

# Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards

**Judith C. Chow and John G. Watson**

*Desert Research Institute, Reno, NV*

**Howard J. Feldman**

*American Petroleum Institute, Washington, DC*

**Janice E. Nolen**

*American Lung Association, Raleigh, NC*

**Barry Wallerstein**

*South Coast Air Quality Management District, Diamond Bar, CA*

**George M. Hidy**

*Envair/Aerochem, Placitas, NM*

**Paul J. Liroy**

*Robert Wood Johnson Medical School, University of Medicine and Dentistry, New Jersey and Rutgers University, Piscataway, NJ*

**Herbert McKee**

*Environmental Consultant, Houston, TX*

**David Mobley**

*Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC*

**Keith Baugues**

*KERAMIDA Environmental, Indianapolis, IN*

**John D. Bachmann**

*Vision Air Consulting, Chapel Hill, NC (formerly Associate Director for Science/Policy and New Programs, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC)*

## INTRODUCTION

Following is the 2007 A&WMA *Critical Review*<sup>1-3</sup> *Discussion*: "Will the Circle Be Unbroken: A History of the U.S. National Ambient Air Quality Standards." In the review, John D. Bachmann traces the regulatory history of U.S. air pollution from the beginning of the 20th century to the present. The review divides this progress into four segments: (1) 1900-1970, from smoke abatement to federal involvement and the establishment of air quality management (AQM) in the 1970 Clean Air Act (CAA); (2) 1971-1976, when the first National Ambient Air Quality Standards (NAAQS) were promulgated and implemented; (3) 1977-1993, which included the

first NAAQS revisions, major CAA amendments, and the evolution of AQM; and (4) 1993-2006, the second and third waves of NAAQS revisions and their implementation in the context of the 1990 CAA amendments.

Invited and contributing discussants agree with, contest, and add to topics treated in the review. Each discussion is self-contained, and joint authorship of this article does not imply that a discussant subscribes to the opinions expressed by others. A discussant's commentary does not necessarily reflect the position of his or her respective organization. In particular, Mobley's comments have not been reviewed by the U.S. Environmental Protection

Agency (EPA) and do not reflect official positions or policy of the agency.

This *Critical Review Discussion* was compiled from written submissions and presentation transcripts that were edited for conciseness, to minimize redundancy, and to provide supporting and instructional citations. Substantial deviations from the intent of a discussant are unintentional and can be addressed in a follow-up letter to the *Journal*. The invited discussants are as follows:

- Mr. Howard J. Feldman is director of regulatory and scientific affairs for the American Petroleum Institute (API). He is charged with developing and promoting credible, cost-effective policies, strategies, positions, standards, and practices; supporting federal and state regulatory and legislative initiatives; and developing and managing relevant, scientifically sound research. He has served as the co-chairman of the NARSTO Executive Steering Committee, which addresses the management of regional and urban air quality in North America.
- Ms. Janice E. Nolen is assistant vice president of national policy and advocacy for the American Lung Association. She directs the development of policy positions on lung disease, air quality, and tobacco control for the nationwide organization and represents the Lung Association with its partner organizations and with federal agencies in policy and regulatory issues. Part of her work involves producing the Lung Association's widely read annual report on air pollution, the *State of the Air*. She serves on EPA's CAA Advisory Committee (CAAAC).
- Dr. Barry Wallerstein is executive officer at the South Coast Air Quality Management District (SCAQMD). He has over 20 yr of experience in urban planning and environmental studies, with an emphasis in air pollution control and public policy development. He has served SCAQMD in various positions since 1984 and was appointed Acting Executive Officer in August 1997. The Governing Board unanimously elevated him to executive officer in November 1998. He has also worked as an environmental control administrator for Northrop, and was a member of the rule development staff in the Mobile Source Division of the California Air Resources Board (CARB).
- Dr. John G. Watson is a research professor in the Division of Atmospheric Sciences at the Desert Research Institute, a part of the Nevada System of Higher Education. He has more than 30 yr of experience in conducting decision-making air quality studies to determine major contributions to excessive concentrations and the effects of emission reduction strategies. He is currently chair of a National Academy of Engineering committee on "Energy and Air Quality Futures in Urban China and the United States."

The contributing discussants are as follows:

- Dr. George M. Hidy is primary of Envair/Aerochem. He has served as an advisor to the electric utility industry and government on air quality issues, and has authored reviews on airborne particles and atmospheric chemistry. His research interests include atmospheric aerosols and their environmental consequences, including health effects. He is Co-Editor of this *Journal*.
- Dr. Paul J. Liroy is a professor in the Department of Environmental and Occupational Medicine, Robert Wood Johnson Medical School, (RWJMS) University of Medicine and Dentistry, New Jersey (UMDNJ), and Deputy Director of Government Relations and Director of the Exposure Science Division of the Environmental and Occupational Health Sciences Institute, RWJMS-UMDNJ and Rutgers University. His research covers environmental health, exposure science, and air pollution problems. He is a member of the EPA Science Advisory Board, and has served as a member or chair of National Research Council (NRC) committees.
- Dr. Herbert McKee is an environmental consultant and 52-yr member of A&WMA. He served approximately 40% of that time as a state or local regulatory official. His experience includes many research projects on ozone (O<sub>3</sub>) measurement and control, among other topics.
- Mr. David Mobley, P.E., is associate director of the Atmospheric Modeling Division of the EPA's Office of Research and Development. He served as coordinator of the NARSTO Emission Inventory Assessment.
- Mr. Keith Baugues, P.E., is technical leader of air services for KERAMIDA Environmental and is past chair of A&WMA's AM-1 Committee on Emission Factors and Inventories.

The musical contributions from Mr. Bachmann and Dr. Watson presented at A&WMA's 100th anniversary meeting in Pittsburgh, PA, will be available on the A&WMA Web site: [www.awma.org](http://www.awma.org).

#### **INVITED COMMENTS FROM MR. HOWARD J. FELDMAN**

The stated goal of the 2007 *A&WMA Critical Review*<sup>1</sup> is to summarize AQM since 1900, with an emphasis on the U.S. NAAQS. The review presents lessons learned, key issues, and challenges for future AQM, as well as possible improvements and alternative approaches for the future. It provides an excellent history of the NAAQS, and it will become one of the fundamental resources on this subject for air quality experts and others. The review could be enhanced with additional attention to the lessons learned and possible new AQM approaches.

The review highlights three key NAAQS issues that are still part of today's decision-making paradigm: (1) establishing protective thresholds for criteria pollutants, (2) setting NAAQS with an adequate margin of safety, and (3) protecting the *public* health and welfare from any known or anticipated *adverse* effect.

In 1979, the EPA Administrator stated, “the Administrator recognizes, however, that controlling O<sub>3</sub> to very low levels is a task that will have significant impact on economic and social activity. It is thus important that the standard not be any more stringent than protection of health demands.”<sup>4</sup> The current science has led experts to question whether thresholds exist, whether there is an adequate margin of safety, and how “public health” and “adverse effects” are defined. The review could have more critically addressed how these issues should affect the O<sub>3</sub> standard<sup>5</sup> to be promulgated in 2008 and future NAAQS reviews.

To enhance current and future AQM, several issues need more attention and analysis than given in the review. These include: (1) how AQM has been executed in the last 30 yr and how it will be conducted in the future, (2) the quality of emission inventories, (3) monitoring technology and human exposure, (4) background levels, and (5) accountability.

With respect to AQM execution, state implementation plans (SIPs) have not always achieved the intended air quality gains; in many cases, SIP control measures failed to achieve the predicted attainment with the NAAQS.<sup>6</sup> SIPs did not show attainment because photochemical models were not “data constrained”—modelers could always replicate O<sub>3</sub> to within  $\pm 30\%$  of monitored values.

In some cases, attainment dates extend well beyond the NAAQS review cycle. The ramifications are that a state could design an attainment program for a given NAAQS, later to have that NAAQS modified or vacated. This could lead to the non-optimum use of planning and control resources and could further delay NAAQS attainment. For example, a state could design an O<sub>3</sub> attainment strategy focused on volatile organic compound (VOC) emission reductions, only to be later confronted with a revised O<sub>3</sub> standard for which oxides of nitrogen (NO<sub>x</sub>) reductions would have been preferable.

Emission inventories, anthropogenic and biogenic, have been flawed,<sup>7</sup> despite major advances over the last 30 yr. Higher than estimated in-use vehicle emissions were detected through two different approaches: (1) the 1987 Southern California Air Quality Study (SCAQ) tunnel experiment revealed that measured carbon monoxide (CO) and VOC emission rates were three and four times higher, respectively, than estimated by available emission models<sup>8</sup>; and (2) on-road vehicle emission monitors revealed that most vehicles were low emitters, with a small fraction producing a large fraction of light-duty vehicle emissions.<sup>9</sup> As described in greater detail below, NARSTO has completed a comprehensive emission inventory assessment.<sup>10</sup> The highest priority should be to reduce emission uncertainties associated with poorly characterized sources.

With respect to monitoring, the review could have addressed the effectiveness of compliance monitors and how interferences might bias the reported data. Attainment is based on these monitored concentrations, yet Leston et al.<sup>11</sup> show differences between monitoring methods that result in a 0.04 ppm difference in measured peak O<sub>3</sub> concentrations.

Human exposure is not addressed in this review, although it has been touched on in prior critical reviews and discussions.<sup>12–15</sup> As air quality standards are set closer to background levels, the roles of indoor sources, penetration of outdoor emissions into the home and workplace, exercise and commuting activity patterns, O<sub>3</sub> titration by nitrogen oxide (NO), local photochemistry, and transnational transport need to be understood. Source contributions that can be controlled need to be separated from contributions that are beyond the reach of the CAA. The importance of background levels was foreshadowed in a 1971 NAAQS press release on photochemical oxidants: “In the case of photochemical oxidants . . . our standards approach levels that occur fairly commonly in nature”<sup>16</sup> This is truer today. At remotely located Trinidad Head, CA, O<sub>3</sub> ranged from 0.03 to 0.05 ppm and a 0.066 ppm maximum hourly value was reported during April.<sup>17,18</sup>

Accountability<sup>19</sup> describes what health and environmental benefits should be expected because of a planned or executed change in emissions. Measurable changes have been found in children’s blood lead (Pb) levels corresponding with the phase-out of leaded gasoline and decreasing ambient concentrations.<sup>20</sup> The accountability paradigm would close the circle by evaluating the associated increase in intelligence quotient (IQ) as hypothesized when the Pb NAAQS was established. The review could have critically addressed how and why, given the societal drivers presented in Figure 1 of the review, air quality progress continues as presented in Figure 10 of the review. This could provide important insight into AQM today and in the future.

#### INVITED COMMENTS FROM MS. JANICE E. NOLEN

The review does an excellent job of distilling complex issues and showing the historical and continuing tension between scientific understanding and political will to act. Congress created NAAQS to drive the process of cleaning up outdoor air pollution. Congress intended the EPA Administrator to base the NAAQS solely on the protection of public health with an adequate margin of safety—a science-based determination that cannot legally take cost of compliance into account. However, as the review shows, the “Big P” of politics never leaves the debate and the ever-present “Big F”—fear of clean-up costs and political repercussions—drives the final decisions more than science ever does. Despite decades of evidence that cleaning up air pollution does not harm local economies, drive away business, or cost more than its benefits, these canards arise each time the debate begins. We are hearing them now in the current comments on the proposed O<sub>3</sub> standard.<sup>21</sup>

The review explores the continuing “margin of safety” debate. Even in 1970, Congress assumed there would be no threshold below which air pollution causes no harm. Setting a margin of safety would protect against harm and cover the gap in research findings. However, we have never reached below the acknowledged, recognized health harms to protect at the margins. Neither the 1997 nor the 2006 NAAQS,<sup>22–24</sup> nor the current O<sub>3</sub> proposal,<sup>25</sup>

approach the “margin of safety” threshold. They stop at the threshold of what is “politically acceptable.”

Unfortunately, political acceptability appears likely to be even more tangled with future NAAQS scientific assessments. Recent changes to the NAAQS review process, as described in the review, will limit the open scientific discussion, long a hallmark of this process. The new process will reduce the amount of technical information that EPA makes available about its determinations. This is a serious and negative decision that will build more political prejudice into parts of the process that have historically been free of them.

Local impacts are not considered when touting the success of “cap and trade” programs.<sup>26</sup> Trading programs target regional,<sup>27–29</sup> national,<sup>30</sup> or worldwide<sup>31,32</sup> (e.g., climate change) emissions. Trading allows sources to ignore local single-source impacts, such as those borne by neighbors to power plants that purchased pollution credits. Cap and trade has helped reduce acid rain and regional PM, but at the cost of continuing health effects in local areas. Planting trees in Chicago, for example, won’t solve the problems of the children who live next to heavily trafficked roads in downtown Washington DC.

The review discusses the CAAAC’s subcommittee on AQM. As a member of that group, the American Lung Association spent 3 yr on these issues. The subcommittee could not develop a consensus on such challenges as managing multiple-pollutant effects. CAAAC members agreed that a multiple-pollutant approach made sense, but a broadly supported AQM system could not be developed. Questions about even single pollutant control—such as limiting urban sprawl—remain unanswered.

The review argues that AQM needs to become better at quantifying risk.<sup>33–35</sup> Quantifying risk is an exercise in search of an audience. The argument assumes that EPA will accept the numbers it develops as a realistic basis for decision-making. However, a lack of political will too often drives the decisions, not a lack of good assessments of risks. The 1997 rationale for selecting 65  $\mu\text{g}/\text{m}^3$  as the 24-hr fine particulate matter ( $\text{PM}_{2.5}$ ) NAAQS (now reduced to 35  $\mu\text{g}/\text{m}^3$ )<sup>24</sup> was that there was too much “uncertainty” in the quantified risks, even to provide the required margin of safety.

More people than ever are at risk from outdoor air pollution, including diabetics and others with chronic, nonrespiratory diseases that place them physically closer to the edge, making them more likely to suffer harm. Emerging research is finding evidence that obese persons may also be in that group.<sup>36</sup> EPA’s core responsibility to protect public health remains urgent.

#### **INVITED COMMENTS FROM DR. BARRY WALLERSTEIN**

The review outlines much progress and demonstrates that U.S. air quality improvement is one of our great treasures in terms of environmental management. However, the 50-yr trend in ambient  $\text{O}_3$  concentrations for Southern California shows that the dramatic downward trend has flattened out in the past 5 yr. We continue to grapple with this challenge.

AQM elements that have been successful are: (1) comprehensive design, (2) delegation of SIP preparation to

state and local agencies, (3) the CAA setting a floor rather than a ceiling, (4) mandatory SIP updates, (5) new source review (NSR), (6) citizens’ litigation rights, (7) technology-forcing regulations, and (8) improvements in air quality monitoring and modeling tools.

As indicated by the elements in Figure 2 of the review, the United States has a comprehensive AQM program. Preparation of SIPs at state and local levels has been beneficial because on-the-ground knowledge is needed to foster involvement of local stakeholders.<sup>37</sup> This aspect has motivated experimentation with novel control methods that have been adopted in other communities or nationwide.

Many programs in Southern California go beyond the minimum requirements established in federal law. SCAQMD is required to update plans every 3–5 yr on the basis of new information, so these plans are living documents.

Until recently, NSR<sup>38,39</sup> has been a great benefit, especially the requirements for Best Available Control Technology (BACT) and emission offsets. However, emission offsets need refinement in the future.  $\text{PM}_{2.5}$  and coarse particulate matter ( $\text{PM}_{10}$ ) emission offsets are scarce in Southern California, with costs of approximately \$100,000 per pound. To move forward we need to make more offsets available or replace the offset requirements.

As SCAQMD’s Executive Officer, I have been subject to citizen suits regarding the CAA. This isn’t a pleasant experience, but the ability to litigate has kept government’s feet to the fire at local, state, and federal levels.

Technology-forcing regulations, as contemplated by the CAA, have benefited the quest for clean air. We now have power plants permitted at less than 2 ppm  $\text{NO}_x$ , a seemingly impossible achievement in 1970. We need a new approach to long-term monitoring, at both sources and receptors, to match and verify the progress in reduced emissions.

Some AQM elements have not been so successful: (1) lack of SIP commitment for federal sources, (2) “Fair Share” responsibility, (3) delays in updating and vacating NAAQS, (4) cumbersome restrictions on voluntary/incentive programs, (5) insufficient consideration of environmental justice and local contributions from air toxics emissions, and (6) preemptions (e.g., tribal lands, railroads, agriculture).

In developing SIPs, local and state agencies must commit to specific control measures, yet the federal government makes no up-front commitment. It tells us, “You can take credit after the fact for what we achieve with federal regulations.” This is a flaw in the law, and we are pursuing changes in federal law that would formally commit EPA to SIP attainment demonstrations.

Related to this is what SCAQMD’s governing board calls “Fair Share” responsibility. In Southern California, approximately 80% of emissions contributing to  $\text{PM}_{2.5}$  and approximately 66% of emissions contributing to  $\text{O}_3$  derive from mobile sources. The primary authority for mobile source emissions, however, rests with the federal government (with some independence granted to California in the 1970 CAA). Although SCAQMD must show

attainment by a federally mandated date, it has no control over the timing and enforcement of mobile source emission limits.

Promulgating and vacating NAAQS have delayed, rather than facilitated, SIP adoption. SCAQMD adopted an aggressive SIP in 2003 with substantial controls projecting O<sub>3</sub> NAAQS attainment by 2010. This was submitted to EPA, but approval was withheld because the O<sub>3</sub> NAAQS were being reviewed. While that review occurred, implementation guidance for the new 8-hr O<sub>3</sub> standard was received stating that the last-approved plan would remain in place until the new one was approved. This caused SCAQMD to revert to a 1998 plan, with the result that the O<sub>3</sub> NAAQS attainment demonstration occurs in 2020 rather than in 2010. This manipulation of the SIP process is a detriment to public health improvement.

Command-and-control regulations need to be augmented with voluntary actions<sup>40,41</sup> and incentives.<sup>42</sup> Even though these have been proven effective, the EPA does not accept their emission reductions without a mandatory component. Hot spots and environmental justice issues could be better handled than they are under current AQM, as treated in detail by other discussants.

Certain facilities that cannot obtain permits within an airshed can at present move onto nearby tribal lands<sup>43</sup> seeking to avoid regulations. Agreements are needed to prevent adverse emission impacts while still retaining the independence of tribal lands. Preemptions on particular sources such as railroads should not be allowed while other sources are doing their fair share of the cleanup. With Southern California's intense goods-movement activity and high population exposure to locomotive emissions, this is a major problem. Emissions from legacy diesel fleets need more attention. Old diesel engines have long lifetimes and are large NO<sub>x</sub>, PM<sub>2.5</sub>, and hazardous air pollutant (HAP) emitters. Fuels and engines are available to reduce emissions,<sup>44,45</sup> but transition to these cleaner systems needs to be accelerated. This will require regulations and incentives that motivate engine owners to make the change.

The interplay between greenhouse gas and criteria pollutant emission reductions is important, and SCAQMD adopted climate-related regulations in the early 1990s. However, achieving one goal must not work against the achievement of others; global warming controls should not take precedence over NAAQS attainment.

Will the circle remain unbroken? SCAQMD's 2003 O<sub>3</sub> SIP shows that the AQM circle contains some fractures. Nevertheless, continuing public health studies provide the basis and the political motivation to continue moving forward. Recent studies by CARB indicate that as many as 5000 individuals per year die prematurely in Southern California from excessive PM<sub>2.5</sub> and PM<sub>10</sub> levels. When these estimates are shared with elected officials and community members, positive responses to politically challenging clean-up strategies are the result. After becoming aware of this premature mortality statistic, the SCAQMD governing board and the local council of governments passed resolutions asking Governor Schwarzenegger and President Bush to declare a Southern California air quality

emergency. There is continuing hope for the future regarding our clean air program, and we will continue investing today for a healthier tomorrow.

#### INVITED COMMENTS FROM DR. JOHN G. WATSON

These comments identify important points made in and omitted from the review, elaborate on the role of science in AQM, and discuss the influence of the U.S. experience on other countries. The review recognizes that effective AQM requires an extraordinary level of technical and scientific information on effects-based ambient targets, measurement of key pollutants at source and receptor, source emissions and compositions, and emission reduction measures. The review observes that scientific and technical findings reshaped the NAAQS in many ways. Discovering the multi-modal size distribution,<sup>46,47</sup> recognizing that excessive secondary pollutant levels (formed from directly emitted gases) such as O<sub>3</sub> and PM<sub>2.5</sub> sulfate (SO<sub>4</sub><sup>2-</sup>) result from regional emissions,<sup>48-50</sup> establishing theoretical and direct relationships between emissions and health and welfare effects,<sup>14,51,52</sup> developing better source and receptor models,<sup>53-55</sup> and inventing new source and ambient measurement technologies<sup>56,57</sup> are all acknowledged as essential activities for periodic NAAQS evaluation, refinement, and attainment. The review observes that the intense science and policy interaction engendered by the periodic (~5-yr) criteria review enables EPA and others to sharpen the most important scientific and analytical questions, then assesses the degree to which they have been answered. These criteria reviews are a great challenge owing to the exponential increase in the number of relevant scientific publications and the uncertainty in generalizing results from studies at specific times and places using different methodologies.

The review also notes some important failures of the CAA and its amendments. One of the biggest failures was the "grandfathering" of facilities, especially coal-fired power plants.<sup>58,59</sup> Table 13<sup>9</sup> demonstrates the adverse effects of this provision on sulfur dioxide (SO<sub>2</sub>) emissions, and implicitly (through lower fuel-use efficiency) on greenhouse gas emissions. The perverse nature of grandfathering is that it becomes more cost-effective to keep an inefficient facility operating than to complete the permitting process for a more efficient, and potentially more profitable, modern facility. The recently adopted Clean Air Interstate Rule (CAIR)<sup>60</sup> will lower the cap on SO<sub>2</sub> and NO<sub>x</sub> allowances in eastern states, and this may result in the needed changes. Revisions to the NSR process will probably not have a detectable effect on these emissions.<sup>39,61,62</sup> A logical change that would address multiple pollutants (including carbon dioxide) would be to limit emissions on the basis of useful energy output (e.g., kilowatts generated) rather than the energy of the consumed input fuel.

The other recognized failure is the lack of multiple-pollutant strategies. The first step in such strategies should determine that emission reductions to attain one NAAQS do not mitigate against attainment of other standards. Fortunately, scientific advances in weekday/week-end analyses,<sup>63-65</sup> nitrate (NO<sub>3</sub><sup>-</sup>)/ammonia (NH<sub>3</sub>) equilibrium modeling,<sup>66,67</sup> and chemical mechanisms that

**Table 1.** SO<sub>2</sub> emissions and energy conversion efficiencies of U.S. coal-fired power plants<sup>39</sup> (classified by the time during which they began operation).

Power Plant Establishment Period	Average SO <sub>2</sub> Emission Rate (lb/MWh)	Percent of Total SO <sub>2</sub> Emitted	Percent of All U.S. Coal-Fired Electricity Generation	Percent of SO <sub>2</sub> Emitted per % of Generated Electricity	Average Operating Percent of Capacity	Average BTU <sup>a</sup> Consumed per kWh Electricity Generated
Pre-1950	20.58	1.02	0.50	2.04	36.35	12,549
1950–1959	15.78	19.64	12.56	1.56	58.93	10,668
1960–1969	13.92	27.12	19.65	1.38	64.37	10,150
1970–1979	9.31	35.75	38.76	0.92	68.29	10,270
1980–1989	6.02	15.49	25.97	0.60	73.17	10,401
Post-1990	3.88	0.98	2.56	0.38	75.80	9,982

Notes: <sup>a</sup>BTU = British thermal unit.

determine limiting pollutants<sup>68</sup> have achieved a level that allows these assessments. However, these methods often lack adequate datasets that allow their valid application. The review notes that some multiple-pollutant effects are implicit in O<sub>3</sub> and PM<sub>2.5</sub> reduction strategies because these involve interactions among CO, SO<sub>2</sub>, NO<sub>x</sub>, VOCs, and NH<sub>3</sub> emissions. Nevertheless, and as noted by other discussants, we have yet to formulate methods to address these along with HAPs and greenhouse gases in a comprehensive manner.

Although dealing with the broad picture, the review did not point out important details that are buried in specific laws, regulations, measurement specifications, and guidance that affect the way AQM is carried out. This is understandable, as there are many of these details that impede progress, but several deserve special mention.

The review explains that a NAAQS consists of an indicator, an averaging time, a concentration level, and a form (number of allowed exceedances). Table 2 compares the current U.S. NAAQS with those of the European Union (EU). Note that short-term PM<sub>2.5</sub> and PM<sub>10</sub> are based on 24-hr averages. Do we really believe that 35 µg/m<sup>3</sup> spread over 24 hr has the same health effect as an 840 µg/m<sup>3</sup> dose over 1 hr? We have the technology to

measure PM over hourly or shorter periods,<sup>69</sup> but we refuse to use it. On the surface, the EU standards in Table 2 look more restrictive than the U.S. NAAQS because their values are often lower. Yet a close examination shows that the number of allowed exceedances is much higher. Even the exceptions allowed by the U.S. NAAQS are comparable to the durations of London, UK; Meuse Valley, Belgium; and Donora, PA, air quality disasters referenced in the review. Are these “statistical” forms really adequate to protect public health?

The review did not recognize that our monitoring concepts are obsolete and need to be updated. EPA’s ambient air monitoring strategy<sup>70</sup> demonstrates that a single focus on determining NAAQS compliance is insufficient. To address future problems, air quality networks must be re-designed to accommodate multiple objectives, including trends, source apportionment, source zones of influence (including hot spots), chemical transport modeling, quantification of background levels, and relationships with human health and other adverse effects. The strategy recommends flexibility with respect to sampler siting and measurement methods to achieve these multiple objectives and accomplishing this re-design within existing resources. Despite typical objections to change, this plan

**Table 2.** Comparison of U.S. NAAQS with EU air quality standards.

Pollutant	EU Standard	EU Average	EU Exceedance	U.S. Standard	U.S. Average	U.S. Exceedance
CO	10 mg/m <sup>3</sup>	8-hr max/day	0/yr	10 mg/m <sup>3</sup>	8 hr	1/yr
				40 mg/m <sup>3</sup>	1 hr	1/yr
SO <sub>2</sub>	350 µg/m <sup>3</sup>	1 hr	24/yr	365 µg/m <sup>3</sup>	24 hr	1/yr
	125 µg/m <sup>3</sup>	24 hr	3/yr	80 µg/m <sup>3</sup>	1 yr	0/yr
NO <sub>2</sub>	200 µg/m <sup>3</sup>	1 hr	18/yr	100 µg/m <sup>3</sup>	1 yr	0/yr
	40 µg/m <sup>3</sup>	1 yr	0/yr			
O <sub>3</sub>	120 µg/m <sup>3</sup>	8-hr max/day	25/3 yr	160 µg/m <sup>3</sup>	8-hr max/day	4th 3-yr average
PM <sub>10</sub>	50 µg/m <sup>3</sup>	24 hr	35/yr	150 µg/m <sup>3</sup>	24 hr	2nd 3-yr average
	40 µg/m <sup>3</sup>	1 yr	0/yr			
PM <sub>2.5</sub>	None	None	None	35 µg/m <sup>3</sup>	24 hr	98%
				15 µg/m <sup>3</sup>	3 yr	0/3 yr
TSP Pb	0.5 µg/m <sup>3</sup>	1 yr	0/yr	1.5 µg/m <sup>3</sup>	0.25 yr	0/quarter
Benzene	0.5 µg/m <sup>3</sup>	1 yr	0/yr	HAPs		
Arsenic (As)	120 µg/m <sup>3</sup>	1 yr	0/yr	HAPs		
Cadmium (Cd)	5 ng/m <sup>3</sup>	1 yr	0/yr	HAPs		
Nickel (Ni)	20 ng/m <sup>3</sup>	1 yr	0/yr	HAPs		
PAH (BaP)	1 ng/m <sup>3</sup>	1 yr	0/yr	HAPs		

Notes: PAH = polycyclic aromatic hydrocarbons; BaP = benzo(a)pyrene; HAPs = hazardous air pollutant limit emissions rather than ambient air concentrations in the United States.

needs to be championed and implemented at the national, state, and local levels. Without changes such as these, there will be little hope of evaluating multiple pollutants.

The same criticism applies to emission measurements. Current stationary source testing for PM<sub>10</sub> certification<sup>71,72</sup> uses 1950s technology that collects particles on a hot in-stack filter, then runs the remaining gases through liquid impingers to collect so-called "condensable" PM. The problem with this is that some of the sulfur and organic gases are also collected in the impingers.<sup>73</sup> This technology needs to be replaced with one that dilutes the hot stack effluents with clean air at ambient temperatures to at least approximate the condensation that occurs when emissions equilibrate with ambient air.<sup>73-77</sup> An interesting emissions anomaly occurs when one considers a large diesel generator that can be operated as a stationary or mobile source. Put it on wheels and it is subject to tests that require dilution to approximately 50 °C<sup>78,79</sup> (still higher than ambient), returning lower PM<sub>10</sub> emissions than it would doing exactly the same with a stationary source emissions test. EPA scientists know this and are working on alternatives,<sup>80</sup> but the urgency of a needed scientific change is unrecognized at the policy level.

Although emphasizing NAAQS, the review did not sufficiently describe the multitude of emission reduction measures that support attainment of the NAAQS.<sup>81,82</sup> These include: (1) emission limits (with certification tests)<sup>83,84</sup>; (2) effluent treatment requirements (Reasonably Available Control Technology [RACT], BACT, Best Available Retrofit Technology [BART], and Lowest Achievable Emissions Retrofits [LAER])<sup>85</sup>; (3) product design specifications<sup>86</sup>; (4) fuel specifications (with certification tests)<sup>87</sup>; (5) emission fees and fines<sup>88</sup>; (6) congestion pricing<sup>89</sup>; (7) forced shutdowns during episodes<sup>90</sup>; (8) emission caps and trading<sup>91</sup>; (9) Inspection and Maintenance programs<sup>92</sup>; (10) energy efficiency requirements<sup>93</sup>; and (11) demonstrated reasonable progress (e.g., for regional haze).<sup>94</sup> These are only a few of many examples.<sup>81</sup> Not all of these have been implemented in the United States, but they are important complements to the NAAQS in achieving successful AQM.

CO, SO<sub>2</sub>, nitrogen dioxide (NO<sub>2</sub>), and Pb NAAQS are essentially attained in the United States, but these still create problems in rapidly developing economies such as China and India. O<sub>3</sub> and PM<sub>2.5</sub> are still problems in the United States as well as other countries. The U.S. experience, as encapsulated in the review and this discussion, provides a basis for developing economies to develop their own AQM strategies. As part of the U.S. National Academy of Engineering committee on "Energy and Air Quality Futures in Urban China and the United States," we visited air quality officials and pollution sources in Huainan and Dalian, China and in Pittsburgh, PA, and Los Angeles, CA. One can see definite parallels in China's AQM reflecting the history presented in the review. The Chinese focus on nearby primary pollutant effects (e.g., CO, SO<sub>2</sub>, and NO<sub>2</sub>) rather than regional and/or secondary pollutants (e.g., O<sub>3</sub> and PM<sub>2.5</sub>). Although the standards and laws are strict, enforcement is sporadic and decentralized. Penalties do not exceed the costs of control.

Monitoring networks are copies of the U.S. compliance network (minus O<sub>3</sub> and PM<sub>2.5</sub>), rather than being designed to address multiple objectives as we hope to do in the United States. As noted by other discussants, as U.S. levels approach background (i.e., unmanageable) levels, emissions from the developing world will become ever more important to our progress. Upon comparing a mid-day, zero-visibility photograph of 1920s Pittsburgh with a beautiful view of Fort Pitt on a crisp March morning, my Chinese colleague turned to me and said, "If the U.S. can do it, China can do it too." We've come a long way, and it's time to finish the job.

#### CONTRIBUTED COMMENTS FROM DR. GEORGE M. HIDY

Although there is little to debate in the review's exposition of the historical record, there are two topics that were not addressed. The first concerns "closing the circle" of risk assessment and management (Figure 2 of the review). The second concerns the creation of AQM-related economic diversification and growth in "new" service and manufacturing industries. The latter is particularly important to the A&WMA and its function of facilitating recruiting and education of, and communications with, its membership.

With regard to risk assessment, Figure 2 of the review closes the AQM circle "track and evaluate results." This step includes the date of NAAQS attainment, monitoring of air and emissions (for trends), and receptor modeling. This step neglects the key element of tracking changes in human health, welfare, and ecosystem measures. This aspect of "closure" in tracking or evaluation is important to stakeholders to confirm their pollution-reduction investments with improvements in environmental well-being.

Tracking improvements in human health with reduction in pollution exposure is a daunting task because the mortality or morbidity signals are small relative to the noise in the individual and population health measures. Credible detection of human response to air pollution at contemporary exposures has been difficult enough to achieve without seeking to measure changes over time. Most illustrative is the airborne Pb case,<sup>20</sup> where reductions in ambient Pb exposure are reflected in reductions in blood Pb levels. However, the response to this reduction in blood chemistry has not been traced to expected changes in neurological measures.

There have been some attempts to design experimental programs to achieve a measure of population response to changes in pollution levels.<sup>19</sup> Attempts have been made to apply time series analysis to changes in human health over a period of change in emissions for NO<sub>2</sub>.<sup>95</sup> The Health Effects Institute (HEI)<sup>19</sup> indicated that perhaps advertent "intervention" studies<sup>96-98</sup> would serve to verify improvements in population health with emission reductions. However, the interpretation of the results of these studies has led to some debate of the precise pollution components responsible for the documented health response.

In the case of ecosystem change with pollution reduction, a recent survey<sup>99</sup> of acid sensitive lakes in the northeastern United States shows improvements in the

acid neutralizing capacity or  $\text{SO}_4^{=}$  content with a decline in acid rain. The response of aquatic biota to such improvements is not evident. Improvements in Northeastern forest health as a result of decline in  $\text{SO}_4^{=}$  or  $\text{NO}_3^-$  deposition have not been documented for sugar maple or red spruce.

EPA staff recognize this limitation and are seeking ways to credibly estimate risk reductions due to emission reductions.<sup>100</sup> NARSTO<sup>101</sup> also has been charged with developing an assessment of AQM practice in North America with one of its goals to review the prospects for improving the tracking and evaluation capabilities of stakeholders for confirming the human and ecosystem response to air pollution reduction.

With regard to the second topic, NAAQS, HAPs, and other AQM regulations have resulted in a major expansion and growth of a segment of the U.S. service and emission control technology industries. The range of response in services included major investment in the development and application of measurement methods, air monitoring networks, source testing, atmospheric modeling, data management, permitting, academic training, and environmental law. The technology-forcing aspects of NAAQS catalyzed major efforts in developing emission controls for transportation and large stationary sources. Controls were even developed for residential wood stoves, restaurant cooking, and street sweepers.

Stakeholder response to standard-setting and control cost-effectiveness has been important to the A&WMA as a stimulus for broad-based membership and its many organized conferences, publications, and other activities. The process of standard setting and implementation continues to challenge not only federal and state governments, but also the private sector in seeking the "best possible" information on which to base decision-making for continuous air quality improvement.

#### **CONTRIBUTED COMMENTS FROM DR. PAUL J. LILOY**

The review makes clear that U.S. AQM worked well in establishing NAAQS that protect public health with varying margins of safety. The robustness of the process is exemplified by two examples. The first is the progressive change in the indicator for the PM NAAQS. Scientific evidence indicated a need to move from a total suspended particulate (TSPs, particles with aerodynamic diameters  $< \sim 30 \mu\text{m}$ ) to smaller size fractions ( $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ ). There is some concern that the  $\text{PM}_{10-2.5}$  fraction ( $\text{PM}_{10}$  minus  $\text{PM}_{2.5}$ ) might have adverse effects, and a 24-hr  $\text{PM}_{10-2.5}$  NAAQS was proposed.<sup>102</sup> This proposal was, unfortunately, not adopted, and it will be left to the "new process" for standard setting to address it. The same applies to multiple-pollutant health effects.

The second example relates to weakening the 1-hr  $\text{O}_3$  NAAQS from 0.08 ppm to 0.12 ppm in 1979. This threshold increase deterred efforts to develop regional control strategies in the eastern United States, and  $\text{O}_3$  strategies reverted to urban, rather than regional, controls. Rombout et al.<sup>103</sup> showed in the mid-1980s that the 0.12 ppm 1-hr  $\text{O}_3$  NAAQS was not even as protective as the 0.1 ppm

8-hr occupational  $\text{O}_3$  threshold limit value (TLV). Research in children's camps and with controlled human exposure-response indicated that an 8-hr standard was necessary to protect public health.<sup>104,105</sup> This 1979 setback was finally reversed after court challenges, resulting in the current 0.08 ppm 8-hr  $\text{O}_3$  NAAQS.<sup>106</sup> The United States is finally implementing regionally based control strategies to reduce human exposures that occur at great distances downwind of emission sources, including large cities. EPA has proposed a new 8-hr average range of 0.07–0.075 ppm, implying a need for more aggressive regional controls.

The review briefly mentioned HAPs and environmental justice as "New Challenges—Back to the Future." These are really "Unfinished Business—Back to the Future." The review notes that HAPs are multiple-pollutant "local" point source problems. HAPs also derive from area and line sources and are key elements of environmental justice.<sup>106,107</sup> Addressing line sources (i.e., roads) for new suburban developments near heavily traveled highways does not address environmental justice. Many people with low incomes are exposed to diesel exhaust from mobile and stationary engines on streets and at distribution centers. Improved monitoring and regulation is needed for these hot spots. A new class of NAAQS based on cumulative exposure to multiple pollutants for specific biological end points should be considered for hot spots. Well-characterized biological markers<sup>108</sup> of exposure and effects could supplement hot-spot air monitoring and result in policy analyses that support augmenting the CAA.

The path to clean air outlined in the review has never been simple, and it will probably be more complex in the future. As mentioned in the review, the idea of smart growth has been on the table, but suburban sprawl has consumed areas surrounding most population centers, and consumption of "greenfields" will not stop soon. The NAAQS process should provide ways to maintain public health in parallel with constantly evolving local and regional multiple pollutants associated with alternate fuels and new products.

#### **CONTRIBUTED COMMENTS FROM DR. HERBERT MCKEE**

The review will be helpful to future workers who believe that "Those who do not understand history are doomed to repeat it." After more than 50 yr experience in AQM, I enjoyed reading about problems and personalities from the past. These comments address  $\text{O}_3$  non-attainment topics that were discussed in the review. A large problem with the 1970 CAA was the combination of a short time for attainment ( $< 4$  yr) and sanctions (especially withholding highway funds) for failure to meet the deadline. In some jurisdictions, the goal of improving public health was forgotten as state governors and legislatures directed regulatory agencies to find any possible way to meet EPA SIP requirements while avoiding sanctions. The review states ". . . setting unrealistic attainment deadlines leads to. . . the development and

approval of paper programs that cannot be implemented or that contain rigged attainment demonstrations." In addition to raising ethical questions, unrealistic deadlines did not work; many urban areas still have not attained the O<sub>3</sub> NAAQS, more than 35 yr after they were first promulgated.

An important limitation was poor understanding of the atmospheric chemistry. The first attempts to meet O<sub>3</sub> NAAQS incorporated the "conventional wisdom" of reducing VOC emissions. Reducing NO<sub>x</sub> emissions was considered a waste of time and resources. A period of 25–30 yr was required to fully understand the contributions of biogenic VOC emissions to O<sub>3</sub> formation (although biogenic VOC emissions were characterized by the mid-1960s<sup>109</sup>). This led to the realization that NAAQS attainment in many areas would be impossible without NO<sub>x</sub> reductions.

In the Houston area, a major O<sub>3</sub> study was conducted by the state and other agencies in 2000<sup>27,110,111</sup> that verified the need for NO<sub>x</sub> reductions. O<sub>3</sub> levels have trended downward in recent years, corresponding to the period when many local industries installed NO<sub>x</sub> control equipment. Data for several years will be needed to assure that the reductions are not caused by meteorological variability. This example shows that complex air quality problems must be understood before control efforts can be successful.

#### **CONTRIBUTED COMMENTS FROM MESSRS DAVID MOBLEY AND KEITH BAUGUES**

Accurate emission inventories are the foundation of cost-effective AQM strategies. Poor emission inventories can lead to over- or undercontrol of sources, or to controls being applied to the wrong sources. This can lead to strategies that fail to achieve the NAAQS or achieve them at unnecessarily high costs.

The NARSTO Emission Inventory Assessment<sup>10</sup> outlines eight key steps to improve emission inventories. These are: (1) reduce uncertainties associated with emissions from key undercharacterized sources, (2) improve speciation estimates, (3) improve existing and develop new emission inventory tools, (4) quantify and report uncertainty, (5) increase inventory compatibility and comparability, (6) improve user accessibility, (7) improve timeliness, and (8) assess and improve emission projections.

The assessment<sup>10</sup> concludes: "It is estimated that the U.S. federal government currently invests approximately \$25 million/yr to develop and update emission inventories." As a basis for comparison, EPA's total budget for air programs, not including climate change, was nearly \$600 million in 2003. Investments in emission inventory research, preparation, and reporting will need to increase substantially to achieve emission inventories that provide the quality and quantity of information expected by AQM decision makers, the regulated community, and the general public. Funding increases ranging from double to an order of magnitude may be required, depending upon the specific area and current levels of involvement. Although additional resources are being invested by state, provincial, and local agencies (an estimated \$10 million/yr in the United States), the total available resources are not

sufficient to achieve the desired improvements in emission inventory programs.

In looking to the future and using the review as a foundation for moving forward, it will be desirable for the NARSTO assessment's recommendations to be addressed in a renewed effort because emission inventories are expected to be even more important for the next generation of air quality issues.

#### **RESPONSE FROM MR. JOHN D. BACHMANN, CRITICAL REVIEW AUTHOR**

The 37th annual *Critical Review* on A&WMA's 100th anniversary was broad in scope. Although attempting to depict the long arc of U.S. air pollution history over the previous century, the review's focus was on the origin, establishment, and revisions of the U.S. NAAQS. Despite its length and supplemental tables, a complete treatment of all relevant topics and issues was not possible, and this discussion provides useful additions. Two citations that should have been included in the review address the science/policy of the development of regional O<sub>3</sub> controls<sup>112</sup> and early implementation of the 1990 CAA amendments.<sup>113</sup>

Mr. Feldman's modeling and inventory concerns prompt an important question: what, given the uncertainties, is the appropriate role for modeling in developing and implementing AQM plans? The review notes that local and state officials recognized technical difficulties with AQM theory and substituted technology approaches in developing the first SIPs.<sup>114</sup> Over time, EPA recognized and encouraged uncertainty evaluation through the 'weight of evidence' approach.<sup>115,116</sup> I agree with Mr. Feldman and Dr. Hidy that expansion of the "track and evaluate progress" step is needed, but this should be accompanied by a re-thinking of the role of air quality modeling, as recommended by the NRC and other AQM evaluations.<sup>82,117–121</sup> As noted in this discussion, inadequate technical understanding of emission/air quality relationships can lead to a lack of progress and may result in inappropriate SIPs, gaming, or paralysis by analysis.<sup>122</sup> The review recognizes the importance of this issue (p 686).

Advancing emission measurement technology and its application for accountability and market-driven programs deserves additional attention. The review notes that market-based approaches work best with continuous emission monitors (CEMs)<sup>123</sup> that improved emission inventories, tracking, and forecasting. Real world in situ and remote sensing measurements and innovative emission inventory/factor strategies will engender a more cost-effective approach to emissions quantification.

I appreciated Dr. Watson's a cappella musical commentary as well as his discussion, which amplifies the importance of ambient and emissions monitoring in AQM. I support his call for more flexible, multiple-pollutant monitoring strategies, which has been slowed by EPA funding constraints. AQM in other countries and the health protection of alternative forms for standards are important topics. He highlights an omission from the review: the development of federal criteria for air pollution episodes and how these work in combination with the air quality index (AQI) to address rare but extreme

events not addressed by the NAAQS. His incomplete taxonomy of emission control approaches that the review did not explore is a bit perplexing; it groups stationary source technology categories such as BACT, RACT, and LAER approaches under “effluent treatment.” The review lumps many of these under the more general category of ‘technology-based’ approaches to contrast them with ‘risk-based’ approaches such as NAAQS. The review explains that the United States did adopt a hybrid approach that uses both of these general approaches as well as others, including market-based systems. The many specific examples of approaches and strategies used or possible in AQM (what about white roofs and more trees?) are worth more consideration than can be provided here.

Ms. Nolan and Mr. Feldman discuss issues at the core of the review, which are how NAAQS are set and reviewed. Mr. Feldman’s suggestion that the review should have specified how these issues could affect the ongoing O<sub>3</sub> NAAQS review is out-of-scope. Strict adherence to a 5-yr review cycle would not necessarily worsen the “changing goal-post” problem of a revised-NAAQS before SIP implementation of the prior NAAQS is completed. This will be a continuing structural problem under any reasonable review schedule. Dr. Wallerstein notes implementation difficulties with the withdrawal of the 1-hr O<sub>3</sub> NAAQS in 2003, 25 yr after the original NAAQS were set and 6 yr after the promulgation of the decision to withdraw them. This example is much more nuanced than suggested by Dr. Wallerstein’s account. The review shows that this issue will persist with the AQM system as long as research and monitoring continue to provide new insights that change our approach to the causes, effects, and reduction of air pollution.

I share one of Ms. Nolan’s concerns about the new NAAQS review process, the substitution of a Federal Register notice for the staff paper. I do not share her pessimism on risk assessment, but I admire her style in characterizing it as “an exercise in search of an audience.” The limited use of the PM risk assessment in 1997 was the direct result of advice from EPA’s Clean Air Science Advisory Committee (CASAC). Ms. Nolan did not acknowledge that the Administrator relied on the O<sub>3</sub> risk assessment, on advice from the CASAC, in the 1997 decision. The review notes that later CASAC panels in 2006 and 2007 recommended use of EPA’s risk assessments in the more recent NAAQS reviews on O<sub>3</sub> and PM; it also notes the difficulties that the increasing specificity of risk assessments has and will present for decision-makers.

Ms. Nolan, Mr. Feldman, and Dr. Lioy, expand on exposure considerations, highlighting gaps in health protection that can occur for criteria pollutants and HAPs near strong local sources (stationary or line) that are called hot spots. I agree with their concerns, but not necessarily with all of their prescriptions. Cap-and-trade systems remain valuable tools for reducing urban and regional pollution; local hot spots can be addressed through appropriate source specific or NAAQS ambient limits. Recent evidence relating proximity to traffic with mortality and other effects<sup>124</sup> present a particular challenge. NAAQS have not worked as well for hot spots. Whether a NAAQS or some alternative make sense will

depend on the underlying nature of the cause/effect relationships. If PM vehicle exhaust emissions with or without associated gaseous pollutants are the cause of adverse effects, future debate will depend on how effective current mobile source emission limits are in reducing exposures. If the issue relates to traffic volume and locally re-suspended coarse particles, an area-specific NAAQS approach could be effective.

I have been an advocate of improving accountability, and I am glad that Mr. Feldman and Dr. Hidy expanded on the topic. Still, atmospheric scientists sometimes have unrealistic expectations for air pollution health research, and health researchers often do not know enough about atmospheric science and exposure. I recall discussions in the 1970s between Dr. Paul Altshuller (director of EPA’s atmospheric laboratory) and Dr. John Knelson (director of EPA’s air health laboratory) in which Dr. Altshuller would say, “tell me what pollutants are important and I’ll measure them” and Dr. Knelson would respond “tell me what’s out there and I can study them.” It will be difficult to provide direct measures of health improvements from specific air pollution programs as levels decrease. Dr. Hidy cites three recent examples of extreme interventions that show health improvements but do not provide specificity about which pollutants are responsible. The recent six-city prospective analysis found a significant reduction in long-term mortality risk as levels of multiple fine particle components dropped between two periods beginning in 1974 and ending 1998.<sup>125</sup> Still, as Dr. Hidy notes, the effort is worthwhile and HEL, EPA, and the Center for Disease Control are working on alternative approaches for tracking health benefits.<sup>126,127</sup>

Dr. Wallerstein’s additions on AQM history in Southern California and SCAQMD’s efforts to link conventional AQM programs with climate issues are important. The review emphasizes California’s leadership in advancing the science, policy, and practice of AQM, and it is important to be aware of what California’s state and local agencies are currently doing.

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#### About the Authors

Judith C. Chow and John G. Watson are research professors with the Division of Atmospheric Sciences at the Desert Research Institute, Reno, NV. Howard J. Feldman is the director of regulatory and scientific affairs with the American Petroleum Institute, Washington, DC. Janice E. Nolen is assistant vice president, national policy and advocacy, with the American Lung Association, Raleigh, NC. Barry Wallerstein is an executive officer with the South Coast Air Quality Management District, Diamond Bar, CA. George M. Hidy is primary of Envair/Aerochem, Placitas, NM. Paul J. Liroy is a professor in the Department of Environmental and Occupational Medicine with the Robert Wood Johnson Medical School, University of Medicine and Dentistry, New Jersey and Rutgers University, Piscataway, NJ. Herbert McKee is an environmental consultant from Houston, TX. David Mobley is the associate director of the Atmospheric Modeling Division with the Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC. Keith Baugues is a technical leader, Air Services, with KERAMIDA Environmental, Indianapolis, IN. John D. Bachmann is with Vision Air Consulting, Chapel Hill, NC (formerly Associate Director for Science/Policy and New Programs, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC). Address correspondence to: Judith C. Chow, Division of Atmospheric Sciences, Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512; phone: +1-775-674-7050; fax: +1-775-674-7009; e-mail: judy.chow@dri.edu.