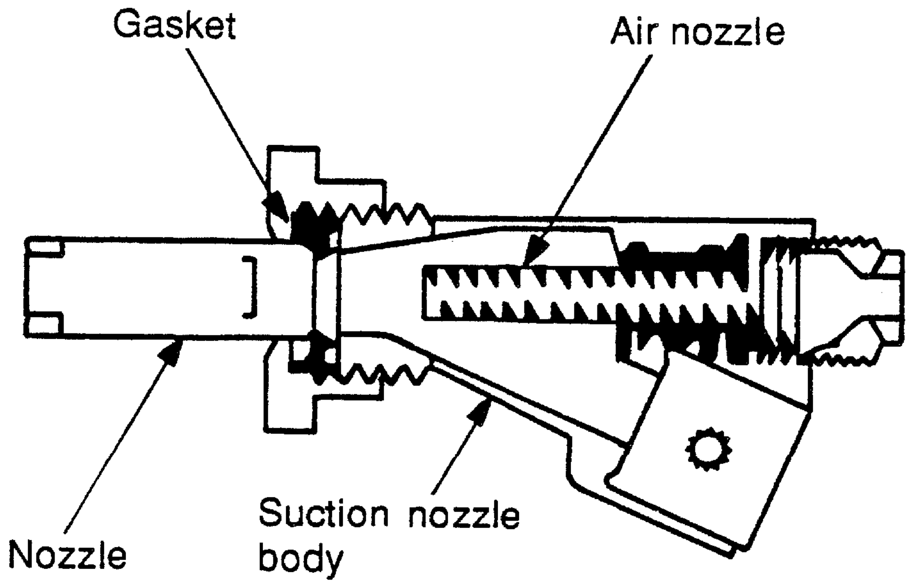

Figure 2-1a. Suction blast nozzle assembly.

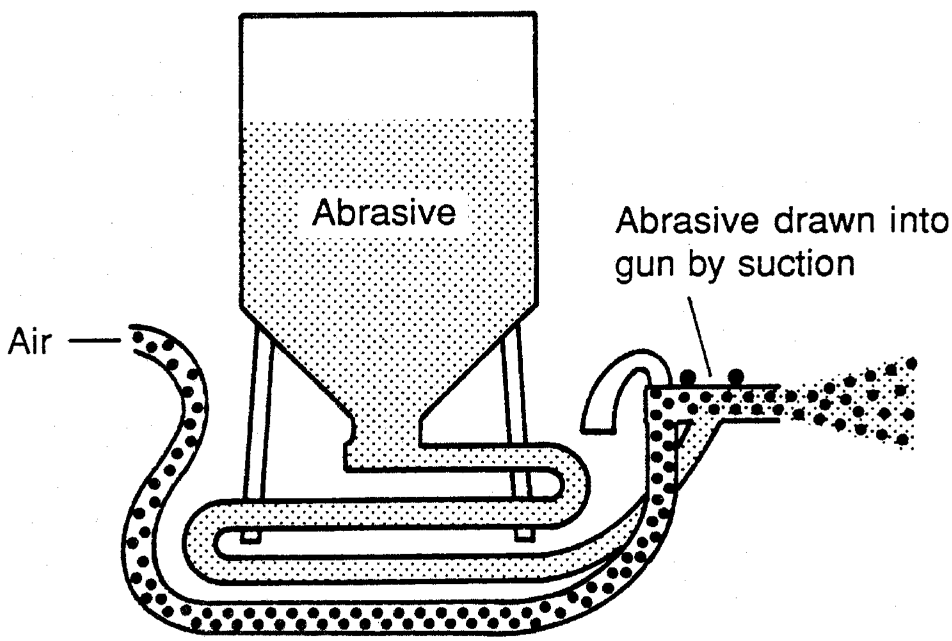

Figure 2-1b. Suction-tape blasting machine.

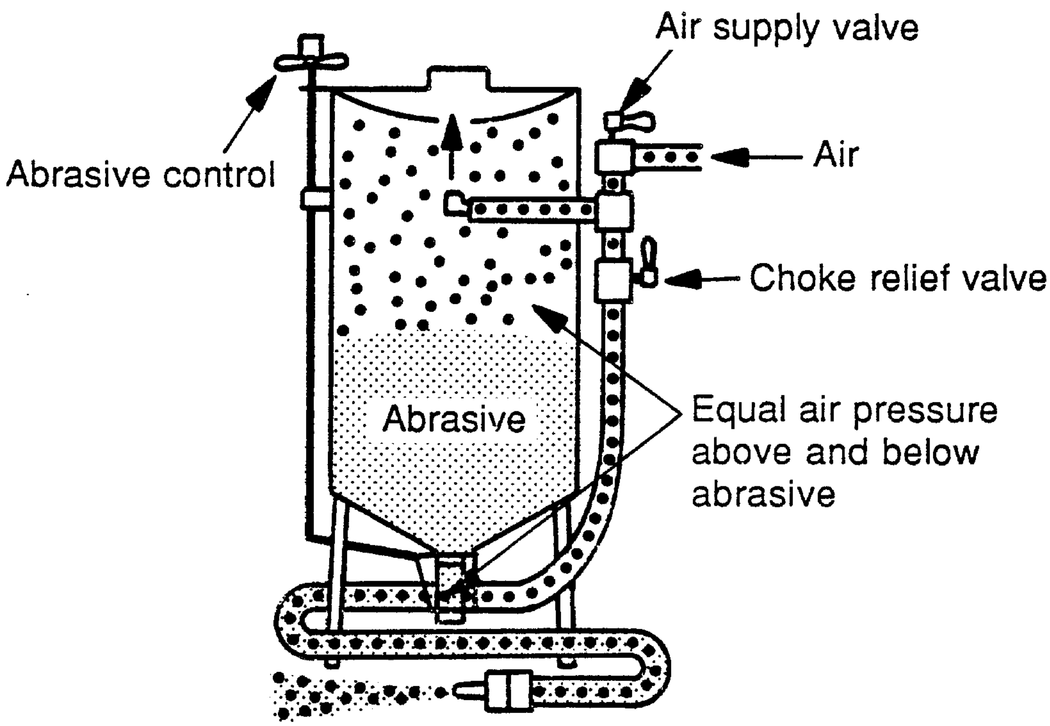

Figure 2-2. Pressure-type blasting machine.

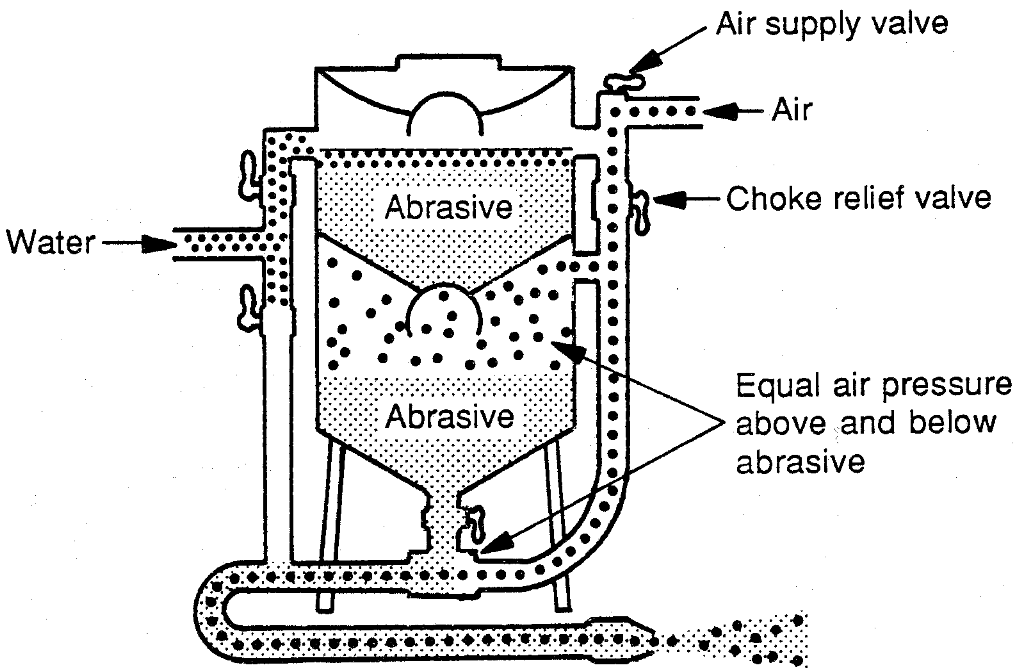

Figure 2-3a. Wet blasting machine.

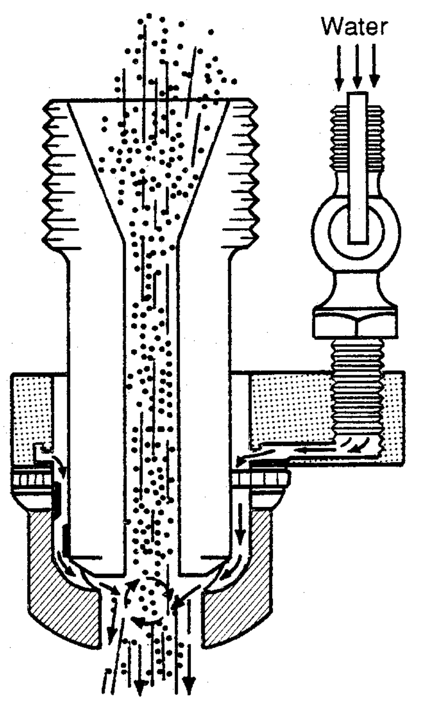

Figure 2-3b. Adapter nozzle converting a dry blasting unit to a wet blasting unit.

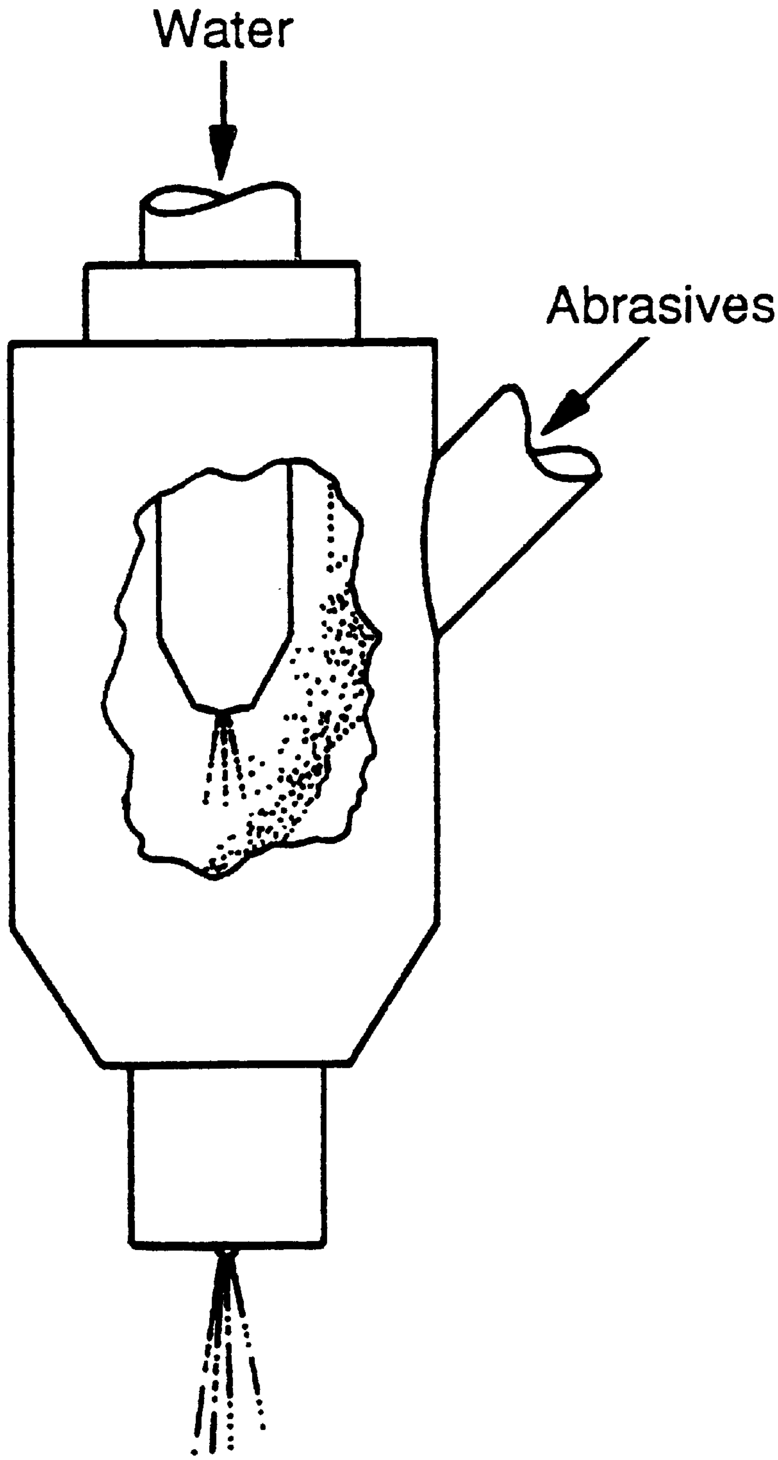

Figure 2-4. Hydraulic blasting nozzle.

$$\dot{m}_a = \dot{m}_s \times \frac{(D_a)^2}{(D_s)^2} \times \frac{\rho_a}{\rho_s} \quad (2\text{-}1)$$

where:

- $\dot{m}_a$ = mass flow rate (lb/hr) of abrasive with nozzle internal diameter D_a
- $\dot{m}_s$ = mass flow rate (lb/hr) of sand with nozzle internal diameter D_s from Table 2-2
- D_a = actual nozzle internal diameter (in.)
- D_s = nozzle internal diameter (in.) from Table 2-2
- ρ_s = bulk density of sand (lb/ft^3)
- ρ_a = bulk density of abrasive (lb/ft^3)

TABLE 2-2. FLOW RATE OF SAND THROUGH A BLASTING NOZZLE AS A FUNCTION OF NOZZLE PRESSURE AND INTERNAL DIAMETER[2]

Nozzle internal diameter, in.	Sand flow rate through nozzle, lb/hr							
	Nozzle pressure, psig							
	30	40	50	60	70	80	90	100
1/8	28	35	42	49	55	63	70	77
3/16	65	80	94	107	122	135	149	165
1/4	109	138	168	195	221	255	280	309
5/16	205	247	292	354	377	420	462	507
3/8	285	355	417	477	540	600	657	720
7/16	385	472	560	645	755	820	905	940
1/2	503	615	725	835	945	1,050	1,160	1,265
5/8	820	990	1,170	1,336	1,510	1,680	1,850	2,030
3/4	1,140	1,420	1,670	1,915	2,160	2,400	2,630	2,880
1	2,030	2,460	2,900	3,340	3,780	4,200	4,640	5,060

The densities of several different abrasives are shown in Table 2-3.

TABLE 2-3. BULK DENSITY OF COMMON ABRASIVES[2]

Type of abrasive	Density, lb/ft^3
Aluminum oxides	160
Sand	99
Steel	487

2.3 DUST CONTROL TECHNIQUES[2,4,6,7]

A variety of techniques have been used to contain and recover the debris generated during abrasive cleaning operations. These techniques may be categorized into the following: blast enclosures, vacuum blasters, drapes, water curtains, wet blasters, and centrifugal blasters. Brief descriptions of each are provided below. A more detailed discussion of each method can be found in Reference 6.

2.3.1 Blast Enclosures

Blast enclosures are designed to completely enclose one or more abrasive blast operations, thereby confining the blast debris. The enclosure floor is usually equipped with funnels to divert the captured debris into adjacent trucks. In one design, a ventilation system is used to remove the airborne dust from the enclosure with the particles removed from the effluent airstream by a wet scrubber. The enclosures are moved as the work progresses.

Blast enclosures can be very effective in containing and recovering abrasive blast debris. However, they are specifically designed for a particular application, relatively expensive, and tend to slow down the overall cleaning rate due to the time required to move the enclosure as the work progresses.

Some leakage of abrasive and paint debris can occur at the joints between the blast enclosure and the structure being cleaned. Although attempts have been made to seal the joints with canvas, this is usually not very effective, particularly when the blast is directed into these areas. A better method to minimize leakage from enclosure joints is to fasten a flexible seal made of rubber, plastic, or thin metal to the inside edges of the enclosure walls. The end of the flexible seal rests on the structure being cleaned, thus reducing the escape of airborne dust.

2.3.2 Vacuum Blasters

Vacuum blasters are designed to remove paint and other surface coatings by abrasive blasting and simultaneously collect and recover the spent abrasive and paint debris with a capture and collection system surrounding the blast nozzle (Figure 2-5). In this type of system, the abrasive is automatically reclaimed and reused as work progresses. Vacuum blasters are made in a variety of sizes but even the smaller units are comparatively heavy and awkward to use. Furthermore, the production rates of the small units are low, and costs are relatively high.

2.3.3 Drapes

Porous drapes (or curtains) on both sides of a truss-type structure (e.g., bridge) have been used to divert debris downward into a barge or lined net under the blasting operation. The top of the drapes are tied to the top of the structure. This technique is relatively inexpensive but also not very effective because dust penetrates the porous drape and spillage occurs due to wind effects.

2.3.4 Water Curtains

In this technique, a water header with a series of nozzles is installed along the edges of the structure being blasted. The water spray from the nozzles is directed downward creating a water curtain to collect debris from abrasive blasting performed below the header. The debris is subsequently washed down to the ground. This technique is relatively inexpensive and does reduce the amount of airborne dust.

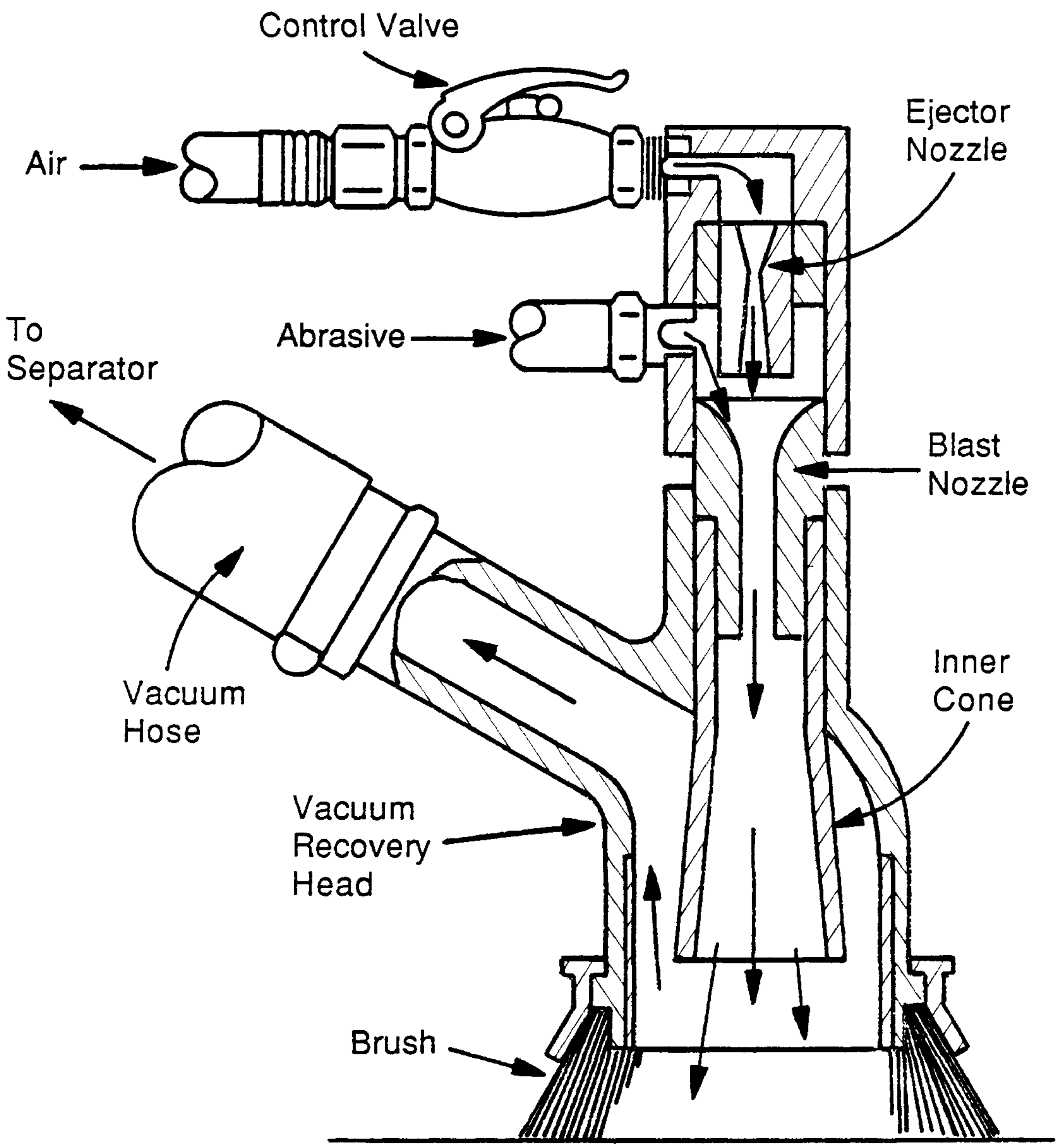

Figure 2-5. Schematic of vacuum blaster head.

However, one disadvantage is that the debris-laden water spills onto the ground (or into the water under a bridge) creating additional contamination and clean-up problems.

One method used to solve the spillage problem associated with water curtains involves the placement of troughs under the spray pattern to catch the water/abrasive mixture and divert it to an appropriate container (e.g., tank truck) for disposal. For low structures, the troughs can be placed on the ground. For high structures, the troughs can be supported from the structure itself. To minimize wind effects, porous drapes can be added, extending from the blast area down to the troughs.

2.3.5 Wet Blasting

Wet blasting techniques include: wet abrasive blasting; high-pressure water blasting; high-pressure water and abrasive blasting; and air and water abrasive blasting. The type of wet blasting method used depends on the application.

Wet abrasive blasting is accomplished by adding water to conventional abrasive blasting nozzles as shown in Figure 2-6. High-pressure water blast systems include an engine-driven, high-pressure pump, high-pressure hose, and a gun equipped with a spray nozzle. If abrasives are introduced to this type of system, high-pressure water and abrasive blasting is provided. Finally, in air and water abrasive blasting systems, each of the three materials can be varied over a wide range, making them very versatile. Compared to dry blasting, all wet blasting techniques produce substantially lower dust emissions.

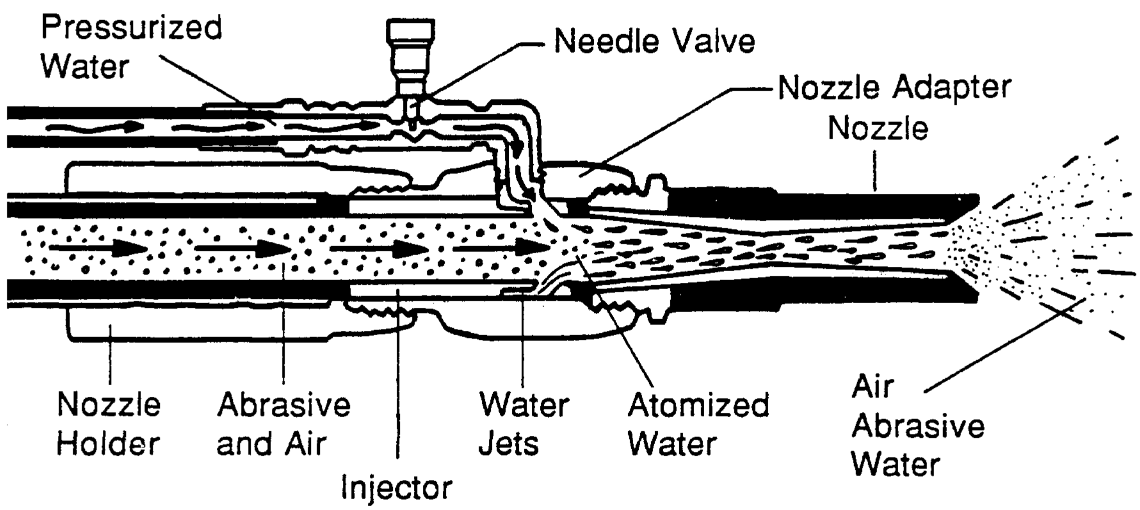

Figure 2-6. Nozzle for air abrasive wet blast.

Most wet abrasive blasters mix the water with the abrasive prior to impact on the surface. This interaction can cause the rate of surface cleaning to be lower than with dry abrasive blasting. To solve this problem, a retrofit device (design to minimize premixing of the water with the abrasive blast) has been developed to fit over the end of conventional abrasive blast nozzles. This device is shown in Figure 2-7.

The two principal parts of the device (Figure 2-7) are a swirl chamber and an exit nozzle. The swirl chamber is equipped with a tangential water inlet. The incoming water swirls around the inside of the chamber and then out the exit nozzle. Centrifugal force causes the water to form a hollow cone pattern

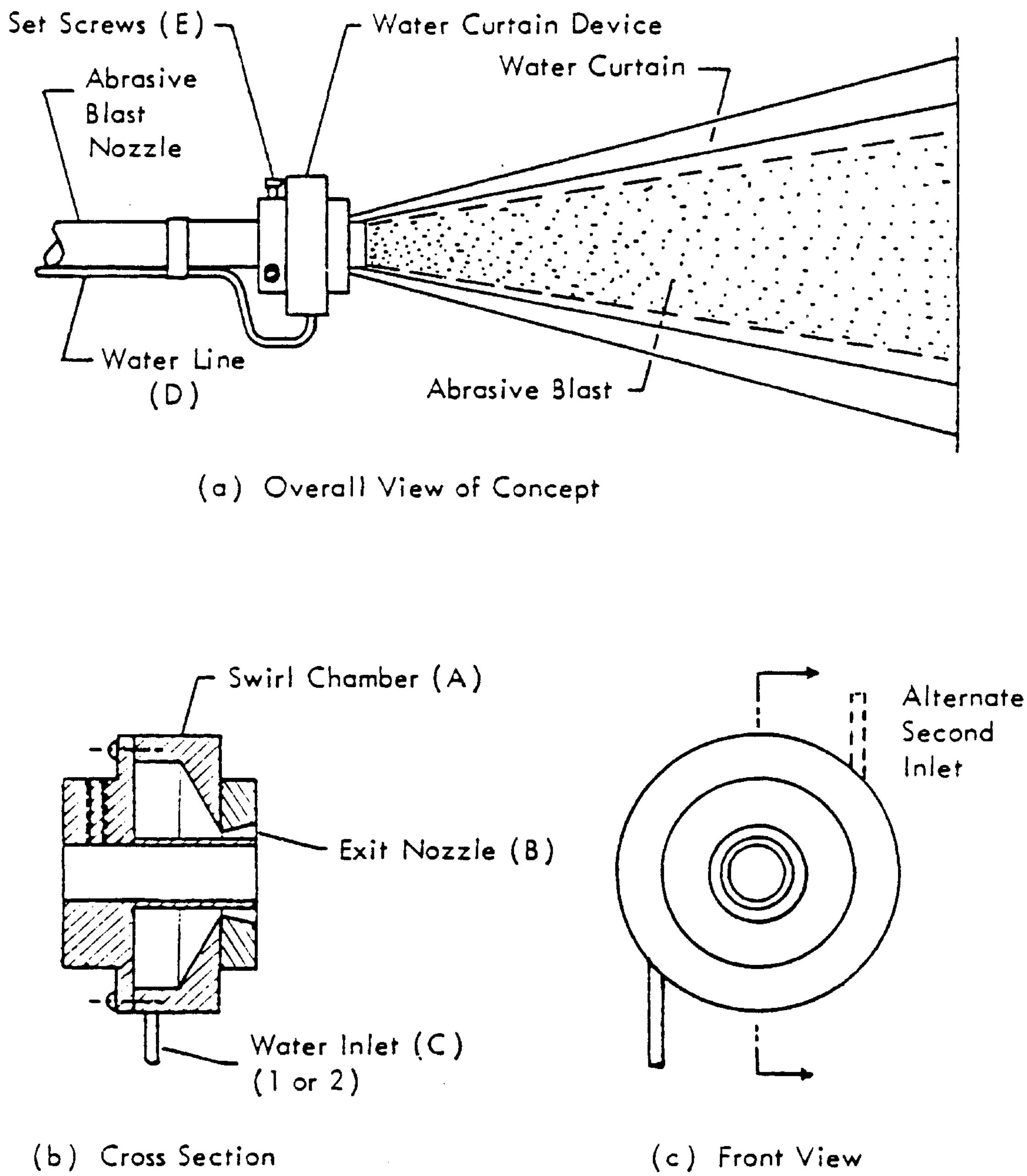

Figure 2-7. Water curtain device for abrasive blast nozzle.

around the abrasive blast stream. The angle of the water cone is controlled principally by the shape of the exit nozzle and centrifugal forces.

The above device is expected to be an improvement over traditional wet abrasive blasting. The modified water nozzle design provides a water curtail around the abrasive/airstream. Thus, the cleaning effectiveness of the abrasive/airstream should not be substantially affected. The device is simple to install and operate with conventional abrasive blasting equipment.

2.3.6 Centrifugal Blasters

Finally, centrifugal blasters use high-speed rotating blades to propel the abrasive against the surface to be cleaned. These blasters also retrieve and recycle the abrasive by the use of a capture and collection system which allows little abrasive or paint debris to escape. Present centrifugal blasters are designed primarily for large, flat, horizontal surfaces such as ship decks. Some have been designed for use on large vertical surfaces such as ship hulls and storage tanks. Some effort has been made to develop small hand-held units for use on bridges and similar structures.

2.4 REFERENCES FOR SECTION 2

1. Written communication from J. D. Hansink, Barton Mines Corporation, Golden, CO, to Attendees of the American Waterways Shipyard Conference, Pedido Beach, AL, October 28, 1991.

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4. B. Baldwin, "Methods of Dust-free Abrasive Blast Clearing," *Plant Engineering, 32(4)*, February 16, 1978.

5. B. R Appleman and J. A. Bruno, Jr., "Evaluation of Wet Blast Cleaning Units," *J. Protective Coatings and Linings, 2(8)*, August 1985.

6. M. K. Snyder and D. Bendersky, *Removal of Lead-based Bridge Paints*, NCHRP Report 265, Transportation Research Board, Washington, DC, December 1983.

7. J. A. Bruno, "Evaluation of Wet Abrasive Blasting Equipment," *Proceedings of the 2nd Annual International Bridge Conference*, Pittsburgh, PA, June 17-19, 1985.

8. J. S. Kinsey, *Assessment of Outdoor Abrasive Blasting*, Interim Report, EPA Contract No. 68-02-4395, Work Assignment No. 29, U. S, Environmental Protection Agency, Research Triangle Park, NC, September 11, 1989.

3. GENERAL DATA REVIEW AND ANALYSIS

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation was a search of the available literature relating to the particulate emissions associated with open abrasive blasting. This search included data contained in the open literature (e.g., National Technical Information Service); source test reports and background documents located in the files of the EPA's Office of Air Quality Planning and Standards (OAQPS); data base searches (e.g., SPECIATE); and MRI's own files (Kansas City and North Carolina). The search was an update of the extensive information collection effort performed in 1989 as reported in Reference 1.

To evaluate candidate documents for acceptability as sources of emission data, the following general criteria were used:

1. Emissions data must be taken only from a primary reference:

a. Source testing data must be obtained directly from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source (or publication) of the test data.

2. The report must contain sufficient data to evaluate the testing procedures and source operating conditions.

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to the above criteria. This set of documents was further analyzed to derive candidate emission factors for abrasive blasting operations.

3.2 DATA QUALITY RATING SYSTEM

As part of MRI's analysis, the final set of reference documents was evaluated as to the quantity and quality of data. The following data were always excluded from consideration:

1. Test series averages reported in units that cannot be converted to the selected reporting units.

2. Test series representing incompatible test methods.

3. Test series in which the control device (or equipment) is not specified.

4. Test series in which the abrasive blasting process is not clearly identified and described.

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

If there was no reason to exclude a particular data set, each was assigned a rating as to its quality. The rating system used was that specified by the EPA's Office of Air Quality Planning and Standards (OAQPS) for the preparation of AP-42 Sections.[2] The data were rated as follows:

A—Multiple tests performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily have to conform to the methodology specified by EPA reference test methods, although such were certainly used as a guide.

B—Tests that are performed by a generally sound methodology, but they lack enough detail for adequate validation.

C—Tests that are based on an untested or new methodology or that lack a significant amount of background data.

D—Tests that are based on a generally unacceptable method, but the method may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally accepted methodology. If actual procedures deviated from accepted methods, the deviations were well documented.

3. Sampling and process data. Adequate sampling and process data were documented in the report. Many variations may be unnoticed and occur without warning during testing. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those specified by EPA (if any) to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:

A—Excellent: Developed from A- and B-rated source test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B—Above average: Developed only from A- or B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. The source category is specific enough so that variability within the source category population may be minimized.

C—Average: Developed only from A-, B- and/or C-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. In addition, the source category is specific enough so that variability within the source category population may be minimized.

D—Below average: The emission factor was developed only from A-, B-, and/or C-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E—Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are footnoted.

The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. Details of the rating of each candidate emission factor are provided in Section 4.

3.4 REFERENCES FOR SECTION 3

1. J. S. Kinsey, *Assessment of Outdoor Abrasive Blasting*, Interim Report, EPA Contract No. 68-02 4395, Work Assignment No. 29, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 11, 1989.

2. *Procedures for Preparing Emission Factor Documents,* EPA-454/R-95-015, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1997.

4. EMISSION FACTOR DEVELOPMENT

4.1 REVIEW OF SPECIFIC DATA SETS

In the prior information search of the literature for documents on the subject of abrasive blasting, 37 individual documents were identified for further evaluation.[1] Upon subsequent review of these documents, 15 were determined to contain some type of applicable air monitoring data. Of these 15 documents, only 9 contained data which were found to be potentially useful in the development of candidate emission factors. Those documents are listed in Table 4-1.

TABLE 4-1. REFERENCE DOCUMENTS REVIEWED DURING LITERATURE SEARCH

Samimi, B., "Silica Dust in Sandblasting Operations," Ph.D. Thesis, Tulane University, 1973.
Samimi, B., et al., "Dust Sampling Results at a Sandblasting Yard Using Stan-Blast in the New Orleans Region: A Preliminary Report," NIOSH-00036278, New Orleans, LA, 1974.
Samimi, B., et al., "The Efficiency of Protective Hoods Used by Sandblasters to Reduce Silica Dust Exposure," *Am. Indus. Hyg. Assn. J.,* 36(2), February 1975.
Landrigan, P. J., et al., "Health Hazard Evaluation Report on the Tobin-Mystic River Bridge," TA80-099-859, NIOSH Report to City Boston Department of Health and Hospitals, Boston, MA, July 25, 1980.
Bareford, P. E., and F. A. Record, "Air Monitoring at the Bourne Bridge Cape Cod Canal, Massachusetts," Final Report, Contract No. DACW 33-79-C-0126, U.S. Army Corps of Engineers, New England Division, Waltham, MA, January 1982.
Beddows, N. A., "Lead Hazards and How to Control Them," *Natl. Safety News,* 128(6), December 1983.
Lehner, E., et al., Memo to D. M. Moline, Department of Public Utilities, Division of Environmental Services, City of Toledo, OH, January 31, 1985.
WhiteMetal, Inc., "Protecting Our Environment with the Jet Stripper," Houston, TX, June 1987.
South Coast Air Quality Management District, "Section 2: Unconfined Abrasive Blasting," Draft Document, El Monte, CA, September 8, 1988.

Besides the documents listed in Table 4-1, the ongoing literature search yielded seven additional test reports, as listed below.

1. Kinsey, J. S., et al., "Development of Particulate Emission Factors for Uncontrolled Abrasive Blasting Operations," U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1995.
2. *NEESA 2-161. Particulate and Chromium Emission Testing at Plastic Media Blasting Facility, BLDG 25, Naval Aviation Depot, Naval Air Station, Alameda, CA*, Naval Energy and Environmental Support Activity, Port Hueneme, CA, May 1990.

3. *Determination of Particulate Emission Rates & Baghouse Removal Efficiency, Hamilton Foundry, Harrison, Ohio*, K&B Design, Inc., Cincinnati, OH, September 3, 1991.

4. Written Communication from D. Borda, The Hamilton Foundry & Machine Co., Harrison, OH, to L. Gruber, Southwestern Ohio Air Pollution Control Agency, Cincinnati, OH, November 27, 1990.

5. *Summary of Source Test Results, Hunter Schlesser Sandblasting, San Leanardo, CA*, Bay Area Air Quality Management District, San Francisco, CA, March 3, 1993.

6. *Summary of Source Test Results, Poly Engineering, Richmond, CA*, Bay Area Air Quality Management District, San Francisco, CA, November 19, 1990.

One additional report (Peart, J., et al. [title unknown] Federal Highway Administration, Washington, DC, 1995.) was requested from the Federal Highway Administration in March 1995 but never received. References 2 through 6 (listed above) document emission tests on enclosed abrasive blasting operations. Brief reviews of References 1 through 6 are provided in the following paragraphs.

4.1.1 Reference 1

The most definitive study in terms of data quality and documentation was reported by Kinsey et al., as cited above. The reported (uncontrolled) emission factors were based on actual air emissions data from a pilot-scale test facility within which full-scale abrasive blasting (surface cleaning) was performed. This entailed the construction and use of a low speed wind tunnel that was large enough to house commercially available abrasive (sand) blasting equipment. Conventional EPA stack sampling and analysis procedures were used in each test to determine emissions of particulate matter (PM) and HAP metals generated by abrasive blasting of mild steel panels (automobile hoods and tank sides) with silica sand. The ten HAP metals are arsenic (As), beryllium (Be), cadmium (Cd), cobalt (Co), chromium (Cr), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), and selenium (Se). Iron (Fe) emissions also were measured. Duplicate test runs were conducted at each of nine test conditions covering the nominal range of wind speeds (5, 10, and 15 mph) and types of cleaned surfaces (precleaned, painted, and rusted). Emissions and facility operating data were collected for each test condition. Finally, uncontrolled PM emission factors were developed for each test condition. The data from this document are assigned an A rating. The EPA reference test methods were used, adequate detail was provided, and no problems were reported.

4.1.2 Reference 2

This reference documents an emission test conducted on an enclosed abrasive blasting operation at a California Naval Aviation Depot. Particulate matter, chromium, and hexavalent chromium emissions were measured at the outlets of two fabric filters that control emissions from the blasting operations. A modified EPA Method 5 sampling train was used to measure PM emissions, and CARB Method 425 was used to measure chromium and hexavalent chromium. The blasting operations use plastic media as the blasting abrasive. The test report does not include process rates, and emission factors could not be developed from the data. The PM concentrations measured during the test averaged 3.61 mg/dscm (0.00158 gr/dscf). The chromium concentrations averaged 0.00187 mg/dscm (8.17×10^{-7} gr/dscf) and the hexavalent chromium concentrations averaged 0.000950 mg/dscm (4.12×10^{-7} gr/dscf). These data are not rated for use in developing emission factors.

4.1.3 Reference 3

This reference documents an emission test conducted on an enclosed abrasive blasting operation at Hamilton Foundry in Harrison, Ohio, on August 20 and 21, 1991. Particulate matter emissions were measured at the inlet and outlet of a fabric filter that controls emissions from the blasting operations and several other plant processes. The fabric filter collection efficiency was 99.9 percent during testing. The results from this test are not useful because several processes are ducted to the fabric filter that was tested.

4.1.4 Reference 4

This reference documents an emission test conducted on an enclosed abrasive blasting operation at Hamilton Foundry in Harrison, Ohio, on October 30, 1990. Particulate matter emissions were measured at the inlet and outlet of a fabric filter that controls emissions from the blasting operations and several other plant processes. The fabric filter collection efficiency was 99.9 percent during testing. The results from this test are not useful because several processes are ducted to the fabric filter that was tested.

4.1.5 Reference 5

This reference documents an emission test conducted on an enclosed abrasive blasting operation at Hunter Schlesser Sandblasting in San Leanardo, CA, on February 10, 1993. Particulate matter emissions were measured at the outlet of a fabric filter that controls emissions from blasting operations. Three CARB Method 5 test runs were completed, and the average PM concentration was 2.3 mg/dscm (0.001 gr/dscf). Glass beads were used as the blast media, and the targeted surfaces included two large motor shields and several handrails. Process rates are not provided in the report.

4.1.6 Reference 6

This reference documents an emission test conducted on an enclosed abrasive blasting operation at Poly Engineering in Richmond, CA, on February 10, 1993. Filterable PM emissions were measured at the outlet of a fabric filter that controls emissions from blasting operations. Three CARB Method 5 test runs were completed, and the average PM concentration was 0.055 gr/dscf. A CARB certified 30/40 mesh garnet was used as the blast media, and the targeted surface was unspecified parts. Process rates are provided (lb/hr of abrasive) in the report, and emission factors were developed in units of lb/1,000 lb of abrasive used. The test report contains incomplete documentation of the stack test data.

The data from this report are assigned a C rating because of the level of detail provided in the report. The test methodology appeared to be sound and no problems were reported. However, sufficient data are not included in the report to allow for a complete review of the test.

4.2 RESULTS OF DATA ANALYSIS

The individual data sets were evaluated using the criteria and rating system developed by the EPA's Office of Air Quality Planning and Standards for the development of AP-42 emission factors. This scheme entails the rating of test data quality followed by the rating of the adequacy of the data base relative to the characterization of uncontrolled emissions from the source.

A summary of the available test data for uncontrolled and controlled abrasive blasting operations are provided in Tables 4-2 and 4-3.

A number of comments should be made with regard to the data contained in Tables 4-2 and 4-3. In the case of Table 4-2, only four of the twelve data sets contained enough information to develop PM and/or lead emission factors for abrasive blasting operations. Six of the other studies involved some type of industrial hygiene or ambient air monitoring in the vicinity of the blasting operation. None of the industrial hygiene/ambient air studies characterized the blasting operation in sufficient detail for further analysis and emission factor development. Finally, two of the tests did not include process rates. Two

TABLE 4-2. SUMMARY OF TEST DATA FOR ABRASIVE BLASTING OPERATIONS[a]

Reference document	Type of operation tested	Type of abrasive	Sampler location	Particle size fraction, µmA[b]	Time weighted average concentration, mg/m^3	Data quality rating	Emission factor, mass/source extent	Comments
Samini, 1973; Samini et al., 1975	Outdoor sandblasting at two steel fabrication yards	Silica sand	Within 5 yd (4.6 m) of sandblaster	TP	1.46-76.8	NR	N/A	31 samples; no process data
				< 11	11.8	NR	N/A	16 sample average; no process data
				RP	0.109-8.93	NR	N/A	29 samples; no process data
Samini et al., 1974	Abrasive cleaning of ship hull	Stan-Blast	< 5 yd (4.6 m) from source	TP	10.2	NR	N/A	Sampling time = 185 min
				RP	4.58	NR	N/A	Blasting time = 180 min; no process data
			Sandblaster's chest	RP	88.8	NR	N/A	Sampling time = 181 min; blasting time = 150 min; no process data
			< 10 yd (9.1 m) from source	RP	2.26-9.88	NR	N/A	No process data available
				< 11	6.98	NR	N/A	
Landrigan et al., 1980	Abrasive bridge cleaning of lead-based paint	Grit (Black Beauty)	27 m downwind of bridge	TSP (Pb)	0.0129	NR	N/A	Data for a 6.1-h sampling period during which canvas shroud was not in place for a 2-h period; Pb contributions from paint chips, vehicle exhaust, and grit; no process data available
Bareford and Record, 1982	Abrasive bridge cleaning of lead-based paint	Sand	Center of plume exiting sandblasting bay	TP	—	D	57-455 lb/h/ sandblaster	2.5% Pb for particles < 2.4 µm; sand usage—700 lb/h per blaster (no exact throughput available)
				TP (Pb)	–	D	1.5-4.8 lb/h/ sandblaster	< 1% Pb for particles > 75 µm; sand usage—700 lb/h per blaster (no exact throughput available)
				< 10	—	D	24 lb/h/ sandblaster	Sand usage—700 lb/h per blaster (no exact throughput available)
				< 10 (Pb)	—	D	0.46 lb/h/ sandblaster	Sand usage—700 lb/h per blaster (no exact throughput available)
Beddows, 1983	General abrasive blasting of lead-based paint	Grit	Breathing zone samples	TP	3-30+	NR	N/A	8-h time-weighted averages; grit from coal slag typically contains from 20-40 µg of Pb/g of material; grit from copper smelting can contain up to 6,000 µg Pb/g of material; no process data reported
Lehner et al., 1985	Abrasive bridge cleaning of lead-based paint	Sand	300-400 ft (91-122 m) downwind of bridge	TSP	0.339-0.482	NR	N/A	24-h time-weighted averages; no process data or controls specified; assumed to be essentially uncontrolled
				TSP (Pb)	0.00122-0.00215	NR	N/A	

TABLE 4-2. (continued)

Reference document	Type of operation tested	Type of abrasive	Sampler location	Particle size fraction, µmA[b]	Time weighted average concentration, mg/m^3	Data quality rating	Emission factor, mass/source extent	Comments
WhiteMetal Inc., 1987	Outdoor blasting of steel panels coated with lead-based paint	30-60 mesh (0.59-0.25 mm) silica sand	5 ft (1.5 m) downwind	TSP	257.61	NR	N/A	Hi-vols installed downwind of dry blasting operation to demonstrate control effectiveness of "Jet Stripper"; no sampling time or process data reported
			50 ft (15 m) downwind	TSP	45.99	NR	N/A	
			100 ft (30 m) downwind	TSP	6.18	NR	N/A	
			200 ft (61 m) downwind	TSP	2.71	NR	N/A	
			500 ft (152 m) downwind	TSP	0.90	NR	N/A	
South Coast Air Quality Management District, 1988	Outdoor abrasive blasting	Sand	In ventilation system duct	TP	N/A	D	0.041 lb/lb sand	Emission factors determined by source test of an uncontrolled indoor blasting operation using a quasi-stack technique; original test report not available
		Grit		TP	N/A	D	0.010 lb/lb grit	
		Shot		TP	N/A	D	0.004 lb/lb shot	
		Other		TP	N/A	D	0.010 lb/lb abrasive	
Kinsey et al., 1995	Blasting of molded steel panels, painted, cleaned, or rusted	30-50 mesh silica sand	40 ft (12 m) downwind	TP, < 10, < 2.5	See Reference 1	A	See Table 4-4	Emission factors determined by source tests in low speed wind tunnel using standard test methods for total particulate, particle size distribution, and iron and 10 HAP metals
NEESA 2-161, 1990	Enclosed blasting of aircraft parts	Plastic	Fabric filter stack	TP	3.61	NR	N/A	Fabric filter-controlled plastic media blast room. No process data. Chromium conc. of 0.00187 mg/m^3 and Cr^{+6} conc. of 0.00095 mg/m^3
Hunter Schlesser Sandblasting, 1993	Enclosed blasting of motor shields and handrails	Glass beads	Fabric filter stack	TP	2.3	NR	N/A	Fabric filter-controlled glass bead blast room. No process data.
Poly Engineering, 1990	Enclosed blasting of unspecified parts	Garnet	Fabric filter stack	TP	126	C	0.00069 lb/lb garnet	1,740 lb/hr of abrasive used to blast 700 lb/hr of parts

[a]From references listed in Table 4-1. N/A = not available or not applicable. NR = not rated.
[b]TP = total particulate matter. RP = respirable particulate matter (≤ 3.5 µmA) as determined using a 10-mm nylon cyclone followed by a 37-mm filter cassette. TSP = total suspended particulate matter (≤ 30-50 µmA) as determined by a high volume air sampler.

TABLE 4-3. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR ABRASIVE BLASTING OPERATIONS[a]

Reference document	Type of operation tested	Type of abrasive	Control technology employed	Sampler location	Particle size fraction, µmA[b]	Average dust concentration, mg/m^3		Measured control efficiency	Comments
						Uncontrolled	Controlled		
WhiteMetal Inc., 1987	Outdoor blasting of steel panels coated with lead-base paint	30-60 mesh (250-590 µm) silica sand	Water jet blasting nozzle (i.e., "Jet Stripper")	5 ft (1.5 m) downwind	TSP	257.6	42.3	84	Comparison of uncontrolled and controlled dust concentrations assumes identical test conditions; original test data not available; no process data or sampling time reported.
				50 ft (15 m) downwind	TSP	46.0	3.3	93	
				100 ft (30 m) downwind	TSP	6.2	0.55	91	
				200 ft (61 m) downwind	TSP	2.7	0.32	88	
				500 ft (152 m) downwind	TSP	0.90	0.19	79	
So. Coast Air Quality Management District, 1988	Outdoor abrasive blasting	All	Wet blasting (as compared to dry blasting)	–	TP	NA	NA	50%	No basis of control estimate provided

[a]From references listed in Table 4-1. NA = not available.
[b]TSP = total suspended particulate matter (~ ≤30-50 µmA) as determined by a high volume air sampler. TP = total particulate matter.

additional studies (not shown in Table 4-2) had sufficient information to develop emission factors, but the stacks that were tested ducted emissions from abrasive blasting and other sources.

Several problems were also noted with the *Bareford and Record* and *South Coast AQMD* emission factor studies contained in Table 4-2. Both sets of emission factors were generally of poor quality and thus were given a D rating based on the criteria discussed above. The emission factors from these studies are not presented in the AP-42 section, but the South Coast AQMD study provides some valuable information on "relative dustiness" (the amount of PM emitted by the various blast media) of several abrasives. The study indicates that total PM emissions from abrasive blasting using grit are about 24 percent of total PM emissions from abrasive blasting with sand. The study also indicates that total PM emissions from abrasive blasting using shot are about 10 percent of total PM emissions from abrasive blasting with sand. This information is presented in the text of the AP-42 section.

With regard to Table 4-3, only two data sets were identified which address control efficiency applied to abrasive blasting operations. Both data sets were found to be extremely limited in scope and of poor quality. As with the data for uncontrolled emissions, documentation of process operation was nonexistent in both cases. However, the control efficiencies presented in these documents are discussed in the AP-42 section.

Table 4-4 provides an overall summary of the particulate emission factors developed in the study by Kinsey, et al. As shown in Table 4-4, the emission factors for total PM tend to increase with wind speed for each of the three types of mild steel surfaces blasted. Because the emissions contained no condensible fraction, the total PM was collected entirely as "filterable" PM. The emission factors for PM-10, on the other hand, show a tendency to decrease when the wind speed exceeds 10 mph. No substantial difference in particulate emissions was observed, however, by either the type of surface cleaned or coating removed by the abrasive.

The emission factors for five HAP metals and Fe are summarized in Tables 4-5, 4-6, and 4-7 for the total PM, PM-10, and PM-2.5 particle size fractions, respectively. Except for Fe, these emission factors are of the order of 10^{-6} kg per kg of sand. Five other HAP metals (As, Be, Co, Sb, and Se) were generally not detected above blank levels.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

Based primarily on lack of documentation of the abrasive blasting process operation associated with most of the tests summarized in Tables 4-2 and 4-3 (as noted above), only References 1 and 6 were used for developing candidate PM emission factors. Reference 1 addresses only silica sand as a blasting medium, and Reference 6 quantifies fabric filter-controlled PM emissions from blasting with garnet.

Regarding overall PM emissions from the Reference 1 abrasive blasting tests, no significant dependence on the surface condition of the mild steel target panels was observed. Moreover, only the factors for total PM emissions showed a consistent dependence on wind speed.

The candidate emission factors for PM-10 and PM-2.5 were derived (using Reference 1 data) as simple averages of the results from the sand blasting of the three target panels, as shown in Table 4-8. The candidate emission factors for total PM were differentiated by wind speed, as shown in Table 4-9.

TABLE 4-4. SUMMARY OF PM TEST DATA FROM REFERENCE 1[a]

Operating condition	Test runs	Total PM emission factor, kg/kg sand	PM-10 emission factor, kg/kg sand[b]	PM-2.5 emission factor, kg/kg sand[c]	Result of mass balance, % closure[d]
Clean surface					
5 mph	17/18	0.029	0.017	0.0024	100
10 mph	9/10	0.068	0.0081	0.0022	95
15 mph	23/24	0.092	0.0045	0.00090	86
Average emission factor		0.063	0.0099	0.0018	
Painted surface					
5 mph	15/16	0.027	0.0059	0.0010	99
10 mph	7/8	0.070	0.052	0.00086	98
15 mph	21/22	0.091	0.0091	0.0013	79
Average emission factor		0.063	0.022	0.0011	
Oxidized surface					
5 mph	19/20	0.025	0.0057	0.0018	100
10 mph	11/12	0.026	0.014	0.0011	100
15 mph	25/26	0.089	0.0030	0.00026	82
Average emission factor		0.047	0.0074	0.0011	

[a]All results to two significant figures. Sand blasting only. Data are A-rated.
[b]Particles ≤10 µm in aerodynamic diameter (equivalent unit density spheres).
[c]Particles ≤2.5 µm in aerodynamic diameter (equivalent unit density spheres).
[d]Percent closure = $\frac{\text{total sand recovered + total particulate emissions}}{\text{total sand fed to tunnel}} = 100$

TABLE 4-5. SUMMARY OF EMISSION FACTORS FOR PM METALS

Operating condition	Test run	Total emission factor, kg/kg sand					
		Cadmium	Chromium	Iron	Manganese	Nickel	Lead
Clean surface							
5 mph	17/18	1.8e-06	2.5e-06	2.8e-04	1.5e-06	2.0e-06	1.8e-06
10 mph	9/10	7.0e-07	6.5e-06	5.1e-04	2.9e-06	4.9e-06	1.3e-06
15 mph	23/24	1.8e-06	9.6e-06	4.2e-04	2.3e-06	8.0e-06	3.9e-06
Average emission factor		1.4e-06	6.2e-06	4.0e-04	2.3e-06	5.0e-06	2.4e-06
Painted surface							
5 mph	15/16	9.5e-07	4.3e-06	2.9e-04	2.0e-06	2.0e-06	7.1e-06
10 mph	7/8	1.1e-06	8.7e-06	3.5e-04	4.0e-06	4.7e-06	1.4e-05
15 mph	21/22	6.3e-06	1.9e-05	5.1e-04	4.0e-06	2.7e-05	2.0e-05
Average emission factor		2.8e-06	1.1e-05	3.8e-04	3.3e-06	1.1e-05	1.4e-05
Oxidized surface							
5 mph	19/20	6.4e-07	1.4e-06	6.2e-04	4.2e-06	1.3e-06	1.6e-05
10 mph	11/12	1.2e-06	5.2e-06	1.6e-03	1.2e-05	7.1e-06	7.8e-06
15 mph	25/26	1.6e-06	7.2e-06	1.3e-03	4.5e-06	8.3e-06	2.3e-05
Average emission factor		1.1e-06	4.6e-06	1.2e-03	7.1e-06	5.5e-06	1.5e-05

TABLE 4-6. SUMMARY OF EMISSION FACTORS FOR PM-10 METALS

Operating condition	Test run	PM-10 emission factor, kg/kg sand					
		Cadmium	Chromium	Iron	Manganese	Nickel	Lead
Clean surface							
5 mph	17/18	1.8e-06	2.4e-06	2.1e-04	1.3e-06	2.0e-06	1.8e-06
10 mph	9/10	a	6.4e-06	3.1e-04	2.1e-06	4.4e-06	1.3e-06
15 mph	23/24	1.3e-06	9.5e-06	2.7e-04	1.6e-06	7.6e-06	3.9e-06
Average emission factor		a	6.1e-06	2.6e-04	1.7e-06	4.7e-06	2.3e-06
Painted surface							
5 mph	15/16	4.8e-07	4.0e-06	1.8e-04	1.4e-06	1.9e-06	3.5e-06
10 mph	7/8	a	8.0e-06	2.8e-04	3.2e-06	4.2e-06	1.0e-05
15 mph	21/22	2.9e-06	1.8e-05	3.0e-04	3.0e-06	2.6e-05	7.9e-06
Average emission factor		a	6.1e-06	2.6e-04	1.7e-06	4.7e-06	2.3e-06
Oxidized surface							
5 mph	19/20	3.7e-7	1.4e-06	3.8e-04	2.4e-06	1.2e-06	7.0e-06
10 mph	11/12	a	5.1e-06	8.2e-04	6.6e-06	6.3e-06	5.6e-06
15 mph	25/26	2.2e-07	6.9e-06	4.8e-04	2.0e-06	7.8e-06	8.4e-06
Average emission factor		a	4.5e-06	5.6e-04	3.7e-06	5.1e-06	7.0e-06

[a] Cadmium was not detected in any of the particle sizing fractions and therefore the calculations could not be performed.

TABLE 4-7. SUMMARY OF EMISSION FACTORS FOR PM-2.5 METALS

Operating condition	Test run	PM-2.5 emission factor, kg/kg sand					
		Cadmium	Chromium	Iron	Manganese	Nickel	Lead
Clean surface							
5 mph	17/18	1.4e-06	1.5e-06	1.1e-04	1.5e-07	1.1e-06	1.1e-06
10 mph	9/10	a	3.3e-06	2.0e-04	2.4e-07	1.6e-06	1.2e-06
15 mph	23/24	8.0e-07	5.4e-06	1.8e-04	7.0e-08	3.0e-06	3.9e-06
Average emission factor		a	3.4e-06	1.7e-04	1.5e-07	1.9e-06	2.1e-06
Painted surface							
5 mph	15/16	2.1e-07	2.1e-06	1.0e-04	2.9e-06	8.6e-07	2.8e-06
10 mph	7/8	a	4.0e-06	1.6e-04	1.2e-06	1.5e-06	5.6e-06
15 mph	21/22	7.6e-08	7.4e-06	1.5e-04	1.2e-07	8.1e-06	6.3e-06
Average emission factor		a	4.5e-06	1.4e-04	5.4e-07	3.5e-06	4.9e-06
Oxidized surface							
5 mph	19/20	3.1e-07	3.2e-07	1.4e-04	4.2e-07	4.2e-07	4.5e-06
10 mph	11/12	a	3.0e-06	1.9e-04	2.4e-07	3.4e-06	4.9e-06
15 mph	25/26	3.1e-09	3.7e-06	2.2e-04	8.6e-08	4.0e-06	6.6e-06
Average emission factor		a	2.4e-06	1.8e-04	2.5e-07	2.6e-06	5.3e-06

[a]Cadmium was not detected in any of the particle sizing fractions and therefore the calculations could not be performed.

TABLE 4-8. CANDIDATE PM-10 AND PM-2.5 EMISSION FACTORS

Surface	PM emission factors, kg/kg sand	
	PM-10	PM-2.5
Precleaned	0.0099	0.0018
Painted	0.022	0.0011
Oxidized	0.0074	0.0011
Average	0.013	0.0013

TABLE 4-9. CANDIDATE TOTAL PM EMISSION FACTORS DIFFERENTIATED BY WIND SPEED

Wind speed	Emission factor (kg/kg sand) by surface type			Average
	Precleaned	Painted	Oxidized	
5 mph	0.029	0.027	0.025	0.027
10 mph	0.068	0.070	0.026	0.055
15 mph	0.092	0.091	0.089	0.091

All of these candidate emission factors are assigned E ratings because they are based on data from a single study.

Data from Reference 6 were used to calculate an emission factor for fabric filter-controlled abrasive (garnet) blasting. This emission factor is shown in Table 4-10.

TABLE 4-10. CANDIDATE EMISSION FACTOR FOR GARNET BLASTING

Source	Control	No. of tests	EMISSION FACTOR RATING	Total PM emission factor, kg/kg of abrasive used	Reference No.
Enclosed blasting of unspecified metal parts with 30/40 mesh garnet	Fabric filter	1	E	0.00069	6

Because the emissions of HAP metals are strongly dependent on the target material composition and its surface condition, no specific candidate emission factors are proposed.

4.4 REFERENCES FOR SECTION 4

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15. South Coast Air Quality Management District, “Section 2: Unconfined Abrasive Blasting,” Draft Document, El Monte, CA, September 8, 1988.

5. PROPOSED AP-42 SECTION 13.2.6

The following pages contain the proposed new AP-42 section for abrasive blasting as it would actually appear in the document.