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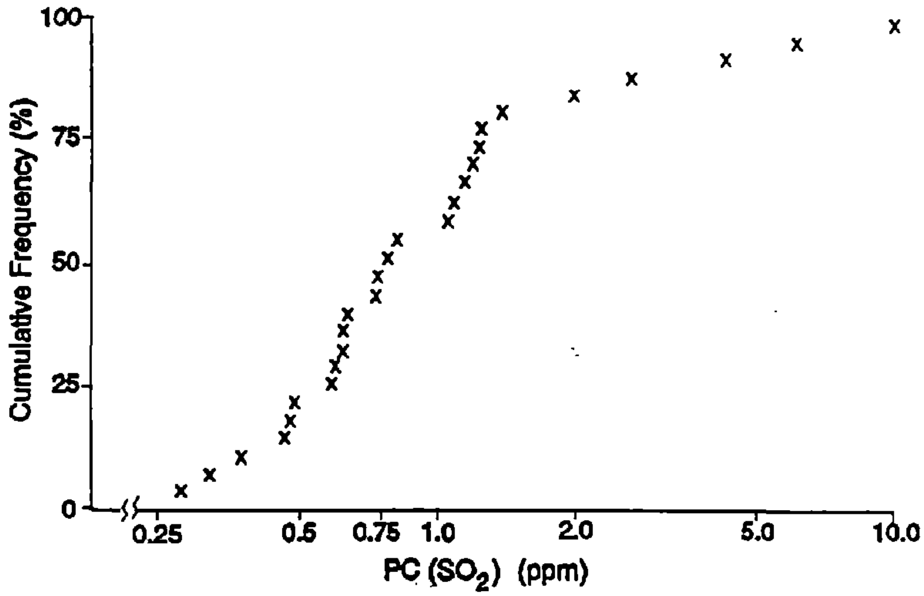
Review of the National Ambient Air Quality Standards for Sulfur Oxides: Assessment of Scientific and Technical Information

Supplement to the 1986 OAQPS Staff Paper Addendum



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REVIEW OF THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR OXIDES: UPDATED ASSESSMENT OF SCIENTIFIC AND TECHNICAL INFORMATION

SUPPLEMENT TO THE 1986 OAQPS STAFF PAPER ADDENDUM

I. INTRODUCTION

A. Purpose

This paper presents a summary of the evaluation and interpretation of key new studies on the health effects associated with short-term sulfur dioxide (SO_2) exposures examined in the draft Environmental Protection Agency (EPA) document, Supplement to the Second Addendum (1986) to Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982): Assessment of New Findings on Sulfur Dioxide Acute Exposure Health Effects in Asthmatics (EPA, 1994) and represents an update of similar material in the 1986 sulfur oxides (SO_x) staff paper addendum (EPA, 1986a). Because the recently available health effects information on SO_2 is related to short-term (5- to 10-minute) exposures, this paper also updates available information on the occurrence of short-term (5-minute) peaks of SO_2 in the ambient air and on the likelihood that the at-risk population will be exposed.

This staff paper supplement is intended to help bridge the gap between the scientific review of recent health effects information contained in the 1994 SO_2 criteria document addendum supplement (subsequently referred to as "CD supplement" or "CDS," EPA, 1994) and the judgments required of the Administrator in determining whether new regulatory initiatives are needed to provide increased protection to asthmatic individuals whose health could be compromised if exposed to high 5- to 10-minute peak SO_2 levels. Factors relevant to this evaluation, as well as staff conclusions and recommendations on alternative regulatory approaches are presented in this paper.

B. Background

1. Legislative Requirements

Two sections of the Act govern the establishment and revision of national ambient air quality standards (NAAQS). Section 108 (42 U.S.C. 7408) directs the Administrator to identify pollutants which "may reasonably be anticipated to endanger public health and welfare" and to issue air quality criteria for them. These air quality criteria are to "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in the ambient air . . ."

Section 109 (42 U.S.C. 7409) directs the Administrator to propose and promulgate "primary" and "secondary" NAAQS for pollutants identified under section 108. Section 109(b)(1) defines a primary standard as one "the attainment and maintenance of which, in the judgment of the Administrator, based on the criteria and allowing an adequate margin of safety, [is] requisite to protect the public health."[1] A secondary standard, as defined in section 109(b)(2), must "specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, based on [the] criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air." Welfare effects as defined in section 302(h) [42 U.S.C. 7602(h)] include, but are not limited to, "effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

The U.S. Court of Appeals for the District of Columbia Circuit has held that the requirement for an adequate margin of safety for primary standards was intended to address uncertainties associated with inconclusive scientific and technical information available at the time of standard setting. It was also intended to provide a reasonable degree of protection against hazards that research has not yet identified. Lead Industries Association v. EPA, 647 F.2d 1130, 1154 (D.C. Cir.

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[1]The legislative history of section 109 indicates that a primary standard is to be set at "the maximum permissible ambient air level . . . which will protect the health of any [sensitive] group of the population," and that for this purpose "reference should be made to a representative sample of persons comprising the sensitive group rather than to a single person in such a group." S. Rep. No. 91-1196, 91st Cong., 2d Sess. 10 (1970). The legislative history specifically identifies bronchial asthmatics as a sensitive group to be protected. Id.

1980), cert. denied, 101 S. Ct. 621 (1980); American Petroleum Institute v. Costle, 665 F.2d 1176, 1177 (D.C. Cir. 1981), cert. denied, 102 S. Ct. 1737 (1982). Both kinds of uncertainties are components of the risk associated with pollution at levels below those at which human health effects can be said to occur with reasonable scientific certainty. Thus, by selecting primary standards that provide an adequate margin of safety, the Administrator is seeking not only to prevent pollution levels that have been demonstrated to be harmful but also to prevent lower pollutant levels that she finds may pose an unacceptable risk of harm, even if the risk is not precisely identified as to nature or degree.

In selecting a margin of safety, the EPA considers such factors as the nature and severity of the health effects involved, the size of the sensitive population(s) at risk, and the kind and degree of the uncertainties that must be addressed. Given that the "margin of safety" requirement, by definition, only comes into play where no conclusive showing of adverse effects exists, such factors, which involve unknown or only partially quantified risks, have their inherent limits as guides to action. The selection of any numerical value to provide an adequate margin of safety is a policy choice left specifically to the Administrator's judgment. Lead Industries Association v. EPA, supra, 647 F.2d at 1161-62.

Section 109(d)(1) of the Act requires that "not later than December 31, 1980, and at 5-year intervals thereafter, the

Administrator shall complete a thorough review of the criteria published under section 108 and the national ambient air quality standards . . . and shall make such revisions in such criteria and standards . . . as may be appropriate . . . ." Section 109(d)(2)(A) and (B) require that a scientific review committee be appointed and provide that the committee "shall complete a review of the criteria . . . and the national primary and secondary ambient air quality standards . . . and shall recommend to the Administrator any . . . revisions of existing criteria and standards as may be appropriate . . . ."

2. Existing Sulfur Oxides Standards and Review to Date

The current primary standards for SO_x, established in 1971, are 80 micrograms per cubic meter ($\mu g/m^3$) [0.03 parts per million (ppm)] annual arithmetic mean, and 365 $\mu g/m^3$ (0.14 ppm), maximum 24-hour concentration not to be exceeded more than once per year. The current secondary standard for SO_x (to protect public welfare) is 1,300 $\mu g/m^3$ (0.5 ppm), maximum 3-hour concentration, not to be exceeded more than once per year. For both primary and secondary standards, SO_x are measured as SO_2. Thus, SO_2 is the current indicator for the SO_x standards.

Review of the original SO_2 criteria and standards was initiated in 1978. The Clean Air Scientific Advisory Committee (CASAC) closed on the revised criteria document (which also addressed particulate matter) in January 1982. An addendum to the CD, which summarized recent controlled human studies on the health effects of SO_2, was issued the same year. A staff paper, which identified critical issues and summarized the staff's interpretation of key studies, received verbal closure at a CASAC meeting in August 1982 and formal written closure in August 1983.

In 1986, in response to the publication in the scientific literature of a number of new studies on health effects of particulate matter and SO_2, a second addendum to the criteria document and a corresponding addendum to the SO_x staff paper were prepared. The CASAC sent the Administrator closure letters on the criteria document addendum, dated December 15, 1986, and on the staff paper addendum, dated February 19, 1987. In the closure letter on the staff paper addendum, the majority of the CASAC recommended consideration of a 1-hour standard in the range of 0.2 to 0.5 ppm SO_2 to protect against 5-minute peaks of 0.4 to 1.0 ppm SO_2. The closure letter on the staff paper addendum is reprinted in Appendix A.

On April 26, 1988 (53 FR 14926), the EPA announced its proposed decision not to revise the existing primary and secondary SO_x standards (measured as SO_2). In reaching the provisional conclusion that the current standards provide adequate protection against the health and welfare effects associated with SO_2, the EPA was particularly mindful of uncertainties in the available evidence concerning the possible need for a new 1-hour standard to protect against health effects associated with 5- to 10-minute SO_2 exposures. Therefore, the EPA specifically requested broad public comment on the alternative of adding a new 1-hour primary standard of 0.4 ppm and making related changes to the existing standards. The EPA's consideration of short-term health effects of SO_2 as well as its rationale for other proposed changes are set forth in the April 26, 1988 notice.

The EPA took final action on the secondary standard portion of the 1988 proposal on April 15, 1993. The rationale for the decision is presented in detail in the April 21, 1993 Federal Register notice that announced the decision (58 FR 21351).

With respect to the primary standards portion of the 1988 proposal, the EPA has entered into a consent decree that requires by November 1, 1994, either: 1) final action on the 1988 proposed decision not to revise the primary standards; or 2) reproposal. The EPA is to take final action on a reproposal 1 year after completion of the public comment period.

The principal question to be resolved with respect to the primary standards is whether a new short-term standard is needed to protect asthmatics at elevated ventilation levels from 5- to 10-minute peak SO_2 levels. During the comment period on the 1988 proposal, a number of issues were raised concerning the possible need for such a standard. These included: 1) the health significance of the responses reported in controlled human studies to 5- to 10-minute SO_2 exposures, particularly at levels below 0.75 ppm; 2) the possibility that moderate to severe asthmatics may experience greater responses than the primarily mild asthmatics studied to date; 3) whether asthmatics already medicated to protect against other environmental stimuli would also be protected against SO_2 exposures; 4) whether a 1-hour standard based on a typical peak-to-mean ratio of 2 to 1 will provide appropriate protection from the full range of sources that have the potential to emit high peak SO_2 levels[2]; and 5) the adequacy of the exposure analysis, which focused only on asthmatics living near power plants.

In order to be better able to address these and other issues, the EPA concluded that the 1986 addendum to the criteria document and the associated SO_2 staff paper addendum should be updated to take into account more recent information.

C. Approach

The approach in this paper is to draw from the criteria document supplement's (EPA, 1994) evaluation and interpretation of the newly available health effects information on short-term SO_2 exposures and to integrate that information with the available information on the occurrence of 5- to 10-minute peak SO_2 levels in the ambient air and associated estimates of potential exposures. Particular attention is drawn to judgments related to determining an appropriate regulatory response given the nature of the reported effects and the likelihood of exposure to short-term peak SO_2 levels. Previous staff conclusions

[2]For present purposes, the peak-to-mean ratio of interest is the ratio of the maximum 5-minute concentration for an hour divided by the hourly average (thus a peak-to-mean ratio of 2 to 1 indicates for that hour the maximum 5-minute average was twice the concentration of the hourly average).

related to the existing primary standards or the secondary standard will not be addressed here.

Section II provides a concise summary of key findings presented in the criteria document supplement on health significance of the effects of brief, concentrated exposures to SO_2 on asthmatics at elevated ventilation. Emphasis is placed on those factors that should be considered in assessing the public health significance of the reported effects. Section III focuses on the available air quality and exposure information to support discussions on the possible need for new regulatory initiatives to address short-term peak levels of SO_2. Drawing from the discussion in Sections II and III, Section IV identifies alternative regulatory options and those factors EPA staff believe should be considered in selecting among the alternatives.

II. ASSESSMENT OF HEALTH EFFECTS

A. Sensitive Population Groups

Based on the assessment in the criteria document supplement, the staff concludes that mild and moderate asthmatic children, adolescents, and adults that are physically active outdoors represent the population segments at most risk for acute SO_2 induced respiratory affects. Individuals with more severe asthmatic conditions have poor exercise tolerance and, therefore, are less likely to engage in sufficiently intense outdoor activity to achieve the requisite breathing rates for notable SO_2-induced respiratory effects to occur (EPA, 1994, p. 48).

Healthy nonasthmatic individuals are essentially unaffected by acute exposures to SO_2 at concentrations below 2 ppm. It has been suggested that nonasthmatic atopic[3] individuals may be at increased risk (EPA, 1986a, pg. 59; 53 FR 14932, April 26, 1988). However, questions have been raised concerning whether the subjects referred to as atopics in one set of studies (e.g., Koenig et al., 1987; Koenig et al., 1988a,b) might be more appropriately considered very mild asthmatics. Another recent study (Linn et al., 1987), that compared the response of atopics and mild asthmatics, found that the atopic group was not

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[3] "Atopic" is a term used to indicate individuals, not diagnosed as asthmatics, with disorders manifested as hypersensitivity to environmental antigens. Examples include hay fever and other allergies. Approximately 8 percent of the U.S. population is estimated to be atopic. Some additional percentage of the population not diagnosed as atopic or asthmatic may also display hyperreactive airway responses to SO_2.

particularly responsive to SO_2. The difference in the incidence of bronchoconstriction in atopics between the different studies is most likely due to criteria used for diagnostic classification, rather than real population differences. As noted in the CDS (EPA, 1994, p. 52), there may be a significant number of undiagnosed asthmatics and a number of subjects without asthma who have exercise-induced bronchospasm. In the process of estimating the number of individuals who are likely to be affected by environmental SO_2 exposure, this uncertainty regarding the incidence of SO_2 sensitivity in the population should be considered.

B. Asthma

In assessing the significance of the SO_2-induced respiratory effects in asthmatic individuals, it is important to have an understanding of asthma as a disease in order to place the findings from the controlled human exposure studies in perspective. The Expert Panel Report from the National Asthma Education Program of the National Heart, Lung and Blood Institute (NIH, 1991) has recently defined asthma as:

> Asthma is a lung disease with the following characteristics: 1) airway obstruction that is reversible (but not completely so in some patients) either spontaneously or with treatment, 2) airway inflammation, and 3) increased airway responsiveness to a variety of stimuli.

As indicated in Table 2-1, there is a broad range of severity of asthma ranging from mild to severe.

Drawing from the discussion in the criteria document supplement, the key information about the disease is presented below:

1) About 10 million people or 4 percent of the population of the United States are estimated to have asthma (NIH, 1991). The true prevalence may be somewhat higher. Some researchers have estimated that 7 to 10 percent of the United States population may be asthmatic (Evans et al., 1987), because some individuals with mild asthma may be unaware that they have the disease and thus go unreported. The prevalence is higher among African-Americans, older (8- to 11- year-old) children, and urban residents (Schwartz et al., 1990).
2) Common symptoms include cough, wheezing, shortness of breath, chest tightness, and sputum production.
3) Asthma is characterized by an exaggerated bronchoconstrictor response to many physical challenges (e.g., cold or dry air, exercise) and chemical and pharmacologic agents (e.g., histamine or methacholine).
4) Daily variability in lung function measurements is a typical feature of asthma, with the poorest function (i.e., lowest forced expiratory volume in 1 second (FEV_1) and highest specific airway resistance (SRaw) being experienced in the early morning hours and the

TABLE 2-1. CLASSIFICATION OF ASTHMA BY SEVERITY OF DISEASE[a]

Characteristics	Mild	Moderate	Severe
A. Pretreatment			
Frequency of exacerbations	Exacerbations of cough and wheezing no more often than 1-2 times/week.	Exacerbation of cough and wheezing on a more frequent basis than 1-2 times/week. Could have history of severe exacerbations, but infrequent. Urgent care treatment in hospital emergency department or doctor's office <3 times/year.	Virtually daily wheezing. Exacerbations frequent, often severe. Tendency to have sudden severe exacerbations. Urgent visits to hospital emergency departments or doctor's office >3 times/year. Hospitalization >2 times/year, perhaps with respiratory insufficiency or, rarely, respiratory failure and history of intubation. May have had cough syncope or hypoxic seizures.
Frequency of symptoms	Few clinical signs or symptoms of asthma between exacerbations.	Cough and low grade wheezing between acute exacerbations often present.	Continuous albeit low-grade cough and wheezing almost always present.
Degree of exercise tolerance	Good exercise tolerance but may not tolerate vigorous exercise, especially prolonged running.	Exercise tolerance diminished.	Very poor exercise tolerance with marked limitation of activity.
Frequency of nocturnal asthma	Symptoms of nocturnal asthma occur no more often than 1-2 times/month.	Symptoms of nocturnal asthma present 2-3 times/week.	Considerable, almost nightly sleep interruption due to asthma. Chest tight in early morning.
School or work attendance	Good school or work attendance.	School or work attendance may be affected.	Poor school or work attendance.
Pulmonary function			
• Peak Expiratory Flow Rate (PEFR)	PEFR >80% predicted. Variability[b] <20%.	PEFR 60-80% predicted. Variability 20-30%.	PEFR <60% predicted. Variability >30%.
• Spirometry	Minimal or no evidence of airway obstruction on spirometry. Normal expiratory flow volume curve; lung volumes not increased. Usually a >15% response to acute aerosol bronchodilator administration, even though baseline near normal.	Signs of airway obstruction on spirometry are evident. Flow volume curve shows reduced expiratory flow at low lung volumes. Lung volumes often increased. Usually a >15% response to acute aerosol bronchodilator administration.	Substantial degree of airway obstruction on spirometry. Flow volume curve shows marked concavity. Spirometry may not be normalized even with high dose steroids. May have substantial increase in lung volumes and marked unevenness of ventilation. Incomplete reversibility to acute aerosol bronchodilator administration.
• Methacholine sensitivity	Methacholine PC_{20} >20 mg/mL.[c]	Methacholine PC_{20} between 2 and 20 mg/mL.	Methacholine PC_{20} <2 mg/mL.
B. After optimal treatment is established			
Response to and duration of therapy	Exacerbations respond to broncodilators without the use of systemic corticosteroids in 12-24 h. Regular drug therapy not usually required except for short periods of time.	Periodic use of bronchodilators required during exacerbations for a week or more. Systemic steroids usually required for exacerbations as well. Continuous around-the-clock drug therapy required. Regular use of anti-inflammatory agents may be required for prolonged periods of time.	Requires continuous, multiple around-the-clock drug therapy including daily corticosteroids, either aerosol or systemic, often in high doses.

[a]Characteristics are general; because asthma is highly variable, these characteristics may overlap. Furthermore, an individual may switch into different categories over time.

[b]Variability means the difference either between a morning and evening measure or among morning peak flow measurements each day for a week.

[c]Although the degree of methacholine/histamine sensitivity generally correlates with severity of symptoms and medication requirements, there are exceptions.

Source: National Institutes of Health (1991).

best function (i.e., highest FEV_1 and lowest SRaw) occurring in the mid-afternoon.

5) The degree of exercise tolerance varies with the severity of disease. Mild asthmatic individuals have good exercise tolerance but may not tolerate vigorous exercise such as prolonged running. Moderate asthmatic individuals have diminished exercise tolerance and individuals with severe disease have very poor exercise tolerance that markedly limits physical activity.

6) Exercise-induced bronchoconstriction is followed by a refractory period of several hours during which an asthmatic individual is less susceptible to bronchoconstriction (Edmunds et al., 1978). This refractory period may alter an asthmatic individual's responsiveness to SO_2 or other inhaled substances.

7) Asthma attacks can result in hospitalization or emergency room treatment. It is estimated that incidence of hospitalization for all asthmatic individuals in the United States is about 45 per 1,000 asthmatics per year (NIH, 1991). Attendance at emergency rooms for asthma in Vancouver, Canada was estimated to account for 1.2 percent of all emergency room visits.

8) Data on asthma attack rates in the United Kingdom suggest an incidence of asthma attacks requiring medical attention, of <1 asthmatic patient-year (Ayres,

1986; Nevill et al., 1993). A similar attack incidence was estimated for the United States patients (Lebowitz et al, 1985; Van Essen-Zandoliet et al., 1992).

9) In assessing the rate of incidence, it should be noted that based on the Los Angeles asthma panel data (EPRI, 1988), only 15 percent of mild asthmatic individuals see a physician annually for their asthma compared to about 67 percent of the moderate asthmatics.

10) Death due to asthma is a rare event; about one per 10,000 asthmatic individuals. Mortality rates are higher among males and about 100 percent higher among non-whites. It has been reported that in two large urban centers (New York and Chicago) mortality rates from asthma among non-whites exceed the city average by up to five-fold and exceed the national average by an even larger factor (Sly, 1988; Evans et al., 1987; NIH, 1991; Weiss and Wagener, 1990; Carr et al., 1992). There may be several possible explanations for this, but the cause of these higher mortality rates has not been explained.

In assessing the results from the controlled human exposure studies discussed below, it should be noted that the individuals who participate in such studies may not be representative of the entire population of individuals with asthma. The subjects of controlled exposure studies typically have mild allergic asthma. In many cases, these individuals can go without medication altogether or can discontinue medication for brief periods of time if exposures are conducted outside their normal allergy season. In addition, African-American and Hispanic adolescents and young adults have not been studied systematically. Subjects who participate in controlled exposure studies are also generally self-selected and this may introduce some bias. Thus, the extent to which the participants in the studies reflect the characteristics of the asthmatic population at large is not known. Nevertheless, the high degree of consistency among studies suggests either that the subjects are generally representative of the population at risk or that any selection bias is consistently present across a diverse group of laboratories.

C. Medication Use

Many asthmatic individuals take medication to relieve symptoms and functional responses associated with exacerbation of this disease. One of the most commonly used asthma medications (beta-agonists) also inhibits responses to SO_2. This has led to suggestions that asthmatic individuals may be protected from responses to SO_2 because they medicate prior to exercise.

However, as discussed in the CD supplement (EPA, 1994), the available data suggest that probably a substantial proportion of asthmatic individuals would not be "protected" by medication use. Most mild asthmatic individuals use medication only when symptoms arise. Roth Associates (1988) reported that out of a panel of 52 asthmatic subjects, whose exercise patterns showed a wide range of variability, one third of the mild asthmatic subjects studied had not used any asthma medication within the past year, and that fewer than half used an inhaled bronchodilator at least once during the past year. Only 20 percent of the moderate asthmatics subjects studied use an inhaled bronchodilator on a regular basis. Marks et al., (1992) also reported that beta-agonist use was infrequent.

Even medication compliance for those on regular medication varies considerably among asthmatic individuals (from none to full compliance). Average compliance figures range from 50 to 70 percent (Smith et al., Weinstein and Cuskey, 1985; Smith et al., 1986; Partridge, 1992). Given the relatively low medication use and compliance rates for many mild and moderate asthmatics individuals, pre-exercise bronchodilator use would not be likely to occur for many potentially SO_2-sensitive individuals.

For a large number of mild asthmatic individuals with normal baseline lung function or well controlled moderate asthmatics on a regular regimen of medication, SO_2 probably represents a limited public health concern, in that exposure is unlikely to reduce their lung function below a critical level that would be of immediate medical concern. However, many moderate asthmatics who come from families with lower socioeconomic status may not have adequate access to the health care system, may have poor compliance for medication use (possibly based on limited availability of medication) and thus may be prone to frequent deterioration of their lung function. Such individuals would be at increased risk from SO_2 exposure because of their potentially poorer baseline level of lung function. Exposure of unmedicated moderate asthmatics to SO_2 could cause additional deterioration of lung function that could be cause for medical concern (EPA, 1994, p. 51).

D. Nature and Time Course of Response

The most striking acute response to SO_2 for asthmatics and others with hyperactive airways is bronchoconstriction (airway narrowing), usually evidenced as increased airway resistance, decreased FEV_1, or decreased peak flow, and the occurrence of symptoms such as wheezing, chest tightness, and shortness of breath (EPA, 1982a; EPA 1986a). This bronchoconstriction response occurs quickly (within 5- to 10-minutes of exposure), with two recent studies showing that the response can begin in as little as 2-3 minutes, although the response does not reach maximal levels until the exposure lasts five or more minutes (Balmes et al., 1987; Horstman et al., 1988). The response is also generally brief in duration; numerous studies have shown that lung function typically returns to normal for most subjects within an hour of exposure. This duration is similar to that experienced in response to exercise and somewhat less than experienced in response to allergens (EPA, 1994). Even if exposure continues beyond the initial 5-10 minutes, lung function may still return to normal as long as the subject ceases to exercise and their ventilation rate decreases to resting levels (Hackney, et al., 1984; Schatcher et al., 1984).

A mild "refractory period" seems to exist in which diminished responsiveness is seen when an individual is re-exposed to SO_2 while at exercise. Lung function responses of approximately 75 percent of those observed after an initial exposure to SO_2 are observed after a second exposure ten to fifteen minutes later (Roger et al., 1985; Kehrl et al., 1987). The response diminishes further with subsequent exposures. However, a few individuals may experience a worsening of response upon re-exposure (Roger et al., 1985). The duration of this refractory period is uncertain, although it does not appear to last longer than 5 hours on average (Linn et al., 1984). Furthermore, longer periods of exposure while at exercise (i.e., 30 minutes) do not lead to a statistically significant worsening of the initial response (Kehrl et al., 1987, p. 352).

An important distinction between the response of asthmatic individuals to SO_2 as compared to their response to allergens is that no evidence indicates that the SO_2 response is accompanied by any "late response," such as that often seen 4 to 8 hours after allergen exposure.

The effects of SO_2 increase with both increased overall ventilation rates and an increased proportion of oral ventilation in relation to total ventilation (EPA, 1986a, p. 10). Oral ventilation is thought to accentuate the response because the scrubbing of SO_2 by the nasal passageways is bypassed. For this reason, in most clinical studies which have observed effects from SO_2, the subjects have been exercising at ventilation rates of 35 to 50 L/min, which equal or exceed the "switching point" (35.3 L/min) from exclusively nasal breathing to oronasal breathing found on average for the general population by Niinimaa et al. (1980).

Ventilation rates in the range of 35-40 L/min are comparable to ventilation rates induced by climbing 3 flights of stairs, light cycling, shoveling snow, light jogging, or playing tennis (Cohen, 1983), and can be induced in the laboratory by walking at 3.5 mph up a 4 percent grade (Kehrl et al., 1987; Folinsbee, personal communication). Ventilation rates in the range of 45-50 L/min are equivalent to moderate cycling, chopping wood, or light uphill running, and can be induced by walking at 3.5 mph up an 8 percent grade (Folinsbee, personal communication). Even though such exercise is not strenuous per se (in that it does not approach an individual's maximum oxygen consumption or the ventilation rates of moderate jogging, heavy cycling, playing basketball, or running), activity and ventilation data indicate that individuals engage in outdoor activities at these ventilation rates only a small percentage of the time (see Section III.D.1).

Since oronasal scrubbing of SO_2 is important in mitigating the effects of SO_2 (EPA, 1986b, p. 4-26), asthmatic individuals who are obligate mouthbreathers, or who are breathing through the mouth due to some temporary condition, may be at greater risk of experiencing responses to SO_2 (since their nasal scrubbing may be bypassed at lower ventilation rates and to a greater extent than for those individuals capable of typical nasal breathing). Several studies have estimated mouthbreathers to constitute approximately 15 percent of the general population (Saibene et al., 1978; Niinima et al., 1980; EPA, 1986b, p. 4-26).

Bronchoconstriction effects may also be exacerbated by cold, dry air and diminished under warm, humid conditions (EPA, 1986b, pp. 4-35 to 4-37). As discussed in the criteria document addendum (EPA, 1986b), Bethel et al. (1984) reported a significant interaction between oral hyperventilation of cold dry air and 0.5 ppm SO_2 via mouthpiece that resulted in a >200 percent increase in SRaw, whereas breathing SO_2 in warm humid air or breathing cold dry air alone resulted in a <40 percent change in SRaw. It has been well documented in numerous studies that SO_2 may interact with weather factors (e.g., cold/dry air) and/or exercise to cause exaggerated bronchoconstriction. This suggests that airway cooling and drying may exacerbate SO_2-induced airway constriction in hyperventilating asthmatic subjects, but insufficient data exist by which to estimate the magnitude of any combined effects of joint SO_2 and cold, dry air exposure under more natural free-breathing conditions during exercise (EPA, 1994, p. 31).

Many features of the SO_2-induced bronchoconstriction response resemble those of exercise-induced bronchoconstriction, including the duration of the effect and the absence of a substantial late response. However, it should be noted that above a sufficient concentration, the response to SO_2 clearly exceeds the response attributable to exercise, and that a number of subjects can experience an effect from SO_2 when at exercise while experiencing little or no effect from exercise in clean air (Linn et al., 1987).

E. Concentration-Response Information

The CD Supplement extensively reviewed several recent, large-scale chamber studies with the aim of further investigating the concentration where clinically significant responses began. Because of the well-documented range in sensitivity to SO_2 among asthmatic persons (e.g., Figure 2-1), variability in an asthmatic individual's day-to-day responsiveness, and the nature of the response itself, it was judged that neither simple group mean statistics nor the responses of particularly sensitive individuals were an appropriate focus. Rather, attention should be focused on the concentrations where a significant proportion of asthmatic individuals tested began to experience effects of concern. Assessing effects of concern involved comparing the responses experienced to SO_2 with those typically experienced in response to typical daily variation in lung function, and to other frequently experienced stimuli, such as exercise or cold/dry air, and noting the frequency with which subjects felt compelled to take medication or diminish workload. The CD Supplement (EPA, 1994) summarized its evaluation of the recent data as follows:

a) At most, only about 10 to 20 percent of mild and moderate asthmatic individuals exposed to 0.2 to 0.5 ppm SO_2

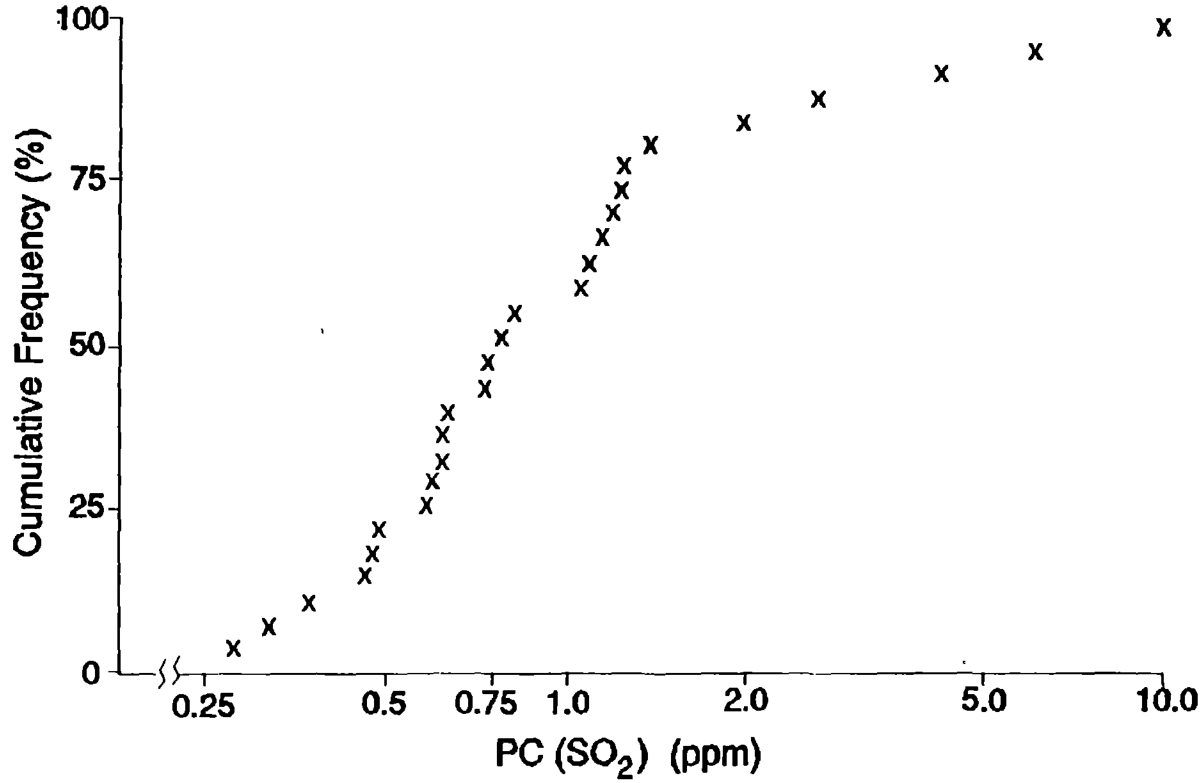

Figure 2-1. Distribution of individual airway sensitivity to SO_2 (Horstman et al., 1986). PC (SO_2) represents concentration of SO_2 that, after correction for exercise (V_e = 42 l/min), resulted in a 100 percent increase in SRaw. Cumulative percentage of subjects is plotted as a function of PC (SO_2) and each data point represents PC (SO_2) for an individual subject. These data show substantial variability in sensitivity among mild asthmatic volunteers.

Source: Horstman et al. (1986)

during moderate exercise are likely to experience lung function changes distinctly larger than those they typically experience. Furthermore, only exceptionally sensitive responders might experience sufficiently large lung function changes and/or respiratory symptoms of such severity to be a potential health concern, leading to the disruption of ongoing activities, the need for bronchodilator medication, or seeking of medical attention.

b) In contrast to the above projected likely consequences of ambient exposures to 0.2 to 0.5 ppm SO_2 of mild and moderate asthmatic persons, considerably larger lung function changes and respiratory symptoms of notably greater severity would be expected to occur due to exposure of such individuals to SO_2 concentrations of 0.6 to 1.0 ppm SO_2. That is, substantial percentages ($\geq$20 to 25 percent) of mild or moderate asthmatic individuals exposed to 0.6 to 1.0 ppm SO_2 while physically active would be expected to have respiratory function changes and severity of respiratory symptoms that distinctly exceed those experienced as typical daily variation in lung function or in response to other stimuli, e.g., moderate exercise or cold/dry air. The severity of the effects for many of these responders, furthermore, is likely to be sufficient to be of concern, i.e., to cause disruption of ongoing activities, use of bronchodilator medication, and/or possible seeking of medical attention. The intensity of distress is much more likely to be perceived as an "asthma attack" than would be the case for most 0.2 to 0.5 ppm

SO_2 effects, although it would still appear relatively unlikely that the short-lived symptoms would be sufficient to cause many to seek emergency medical attention.

The CD supplement (EPA, 1994) concludes that while the relative health significance of the responses seen to SO_2 are difficult to judge (see further discussion below), more concern should be focused on the response to ≥ 0.6 ppm SO_2 than to concentrations of $SO_2 \leq 0.5$ ppm (EPA, 1994, p. 46).

F. Other Considerations

In addition to information on the nature and severity of effect as indicated by clinical parameters, there are several other factors that the Administrator may wish to consider:

1. SO_2 Responsiveness and Asthma Severity

One concern voiced in the last review was whether more severe asthmatic individuals than those studied to date might be more responsive or experience more severe effects from SO_2. At that time, the evidence was judged insufficient to answer that question (Appendix A).

Several of the more recent studies reviewed in the CD supplement (Linn et al., 1987, 1990; McManus et al., 1989) provide information on this question by reporting the responses of asthmatic individuals with moderate to severe disease, medication-dependent disease, or older individuals with "intrinsic" asthma. When airway resistance was examined, the moderate asthmatic subjects were observed to have similar relative changes but larger absolute changes to those observed for mild asthmatic individuals (Linn et al., 1987). As the CD supplement suggests (EPA, 1994, pp. 21-24), similar function declines may have a greater impact on individuals with lower baseline lung function, a situation more typical of moderate or severe asthmatics.

In addition, a recent study suggests that older "intrinsic" asthmatic subjects (McManus et al., 1989) may experience bronchoconstriction, albeit from a mouthpiece exposure, even while resting. The CD supplement concludes that while the data is suggestive of greater responsiveness among those with more severe disease, the question remains to be unequivocally resolved. However, because of the lower baseline function in moderate and severe asthmatic persons, especially those lacking optimal medication, any effect of SO_2 would further reduce their lung function toward levels that may become cause for medical concern (EPA, 1994, p. 44).

The CD supplement also notes that severe asthmatics are less likely to be sufficiently physically active, because of low exercise tolerance, to be frequently at risk from peak concentrations of SO_2. In addition, this segment of the asthmatic population would be most likely to premedicate prior to engaging in substantial outdoor activity.

2. Effects of Asthma Medications on the SO_2 Response

Interest has been expressed concerning the ability of typical asthma medications to protect against the effects of SO_2. An argument can be made that if medications routinely used by an asthmatic, for reasons separate from the pollutant itself, also confer protection against the effects of the pollutant, then this consideration should be factored into the evaluation of risk. It now appears that most regularly administered medications, such as inhaled steroids and methylxanthine medications (such as theophylline) appear relatively ineffective in protecting against the SO_2 response (EPA, 1994, p. 34-41). In contrast, inhaled beta-agonist bronchodilators are highly effective in reducing or eliminating the lung function responses to SO_2 (EPA, 1994, p. 38). Since bronchodilators are most effective in preventing effects if taken relatively shortly before exposure, the frequency with which asthmatic individuals premedicate prior to exercise is of interest.

As pointed out in Section C above, many asthmatics do not use bronchodilators at all or do not use them with a frequency to suggest that they consistently premedicate prior to exercise. In fact, as pointed out above (Section E), many of the mild asthmatic individuals, including those responsive to SO_2, have little or no exercise-induced bronchoconstriction at the exercise levels examined here, and thus would probably not feel a compelling need to premedicate prior to exercise. Data on the medication use of some of subjects in the clinical studies bear out the conclusions that in general, mild asthmatics use bronchodilators infrequently, as do some moderate asthmatics; although a substantial portion of moderate asthmatic may use bronchodilators frequently (EPA, 1994, Appendix B memo).

Another factor to consider is that there is some suggestion that excessive use of beta-agonist bronchodilators leads to a worsening of asthma status (EPA, 1994, p. 41).

3. Effect of Other Air Pollutants on SO_2 Responsiveness

Koenig et al. (1990) reported that response to SO_2 in adolescent asthmatic subjects was potentiated by prior exposure to 0.12 ppm ozone (O_3). After 45 minutes of O_3 exposure by mouthpiece, a 15-minute mouthpiece exposure to low concentrations of SO_2 (0.1 ppm) produced statistically significant decreases in FEV_1 (8 percent total change, versus a 3 percent change without prior O_3 exposure). Symptoms scores did not change significantly (although an increase in symptoms was reported for the combined O_3 and SO_2 exposure). Because of the reliance on mouthpiece exposures at single concentrations for both pollutants, it is difficult to fully evaluate the potential implications of this experiment for ambient exposures to SO_2, but it gives suggestive evidence that brief SO_2 exposures encountered against a background of elevated O_3 levels may lead to greater effects than those seen in the controlled human exposure studies that examined SO_2 alone.

The effects of prior NO_2 exposure on SO_2-induced bronchoconstriction has been examined in two other studies (Jorres and Magnussen, 1990; Rubinstein et al., 1990). One mouthpiece study indicates that a 30-minute peak of NO_2 at 0.25 to 0.30 ppm increased airway responsiveness to SO_2 among asthmatic individuals (probably due to a nonspecific increase in bronchial responsiveness), while a chamber study found no change in responsiveness except for one subject (EPA, 1994, pp. 42-43).

4. Effects of SO_2 In the Context of the Typical Experience of Asthmatic Individuals

Another factor that might be considered in assessing the severity of SO_2 effects is the frequency with which the sensitive population experiences similar effects as a result of normal variation and reactions to other stimuli. As indicated above, asthmatic "episodes," as indicated by self-reported asthma attacks, self-reported symptoms (EPA, 1994, Appendix B memo), or visits to the physician or emergency room (EPA, 1994, pp. 7-8), seem to be a relatively infrequent occurrence for many or most adult asthmatics. While it is uncertain how individuals would perceive their responses from SO_2, those experiencing pronounced responses to 0.6 to 1.0 ppm may perceive these events to be asthma attacks (although it is judged relatively unlikely that the effects would cause many to seek emergency medical attention) (EPA, 1994, p. 50). In addition, the symptoms suffered by those responding to SO_2 may attain levels of severity greater than experienced on a typical day-to-day basis, especially among mild asthmatics (EPA, 1994, Appendix B memo).

Table 2-2 shows that, for the indicator of lung function as well, the effects seen in response to SO_2 in the more sensitive asthmatic individuals (especially the most sensitive 25 percent)

Table 2-2. LUNG FUNCTION CHANGES IN RESPONSE TO 0.6 AND 1 PPM SO_2 COMPARED TO TYPICAL DAILY CHANGE AND RESPONSES TO EXERCISE

ASTHMATIC SEVERITY	DAILY CHANGE	PERCENTILE OF TEST SUBJECTS	MODERATE EXERCISE	SO_2 (corr. for exc.)	TOTAL CHANGE
MILD FEV_1	-8%	50th	-2%	-21%	-21%
		75th	-7%	-26%	-30%
MODERATE FEV_1	-13%	50th	-8%	-10%	-25%
		75th	-14%	-31%	-39%
MILD (1985) SRaw	?	50th	+46%	+118%	+164%
		75th	+59%	+230%	+249%

Modified from Table 2 of CDS Appendix B memo. Table shows that the response due to SO_2 alone (corrected for exercise) or the total response (considering the combined effects of SO_2 and exercise) considerably exceeds the change due to exercise or the typical daily change in most cases, especially for the most sensitive 25% of responders (the 75th percentile group). The exercise and SO_2 numbers should not be expected to sum to equal "Total Change" (see CDS, Appendix B memo).

considerably exceeds the change in lung function due to exercise or daily variability. A second comparison to exercise showed that, when the symptom and lung function responses were examined in combination (along with, in some cases, medication use), the total effect of SO_2 combined with exercise on asthmatic individuals clearly exceeded the effects of exercise alone. For example, approximately 6-43 percent of asthmatic subjects experienced what were classified as severe lung function changes and moderate symptoms in response to SO_2, while no subjects did so after exercise alone (EPA, 1994, Appendix B memo).

In summary, present data suggests that the effects experienced by those asthmatic individuals responding to 0.6 to 1.0 ppm SO_2 are likely to be perceived as distinctive, notable events outside the range of responses frequently experienced. However, perception of symptoms is not necessarily a good index of functional status. Some patients with near-fatal asthma attacks had a poor perception of their breathing difficulty and were thus unable to perceive an attack of severe bronchospasm (EPA, 1994, p. 30).

G. <u>Conclusions</u>

In conclusion, the primary reasons for concern over the effects of SO_2 in the range of 0.6 - 1.0 ppm are that a substantial percentage of asthmatic individuals (≥20 to 25 percent) experience pronounced changes in lung function that may be viewed as a mild asthma attack, cause discomfort, prompt self-administration of medication, and cause some individuals to alter their activity (even from a 10-minute exposure). Most adult asthmatic individuals do not seem to experience asthmatic episodes of similar magnitude with great frequency. Most regularly administered medications are not very effective in blocking the SO_2 response, and to obtain protection from the most commonly used effective medication (beta-agonists), the asthmatic individual has to anticipate the need to premedicate prior to exposure. (Although some asthmatics premedicate routinely before exercise, such premedication is likely to be infrequently practiced for much of the sensitive population). Lastly, some conditions, such as prior exposure to O_3, may exacerbate the response.

Factors that serve to mitigate, to some degree, concern over SO_2 effects are that the response, like most asthma responses, resolves over time; in most cases, the response has run its course within an hour, with no evidence of later heightened sensitivity such as is seen in a "late response." In addition, while some individuals may reduce activity, most of the subjects exposed at 0.6 to 1.0 ppm do not feel such a need and can still function effectively despite whatever effects they perceive from the SO_2 exposure. Finally, medication does exist (primarily beta-agonists) that can ameliorate the responses, either if taken shortly before exposure or after the response has begun.

Given the above information, the staff agrees with the recommendation of the CD supplement (EPA, 1994) that the likely frequency of occurrence of such SO_2-induced effects is a factor to be considered in assessing the degree of public health concern posed from exposures to peaks of SO_2.

III. AIR QUALITY AND EXPOSURE CONSIDERATIONS

Because the most recent health effects information on SO_2 is related to short-term (5- to 10-minute) exposures, this section summarizes recent information on the occurrence of monitored high, 5- to 10-minute concentrations of SO_2 in the ambient air. New information is presented on the variability of 5- to 10-minute peak SO_2 concentrations within particular hourly periods, which relates to the averaging time necessary for any effective short-term standard. Estimates of the nationwide prevalence of these short-term peaks of SO_2 are given.

A. Occurrence of 5-Minute Peaks of SO_2 in the Ambient Air

A central issue raised during the comment period on the 1988 proposal concerned whether the staff underestimated the prevalence of short-term, 5- to 10-minute peaks of SO_2. Concern focused on two issues: 1) whether nonutility sources, which were qualitatively but not quantitatively considered in staff estimates of exposure, might contribute a substantial number of 5-minute peaks of SO_2, and 2) whether a 1-hour standard of 0.4 ppm (based on a typical peak-to-mean ratio of approximately 2 to 1 derived principally from utility data) would provide adequate protection from high 5-minute peak SO_2 levels near nonutility sources. Since that time, staff has sought to obtain information on the occurrence of short-term peaks of SO_2 in the ambient air. The following analysis focuses primarily on the prevalence of peaks >0.75 ppm SO_2 for 5 minutes or more, because this benchmark is approximately equal to the levels that would be protected against by the 1-hour, 0.4 ppm standard advanced for comment in 1988. For comparison purposes, the prevalence of peaks >0.5 ppm was also determined if available data allowed.

Obtaining 5-minute data has proved difficult because the shortest averaging period typically retained in monitoring data banks is 1 hour. Moreover, the existing monitors are sited in locations that are designed to be representative of air quality levels associated with 24-hour, annual, and 3-hour concentrations, rather than to detect short-term peaks.

Despite these problems, data-gathering efforts to date indicate that peak 5-minute levels of SO_2 >0.75 ppm can occur around a number of different sources.[4] While the data from these ambient monitoring sites cannot always be attributed solely to a single source, 5-minute concentrations of SO_2 in excess of 0.75 ppm have been recorded by a number of ambient air monitors sited primarily to detect SO_2 emitted from distinct point sources. These include one or more sources in the following source types: utility boilers, industrial boilers, refineries, pulp and paper mills, copper smelters, primary lead smelters, sulfuric acid plants, and steel mills (coke ovens). For those sources for which the data were available, the number of peaks >0.50 ppm was also calculated (Stone, 1994).

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[4]In this paper, information on ambient 5-minute concentrations of SO_2 refers to the highest of the 12 block averages (12:00 to 12:05, 12:06 to 12:10, etc.) possible during a clock hour.

Data collected from monitors located near these source types are summarized in Table 3-1. The SO_2 peak concentrations enumerated in Table 3-1 were measured in the ambient air during the years 1988 to 1993. Seven of the 12 sites listed recorded high 5-minute peaks in the 1993 calendar year. These data suggest that around some sources, numerous 5-minute peaks of SO_2 >0.75 ppm can occur. However, in some cases, fewer peaks have been recorded around other sources of the same general type.

A few of the sources listed in Table 3-1 have recently installed improved pollution control equipment which would be expected to reduce the occurrence of SO_2 peaks. Thus, the data in Table 3-1 are not intended to represent "typical" frequencies of 5-minute peaks of SO_2 around the different source types listed. They do illustrate that ambient peaks of SO_2 >0.75 ppm can occur near a variety of sources.

Finally, it should be noted that high peaks did occur on days when the existing 24-hour or 3-hour standards were exceeded. In general, however, these data suggest that the current NAAQS may offer less protection against brief, concentrated peaks of SO_2 than previous staff analyses indicated.

B. <u>Peak-to-Mean Ratios</u>

The 1982 staff paper and the 1986 addendum summarized the available information on the variance of 5- to 10-minute peak concentrations within particular hourly periods. Based on its assessment of the available data (Larsen, 1968; Burton and Thrall, 1982; Thrall et al., 1982; Rote and Lee, 1983; Armstrong,

TABLE 3-1. Number of Ambient 5-minute Averages >0.75 and >0.50 ppm SO_2
Selected Sites, 1989-93

Source	Approximate # of Hours With 1 or More 5-min Peaks / Period of Time	
	>0.75 ppm	>0.50 ppm
Sulfuric Acid Plant	18/0.05 yr.	38/0.05 yr.
Petroleum Refinery/Industrial Complex[2]	56/0.38 yr.	114/0.38 yr.
Sulfite Paper Mill	83/1.0 yr.[1]	-
Allegheny County, PA[2]	35/0.92 yr.	-
Copper Smelter[2]	73/2.5 yr.	-
Primary Lead Smelter	72/1.15 yr.	125/1.15 yr.
Copper Smelter	14/1.0 yr.	51/1.0 yr.
Steel Mill	32/2.15 yr.	74/2.15 yr.
Utility/Industrial Complex	15/5.16 yr.	88/5.16 yr.
Industrial Boiler/Kraft Paper Mill	1/0.31 yr.	2/0.31 yr.
Petroleum Refinery	0/1.0 yr.	0/1.0 yr.
Petroleum Refinery	0/1.0 yr.	6/1.0 yr.

[1]Actually indicates instantaneous peak concentrations >1.0 ppm
[2]These sources had more than one monitor in their proximity. Data used from all monitors, but hours with peaks only counted once, regardless of how many of the monitors recorded a peak for that hour.

1985, 1986) and relying on the premise that utilities would be the dominant source of 5-minute exposures, the staff concluded that 5-minute peak values were typically twice that of the associated 1-hour value. Thus, it was thought an hourly standard of 0.4 ppm would protect against 5-minute peaks of approximately 0.8 ppm or higher.

The use of a 2 to 1 peak-to-mean ratio was questioned during the public comment period on the 1988 proposal. One commenter (Environmental Defense Fund, item IV-D-72, Docket A-84-25) submitted data collected near three sulfite paper mills indicating that high 5-minute peak SO_2 levels could occur that were associated with very low hourly averages (i.e., peak-to-mean ratios in excess of 2 to 1). While these data are limited to one source type (and one of the sources had no controls on pertinent equipment that resulted in very high 5-minute peaks), they brought into question whether a peak-to-mean ratio of 2 to 1 is generally applicable to all source types.

To assess this question further, the staff examined other data sets that summarize data collected from several monitors (a refinery, a copper smelter and an industrial complex dominated by a coke oven located in Allegheny County, Pennsylvania) and from a single monitor (primary lead smelter). In the cases of the refinery and the coke oven complex, several sources may have contributed to the reported SO_2 values.

The analysis of these data was restricted to just those hours recording 5-minute peaks >0.75 ppm. Therefore a peak-to-mean ratio was derived only for hours containing high 5-minute peaks, but these are precisely the events any new standard would be designed to guard against. Because of this restriction the number of observations in these data sets is far less than those examined in the 1982 staff paper and the 1986 addendum.

All of the mean and median peak-to-mean ratios for each of these data sets are in excess of 2 to 1 (Table 3-2). The range of hourly averages associated with 5-minute peaks >0.75 is very broad, and in isolated instances peaks >0.75 ppm were observed during hours in which the hourly average did not exceed 0.2 ppm.

While much of the variability in these peak-to-mean ratios likely results from emission-rate variability, and sources with better controlled, more uniform emissions may have fewer peaks and fewer hours with high peak-to-mean ratios, Table 3-2 suggests that no "typical" peak-to-mean ratio exists that can be used to determine a uniformly-applicable hourly standard. Given the broad range in hourly values associated with concentrated 5-minute peaks of SO_2, it appears that reliance on any single hourly peak-to-mean ratio will risk over-controlling some sources (if a high peak-to-mean ratio is assumed and a low hourly standard chosen) or under-controlling other sources (if a low peak-to-mean ratio is assumed and a high hourly standard chosen).

For example, among Allegheny County monitors, 84 hours had average concentrations above 0.25 ppm, yet only 19 of these hours (23 percent) had 5-minute peaks above 0.75 ppm. During the same time period, peaks were recorded in 22 hours with average

TABLE 3-2. Peak-to-Mean Ratios

Source	Peak-to-Mean	
Copper Smelter	3.5	Average
	3.6	Median
	7.5-1.2	Range
	0.17	MinHour (ppm)[1]
	90	No. of Observations
Allegheny County, Pa	4.0	Average
	3.7	Median
	10.9-1.4	Range
	0.07	MinHour (ppm)
	39	No. of Observations
Refinery/Industrial Complex	2.9	Average
	2.4	Median
	7.3-1.1	Range
	0.11	MinHour (ppm)
	23	No. of Observations[2]
Primary Lead Smelter	4.0	Average
	3.22	Median
	10.37-1.68	Range
	0.09	MinHour (ppm)
	22	No. of Observations

[1] "MinHour" refers to the minimum hourly average associated with minute peak of >0.75 ppm.

[2] The refinery/industrial complex data contains fewer observations than indicated in Table 3-1 because hourly averages wer not available for all the hours recording high 5-minute peaks.

concentrations below 0.25 ppm (Smith, 1993). If, for the purposes of illustration, we assume an hourly standard of 0.25 ppm was in place, some of the 5-minute peaks would have been restricted. However, many hourly concentrations without peaks would be controlled, and the majority of the 5-minute peaks still could have occurred, since the associated hourly concentrations would be permissible.

C. Nationwide Estimates of Short-Term Peak SO_2 Levels

The staff attempted to estimate the nationwide prevalence of 5-minute peaks ≥ 0.50 and ≥ 0.75 ppm. Because 5-minute SO_2 data are not readily available, it was necessary to rely on hourly data to generate more comprehensive estimates of the likelihood of high short-term SO_2 peaks than those presented in Table 3-1. The use of hourly data requires employing peak-to-mean ratios to obtain estimates of 5-minute concentrations; however, as pointed out above, peak-to-mean ratios may not give a reliable indication of high short-term peak SO_2 levels. To address this problem, staff assumed an upper bound peak-to-mean ratio of 3-to-1 (5-minute concentration to hourly average) and a lower bound peak-to-mean ratio of 2-to-1.

For example, to obtain lower bound estimates of exposure to 5-minute, 0.75 ppm concentrations using the 2-to-1 peak-to-mean ratio assumption, the staff examined all hourly averages reported in the AIRS database for the year 1992 that exceeded 0.38 ppm. An hourly average of 0.38 ppm is the approximate value at which a typical peak-to-mean ratio of 2 to 1 would predict on average a

5-minute value ≥0.75 ppm.[5] Fifty monitors (out of 721 monitors, or approximately 7 percent) recorded at least one hourly average as high as 0.38 ppm (Table 3-3A). At these monitors, only two values greater than the level of the 24-hour primary standard and two values greater than the 3-hour secondary standard were recorded in 1992 (excluding a monitor based at the Hawaiian Volcano).

Because several monitors can be located around a single source, the number of counties (38) that had recorded hourly averages ≥0.38 ppm may provide a better indication of the number of distinct sources or sites. This represents approximately a 50 percent reduction in the number of counties reporting 1-hour averages ≥0.38 ppm since 1978. Much of this reduction has occurred since 1989 (Smith, 1993). While estimating potential population exposure is difficult, especially since the geographic extent of the area affected by any short-term peaks is uncertain, 18 of these 38 counties contained urban populations (cities or towns).

For the upper bound estimate of exposure, all hourly averages ≥0.25 ppm were also examined assuming a peak-to-mean ratio of 3 to 1 to predict the potential for high 5-minute values. Based on the available data, the assumption that all

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[5]The use of hourly averages to estimate high 5-minute peaks must be viewed as approximate because some of the monitors recording high hours will not have associated 5-minute peaks 2 (or 3) times as high; on the other hand, some monitors with low hourly averages that therefore do not appear on Table 3-3 may have high 5-minute peaks.

TABLE 3-3. Analysis of Hourly Averages Nationwide[1]

A. Sites Recording High Hourly Averages - 1992

Sites Recording Hourly Averages		
≥ 0.38 ppm	≥ 0.25 ppm	≥ 0.17 ppm
50 total sites	132 total sites	247 total sites
(7%)	(18%)	(34%)
38 counties/18 cities	91 counties/65 cities	148 counties/124 cities

B. Sites Recording Multiple High Hourly Averages - 1992

Hourly Avg. (ppm)	Case (ppm, Peak-to-Mean)	Location	Number of Readings ≥ the Hourly Average		
			1	3	5
0.38	0.75, 2 to 1	Sites Counties	50 38	16 12	9 7
0.25	0.75, 3 to 1 0.5, 2 to 1	Sites Counties	132 91	74 56	52 39
0.17	0.5, 3 to 1	Sites Counties	247 148	164 107	119 82

C. Sites Recording High Readings in 1990, 1991, & 1992

0.38 ppm	0.25 ppm	0.17 ppm
19 sites	72 sites	156 sites
16 counties	57 counties	106 counties

[1]For this table, all site counts exclude the Hawaii Volcano, which is a nonanthropogenic source.

hourly averages ≥0.25 ppm may have 5-minute peaks of 0.75 ppm or greater associated with them appears to be conservative. The numbers of both monitors and counties with at least one hourly average ≥0.25 ppm are significantly greater than those for hourly averages ≥0.38 ppm (Table 3-3A). At this bound, 132 monitoring sites and 91 counties, 65 of which contain urban populations, potentially could experience 5-minute peak SO_2 levels ≥0.75 ppm.

For comparison, the staff also assessed the number of sites that potentially could have 5-minute SO_2 levels ≥0.5 ppm. The number of sites recording at least one hourly average ≥0.25 ppm (132 sites, 91 counties, 65 urban areas) serves as an estimate of the number of sites that might experience 5-minute SO_2 level ≥0.5 ppm, assuming a peak-to-mean ratio of 2 to 1 (lower bound). In that same year, 247 sites, located in 148 counties with 124 urban areas, recorded at least one hourly value ≥0.17 ppm and potentially could experience 5-minute peaks ≥0.5 ppm, assuming a peak-to-mean ratio of 3 to 1 (upper bound).

The staff next examined how many of the sites and counties experienced multiple hourly averages ≥0.38 ppm, 0.25 ppm, and 0.17 ppm during 1992. The results for the number of sites recording 1, 3, and 5 hourly averages greater than or equal to the three cutpoints are presented in Table 3-3B. The number of sites recording multiple hourly averages ≥0.38 ppm decline much more sharply than those recording hourly averages ≥0.25 ppm or 0.17 ppm. Only nine sites recorded five hourly averages ≥0.38

ppm while 52 sites recorded five hourly averages ≥0.25 ppm and 119 sites recorded five hourly averages ≥0.17 ppm.

The staff also examined data from 1990 and 1991 to determine how many of the sites that recorded high hourly averages in 1992 also had high hourly averages in the preceding 2 years (Table 3-3C). Of the 50 sites that recorded at least 1 hourly average ≥0.38 in 1992, only 19 record those values in all 3 years. Of the 132 sites recording hourly averages ≥0.25 ppm, only 72 of those sites recorded hourly averages of ≥0.25 ppm in all of the 3 years examined. Similarly, of the 247 sites recording hourly averages of ≥0.17 ppm in 1992, 157 recorded high hourly averages in all 3 years. This information suggests that the occurrence of monitored high hourly averages at a given site is variable.

The use of existing hourly data to assess the potential prevalence of 5-minute peak SO_2 levels has other limitations beyond those introduced by the use of peak-to-mean ratios. The existing monitoring network is designed to accurately characterize ambient air quality associated with 3-hour, 24-hour, and annual SO_2 concentrations rather than to detect short-term peak SO_2 levels. As a result, the EPA's monitoring guidance on siting criteria, the spanning of SO_2 instruments, and instrument response time (Eaton et al., 1991) could lead to underestimates of high 5-minute peaks and thus 1-hour averages for hours containing those peaks. Such underestimates would lead to underestimates of the number of nationwide sites recording high hourly values in the results given above.

Monitor siting constraints may be the biggest potential source of underestimation of the occurrence of SO_2 peaks. In 1992, approximately 700 monitors reported data. This contrasts to the more than 6,000 sources that may produce high peak SO_2 levels (Appendix B, Table B-2). Therefore, it is likely that changes in monitoring siting and density in the proximity of SO_2 sources would increase the number of high 5-minute and associated 1-hour averages recorded.

D. Nationwide Estimates of Exposure

Another approach to estimating the frequency of short-term peaks of SO_2 is through exposure analysis, a technique that has the added advantage of incorporating the likelihood that an asthmatic individual may experience a response to that peak. Exposure analysis predicts both the frequency that a concentrated peak of SO_2 will occur (through air quality modeling) and the probability that an asthmatic individual will be outdoors at sufficient ventilation to be at risk from that peak. In the analyses discussed below the probability of an "air quality event" of a 5-minute peak >0.5 ppm SO_2 (or >0.75 ppm) is determined and combined with the probability that an asthmatic individual will be outdoors at sufficient ventilation (>35 L/min).

Since both the existence of concentrated peaks of SO_2 and episodes of breathing at elevated ventilation outdoors are relatively infrequent occurrences, the combined probability of these events occurring simultaneously is relatively low.

However, when a source produces numerous concentrated peaks or affects a large enough population, the likelihood increases that at least some asthmatic individuals in the vicinity will encounter a peak while at sufficiently high ventilation outdoors.

The following discussion briefly reviews activity data used for these analyses, and presents the results of two analyses evaluating the probability that an asthmatic individual will be outdoors at elevated ventilation and be exposed to a short-term peak of SO_2 as a result of emissions from either utility or nonutility sources. The utility exposure analysis was performed by a contractor, System Applications, Inc., for the Utility Air Regulatory Group. The nonutility analysis was performed by the same contractor using a similar methodology for the Environmental Protection Agency.

1. <u>Activity patterns</u>

Both exposure analyses used activity data derived from a diary study of the general population carried out in Cincinnati, Ohio. When this data was aggregated into hour blocks, from 0-3.5 percent of the people-hours were spent outdoors exercising at a "high" activity level (Stoeckenius et al., 1990, p.8 and Fig. 2-2).

For these analyses, individuals at a "high" activity level were considered to be ventilating on average >35 L/min, the point at which a majority of the general population begins oronasal breathing (breathing through both mouth and nose). This is the point at which nasal scrubbing of SO_2 begins to be bypassed and an asthmatic person is at greater risk of experiencing a response. This is probably a reasonable approximation; however, further work has shown some individuals at medium or moderate activity may ventilate at >35 L/min, while some individuals do not ventilate at that level, on average, even during what they describe as "high" or "fast" activity.

Comparing the activity patterns for the general population with the activity patterns of asthmatic persons is difficult. Many mild asthmatic individuals, who constitute the majority of asthmatic persons, and also some moderate asthmatics, are encouraged, as part of their therapy, to exercise to maintain lung function. Thus, some asthmatic individuals may be more active than the general population. However, approximately 20 percent of people with asthma report at least some activity limitation from their disease (NCHS, 1993), and it is reasonable to expect that many of these individuals (particularly those with severe disease) would be less active than the general population.

The only activity study which attempted to obtain a representative sample of asthmatics found their activity levels to be comparable to, or slightly greater than the general population estimates (Roth Associates, 1988). Other studies (Linn, 1991), composed primarily of individuals with moderate and/or severe disease, have found comparable or lower activity patterns (Appendix B).

2. Exposure Analysis Results

The exposure analyses combine the probability of being at elevated ventilation with the probability of encountering a peak of SO_2. The probability of occurrence for a peak of SO_2 is determined by using an air quality model to predict the number of peaks occurring in an area within a year. The precision of the air quality model estimate depends greatly on the quality of the emissions data. For the utility analysis, detailed information on actual emissions was available on a plant-by-plant basis. For the nonutility analysis, actual data were not available. As discussed in Appendix B, the following assumptions were made: for many sources constant operation at the maximum hourly design rate was assumed (a very high rate of operation), while for other sources constant operation at the annual average emission rate was assumed (a rate lower than that attained approximately half the hours for the year, and probably lower than many hours with high peaks). Neither approach to nonutility emissions provides what would be most desirable, estimates of the frequency and the geographic extent of concentrated peaks resulting in part from emissions fluctuations of less than one hour duration.

The lack of emissions data means that the nonutility analysis has a large source of uncertainty not shared by the utility analysis. Because of this, the nonutility estimates of exposure events, and number of asthmatic individuals exposed, are given as ranges that depend on some of the modeling assumptions. Both analyses have a number of additional uncertainties that are listed in Table 3-4, and described in Appendix B. Given these uncertainties, these analyses were not intended to generate precise estimates of the number of asthmatic individuals exposed. However, these analyses do provide estimates of the relative size of the potentially exposed population.

The analyses (Table 3-5) indicate that numerous exposures of asthmatic individuals at exercise outdoors to concentrations ≥0.5 ppm may occur nationwide (180-395,000 events). (Throughout the following text and tables, all references to "exposures," "SO_2 exposures," or "asthmatic individuals exposed" refer to exposures of asthmatic individuals to SO_2 while at exercise outdoors). However, relative to the total population of asthmatic individuals, short-term SO_2 exposures do not appear to be a pervasive problem. The 68,000 - 166,000 asthmatic individuals estimated to be exposed 1 or more times per year to concentrations ≥0.5 ppm SO_2 comprise approximately 0.7-1.8 percent of the total asthmatic population. Because the population of asthmatic individuals living in the vicinity of SO_2 sources (and thus having the potential to be exposed to SO_2) is smaller than the total asthmatic population, it follows that more

TABLE 3-4. SOME IMPORTANT SOURCES OF UNCERTAINTY IN EXPOSURE CALCULATIONS

Source	Likely Magnitude & Direction of Error on Exposure Estimate
Modeling Uncertainties	
Prototype selection/binning	Unknown
Meteorological modeling uncertainties	Unknown
Peak-to-Mean Ratio	
Representativeness	Small to moderate, unknown
Weather & ratio uncoupling	Small to moderate, unknown
Exposure Modeling	
Activity pattern update (ventilation rates, timing of exercise)	Small to moderate, unknown
Asthmatic activity patterns	Small to moderate, over
Uniform population assumptions (around utilities)	Small, unknown
Emissions	
Nonutility emission estimates	Large, over for some sources, under for some sources
Non-included sources	Small to moderate, under
Estimates of affected areas	Small, under
Complex terrain	Unknown, under
Overlapping sources	Small to moderate, under
Multiple peaks in an hour	Small, under

TABLE 3-5

SO_2 EXPOSURE ANALYSIS RESULTS (0.5 PPM)			
NATIONWIDE			
Total Exposure Events	180,000-395,000		
No. of Asthmatic Persons Exposed 1X or More	68,000-166,000		
Percent of Total Asthmatic Population	0.7-1.8%		
SECTOR-SPECIFIC			
UTILITIES		**NON-UTILITIES**	
Exposure Events	68,000	Exposure Events	114,000-325,000
Full Load Exposure Events	~118,000[1]	No. of Asthmatic Persons Exposed 1X or More	24,000-122,000
Post-Title IV Exposure Events	40,000		
		Industrial Boilers Exposure Events	56,000-201,000
Post-Title IV 0.75 ppm Exposure Events	9,000		

[1]Estimated from Table B-1, Appendix B, applying the 5% correction (Rosenbaum et al., 1992, p.2).

than 0.7-1.8 percent of this subset would be exposed.[6] Because the total number of exposure events exceeds the estimated number of asthmatic individuals exposed by approximately 2-to-3-fold, asthmatics exposed to SO_2 at exercise are being exposed two to three times a year on average, with more frequent exposures possible for a substantial fraction.

The analyses indicate that asthmatic individuals are more likely to be exposed multiple times during a year around nonutility sources than utility sources. The 114,000 to 326,000 estimated exposures around nonutility sources are estimated to affect 24,000 to 122,000 asthmatic persons, implying that exposed individuals may be exposed more than four times a year, on average.

This is in contrast to the utility situation, in which 68,000 exposures are estimated to affect approximately 44,000 asthmatic persons. However, the utility analysis did not take into account the potential concentrating effects of terrain for the estimated 25 percent or more of power plants estimated to be located in complex terrain, which might be expected to increase the chance that a proportion of asthmatic individuals living in

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[6] The utility analysis in Table B-1 of Appendix B does generate estimates of the number of asthmatics exposed as a percentage of the number living in the vicinity of power plants, but the non-utility analysis acknowledges that it cannot discriminate amongst individuals living in proximity of more than one source. For example, an asthmatic individual is counted twice if living in vicinity of two sources. Thus, double counting and an overestimate of the asthmatic population with the potential to be exposed would be expected to occur.

the vicinity of those plants would be exposed multiple times per year.

The utility sector accounts for about 17-37 percent of the total exposures. If the full load emissions allowable under their permits were assumed rather than actual emissions, the total exposure events from utilities increases approximately 75 percent. Under full implementation of the restrictions being put into place under the Title IV program to address acid deposition, by the year 2015, exposures to emissions from utility boilers are estimated to drop to about 58 percent of current levels, contingent on trading decisions. An analysis of estimated exposure events at 0.75 ppm SO_2 after the Title IV program shows that exposures for utility sources at this higher concentration are less than one-fourth of those at 0.5 ppm.

Among the nonutility sources, industrial boilers are the source category most responsible for potential exposures, accounting for approximately half the total exposure events from this sector. Other categories that may result in a substantial number of exposures include petroleum refineries, pulp and paper mills, sulfuric acid plants, and aluminum smelters (not included in the analysis were lead smelters, steel mills, cement plants, and other potential sources of exposures). Among certain source categories, such as aluminum smelters, copper smelters and sulfite mills, estimates indicate that from 1.5 to 3 percent to as much as 10 to 30 percent of the asthmatic individuals living in the vicinity may be exposed at least once per year, depending on assumptions made in the air quality modeling (Appendix B, Table B-2 and Notes).

When individual source categories could be examined more extensively, the risk of exposures was very unevenly distributed across the sources in the category. For instance, approximately 75 percent of the utility sector's post Title IV exposures were estimated to result from less than 10 percent of the power plants (Burton et al., 1987; Rosenbaum, 1992, Table 3). Similarly, approximately half of the total industrial boiler exposures can be attributed to a small proportion (1.5 percent) of the total population of industrial boilers analyzed (Stoekenius et al., 1990, Table 2-14).

For other source categories, the same "clustering of risk" phenomenon may also be evident: for instance, sulfite paper mills account for twice as many estimated exposures as kraft mills, but represent only a sixth of the total paper mills. Information on a source's mode of operation, control equipment, and types of raw materials or fuel used may help in developing focused, efficient implementation efforts.

E. Conclusions

The available air quality and exposure data provides a strong indication that the likelihood that asthmatic individuals will be exposed to 5- to 10-minute peak SO_2 concentrations is quite low when viewed from a national perspective. The data also indicate, however, that high peak SO_2 concentrations can occur around certain sources or source types with some frequency. This suggests that asthmatic individuals that reside in the vicinity of such sources or source types may be at greater risk than that indicated for the asthmatic population as a whole. Because of this, the staff recommends that the Administrator consider targeted strategies when assessing approaches for reducing potential peak SO_2 exposures.

IV. STAFF CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment and interpretation of the health effects information presented in the criteria document supplement and summarized above, the staff concludes:

1) About 10 million people, or 4 percent of the population of the United States, are estimated to have asthma. The prevalence is higher among African-Americans, older children (8 to 11 years old), and urban residents. Common symptoms include cough, wheezing, shortness of breath, chest tightness, and sputum production. Asthma is characterized by an exaggerated bronchoconstrictor response to many physical challenges (e.g., cold or dry air, exercise, specific stimuli such as pollen) and chemical and pharmacological agents. Daily variability in lung function measurements is also a typical feature of asthma. Asthma attacks can result in hospitalization or emergency room treatment. Death due to asthma is, however, a rare event. Many asthmatic individuals take medication to relieve symptoms and functional responses associated with exacerbation of this disease. One of the most commonly used asthma medications (beta-agonist) also inhibits or ameliorates responses to SO_2. Available data suggest, however, generally low medication use and compliance rates for many mild and moderate asthmatic individuals.

2) Mild and moderate asthmatic children, adolescents and adults represent the population groups most at risk for short-term peak SO_2 induced effects. More severe asthmatic individuals have very poor exercise tolerance and therefore are less likely to engage in sufficiently intense exercise to permit notable SO_2-induced effects to occur.

3) A substantial percentage (≥20 to 25 percent) of mild to moderate asthmatic individuals exposed for 5 to 10 minutes to 0.6 to 1.0 ppm SO_2 during moderate exercise would be expected to have respiratory function changes and severity of respiratory symptoms that clearly exceed those experienced from typical daily variation in lung function or in response to other stimuli (e.g., moderate exercise or cold/dry air).

4) After the initial 5 minutes of exposure to 0.6-1.0 ppm SO_2 the severity of effects for many of the responders is likely to be sufficient to be of concern, i.e., to cause disruption of ongoing activities, use of bronchodilator medication, and/or possible seeking of medical attention. At SO_2 concentrations in this range the intensity of distress is much more likely to be perceived as an "asthma attack" than would be the case at exposures below 0.5 ppm SO_2.

5) The effects observed after exposure to 0.6 to 1.0 ppm SO_2 are relatively transient (not lasting more than a

few hours) and are not likely to worsen or to reoccur with the same magnitude of response if re-exposure to another SO_2 peak occurred within the next several hours after the initial exposure, should they choose to resume physical exertion after amelioration or cessation of any initial SO_2-induced distress.

6) At SO_2 concentrations at or below 0.5 ppm, only a relatively small percentage (≤10 to 20 percent) of mild and moderate asthmatic individuals exposed to 0.2 to 0.5 ppm SO_2 during moderate exercise are likely to experience lung function changes distinctly larger than those they typically experience. Furthermore, compared to the response at 0.6 to 1.0 ppm SO_2, the response at or below 0.5 ppm SO_2 is less likely to be perceptible and of immediate health concern.

In assessing the public health significance of the effects reported at 0.6 ppm SO_2 or above, the Administrator should also consider the following factors: 1) the effects reported for mild or moderate asthmatic individuals are likely to be more pronounced if that individual is at higher than moderate ventilation; 2) the degree of concern or perceived significance of the response would likely increase with increased frequency of exposure over the course of the year; 3) while prophylactic bronchodilator medication use prior to exercise might protect against SO_2-induced effects, the relatively low medication compliance rates indicate that many mild and moderate asthmatic individuals may be unprotected, of particular concern are those individuals of lower socioeconomic status with limited access to health care; 4) the available epidemiological data do not provide a basis for concluding that SO_2 contributes to excess asthma mortality rates observed among non-white population groups in large urban areas; and 5) the available air quality and exposure data provides a strong indication that the likelihood that asthmatic individuals will be exposed to 5- to 10-minute peak SO_2 level is quite low when viewed from a national perspective. Yet, the data also indicate that peak SO_2 concentrations do occur and suggest that asthmatic individuals that reside in the vicinity of certain sources or source types will be at increased risk.

Based on its assessment of the available health, air quality and exposure data, the staff recommends that the Administrator consider three possible regulatory alternatives:

1) Establish a new 5-minute NAAQS in the range of 0.6 to 1.0 ppm SO_2 expressed as the maximum 5-minute block average in 1 hour. In view of the nature of the response and the low probability that a given asthmatic individual will be exposed while at elevated ventilation, consideration should also be given to permitting multiple exceedances (e.g., up to 5) during a year. If the Administrator determines that a new 5-minute NAAQS is needed, the staff also recommends that it be implemented through a risk-based, targeted

approach focusing on those sources that are most likely to produce repeated high 5-minute peaks during the course of a year.

2) Establish a new regulatory program under the general authority of section 303 of the Clean Air Act. Such a new program should establish a target level for control in the range of 0.6 to 1.0 ppm SO_2 expressed as the maximum 5-minute block average in 1 hour. In establishing the target level, the staff recommends that multiple exceedances (e.g., up to 5) be permitted during a year and that the program be implemented through a risk-based, targeted strategy. This approach would be designed to supplement the existing NAAQS by placing, in effect, a cap on short-term peak SO_2 ambient levels, the exceedance of which would result in enforceable action against the source(s) causing or contributing to the exceedance. Thus, the program would provide additional protection for asthmatic individuals, without many of the burdens that implementation of a new 5-minute NAAQS would impose upon the states.

3) Retain the existing suite of standards but augment their implementation by focusing on those sources that are likely to produce high 5-minute peak SO_2 levels. This approach would be aimed at assuring that the existing standards are met through more targeted

monitoring and adherence to existing regulatory provisions governing good operating practice and upset and malfunctions, thereby providing some additional protection against short-term peaks.

In selecting among these alternatives, the staff recommends that the Administrator consider the nature and significance of the health effects associated with short-term peak SO_2 levels and the size of the mild and moderate asthmatic population potentially at risk. Given the available scientific and analytical data, the staff recognize that the ultimate decision of the Administrator will be based in part on policy/legal considerations.

APPENDIX A

SAB-CASAC-87-022

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

February 19, 1987

OFFICE OF
THE ADMINISTRATOR

The Honorable Lee M. Thomas
Administrator
U.S. Environmental Protection Agency
Washington, DC 20460

Dear Mr. Thomas:

The Clean Air Scientific Advisory Committee (CASAC) has completed its review of the 1986 Addendum to the 1982 Staff Paper on Sulfur Oxides (Review of the National Ambient Air Quality Standards for Sulfur Oxides: Updated Assessment of Scientific and Technical Information) prepared by the Agency's Office of Air Quality Planning and Standards (OAQPS).

The Committee unanimously concludes that this document is consistent in all significant respects with the scientific evidence presented and interpreted in the combined Air Quality Criteria Document for Particulate Matter/Sulfur Oxides (1982) and its 1986 Addendum, on which CASAC issued its closure letter on December 15, 1986. The Committee believes that the 1986 Addendum to the 1982 Staff Paper on Sulfur Oxides provides you with the kind and amount of technical guidance that will be needed to make appropriate decisions with respect to the standards. The Committee's major findings and conclusions concerning the various scientific issues and studies discussed in the Staff Paper Addendum are contained in the attached report.

Thank you for the opportunity to present the Committee's views on this important public health and welfare issue.

Sincerely,

Morton Lippmann, Ph.D.
Chairman
Clean Air Scientific Advisory Committee

cc: A. James Barnes
Gerald Emison
Lester Grant
Vaun Newill
John O'Connor
Craig Potter
Terry Yosie

SAB-CASAC-87-ι

SUMMARY OF MAJOR SCIENTIFIC ISSUES AND CASAC CONCLUSIONS ON THE 1986 DRAFT ADDENDUM TO THE 1982 SULFUR OXIDES STAFF PAPER

The Committee found the technical discussions contained in the Staff Paper Addendum to be scientifically thorough and acceptable, subject to minor editorial revisions. This document is consistent in all significant respects with the scientific evidence presented in the 1982 combined Air Quality Criteria Document for Particulate Matter/Sulfur Oxides and its 1986 Addendum, on which the Committee issued its closure letter on December 15, 1986.

Scientific Basis for Primary Standards

The Committee addressed the scientific basis for a 1-hour, 24-hour, and annual primary standards at some length in its August 26, 1983 closure letter on the 1982 Sulfur Oxides Staff Paper. That letter was based on the scientific literature which had been published up to 1982. The present review has examined the more recently published studies.

It is clear that no single study of SO_2 can fully address the range of public health issues that arise during the standard setting process. The Agency has completed a thorough analysis of the strengths and weaknesses of various studies and has derived its recommended ranges of interest by evaluating the weight of the evidence. The Committee endorses this approach.

The Committee wishes to comment on several major issues concerning the scientific data that are available. These issues include:

- Recent studies more clearly implicate particulate matter than SO_2 as a longer-term public health concern at low exposure levels.

- A majority of Committee members believe that the effects reported in the clinical studies of asthmatics represent effects of significant public health concern.

- The exposure uncertainties associated with a 1-hour standard are quite large. The relationship between the frequency of short-term peak exposures and various scenarios of asthmatic responses is not well understood. Both EPA and the electric power industry are conducting further analyses of a series of exposure assessment issues. Such analyses have the potential to increase the collective understanding of the relationship between SO_2 exposures and responses observed in subgroups of the general population.

- The number of asthmatics vulnerable to peak exposures near electric power plants, given the protection afforded by the current standards, represents a small number of people. Although the Clean Air Act requires that sensitive population groups receive protection, the size of such groups has not been defined. CASAC believes that this issue represents a legal/policy matter and has no specific scientific advice to provide on it.

CASAC's advice on primary standards for three averaging times is presented below:

1-Hour Standard - It is our conclusion that a large, consistent data base exists to document the bronchoconstrictive response in mild to moderate asthmatics subjected in clinical chambers to short-term, low levels of sulfur dioxide while exercising. There is, however, no scientific basis at present to support or dispute the hypothesis that individuals participating in the SO_2 clinical studies are surrogates for more sensitive asthmatics. Estimates of the size of the asthmatic population that experience exposures to short-term peaks of SO_2 (0.2 - 0.5 parts per million (ppm) SO_2 for 5-10 minutes) during light to moderate exercise, and that can be expected to exhibit a bronchoconstrictive response, varies from 5,000 to 50,000.

The majority of the Committee believes that the scientific evidence supporting the establishment of a new 1-hour standard is stronger than it was in 1983. As a result, and in view of the significance of the effects reported in these clinical studies, there is strong, but not unanimous support for the recommendation that the Administrator consider establishing a new 1-hour standard for SO_2 exposures. The Committee agrees that the range suggested by EPA staff (0.2 - 0.5 ppm) is appropriate, with several members of the Committee suggesting a standard from the middle of this range. The Committee concludes that there is not a scientifically demonstrated need for a wide margin of safety for a 1-hour standard.

24-Hour Standard - The more recent studies presented and analyzed in the 1986 Staff Paper Addendum, in particular, the episodic lung function studies in children (Dockery et al., and Dassen et al.) serve to strengthen our previous conclusion that the rationale for reaffirming the 24-hour standard is appropriate.

Annual Standard - The Committee reaffirms its conclusion, voiced in its 1983 closure letter, that there is no quantitative basis for retaining the current annual standard. However, a decision to abolish the annual standard must be considered in the light of the total protection that is to be offered by the suite of standards that will be established.

The above recommendations reflect the consensus position of CASAC. Not all CASAC reviewers agree with each position adopted because of the uncertainties associated with the existing scientific data. However, a strong majority supports each of the specific recommendations presented above, and the entire Committee agrees that this letter represents the consensus position.

Secondary Standards

The 3-hour secondary standard was not addressed at this review.

A-84-2:
V-D-36

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

June 1, 1994

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

EPA-SAB-CASAC-LTR-94-007

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M St., S.W.
Washington, D.C. 20460

Subject: Clean Air Scientific Advisory Committee Closure on the Supplements to Criteria Document and Staff Position Papers for SO_2

Dear Ms. Browner:

The Clean Air Scientific Advisory Committee (CASAC) at a meeting on April 12, 1994, completed its review of the documents: Supplement to the Second Addendum (1986) to Air Quality Criteria for Particulate Matter and Sulfur Oxides; Assessment of New Findings on Sulfur Dioxide and Acute Exposure Health Effects in Asthmatics; and Review of the National Ambient Air Quality Standards for Sulfur Oxides: Updated Assessment of Scientific and Technical Information, Supplement to the 1986 OAQPS Staff Paper Addendum. The Committee notes, with satisfaction, the improvements made in the scientific quality and completeness of the documents.

With the changes recommended at our March 12 session, written comments submitted to the Agency subsequent to the meeting, and the major points provided below, the documents are consistent with the scientific evidence available for sulfur dioxide. They have been organized in a logical fashion and should provide an adequate basis for a regulatory decision. Nevertheless, there are four major points which should be called to your attention while reviewing these materials:

1. A wide spectrum of views exists among the asthma specialists regarding the clinical and public health significance of the effects of 5 to 10 minute concentrations of sulfur dioxide on asthmatics engaged in exercise. On one end of the spectrum is the view that spirometric test responses can be observed following such short-term exposures and they are a surrogate for significant health effects. Also, there is some concern that the effects are underestimated because moderate asthmatics, not severe asthmatics, were used in the clinical tests.

At the other end of the spectrum, the significance of the spirometric test results are questioned because the response is similar to that evoked by other commonly encountered, non-specific stimuli such as exercise alone, cold, dry air inhalation, vigorous coughing, psychological stress, or even fatigue. Typically, the bronchoconstriction reverses itself within one or two hours, is not accompanied by a late-phase response (often more severe and potentially dangerous than the immediate response), and shows no evidence of cumulative or long-term effects. Instead, it is characterized by a short-term period of bronchoconstriction, and can be prevented or ameliorated by beta-agonist aerosol inhalation.

2. It was the consensus of CASAC that the exposure scenario of concern is a rare event. The sensitive population in this case is an unmedicated asthmatic engaged in moderate exercise who happens to be near one of the several hundred sulfur dioxide sources that have the potential to produce high ground-level sulfur dioxide concentrations over a small geographical area under rare adverse meteorological conditions. In addition, CASAC pointed out that sulfur dioxide emissions have been significantly reduced since EPA conducted its exposure analysis and emissions will be further reduced as the 1990 Clean Air Act Amendments are implemented. Consequently, such exposures will become even rarer in the future.

3. It was the consensus of CASAC that any regulatory strategy to ameliorate such exposures be risk-based - targeted on the most likely

sources of short-term sulfur dioxide spikes rather than imposing short-term standards on all sources. All of the nine CASAC Panel members recommended that Option 1, the establishment of a new 5-minutes standard, not be adopted. Reasons cited for this recommendation included: the clinical experiences of many ozone experts which suggest that the effects are short-term, readily reversible, and typical of response seen with other stimuli. Further, the committee viewed such exposures as rare events which will even become rarer as sulfur dioxide emissions are further reduced as the 1990 amendments are implemented. In addition, the committee pointed out that enforcement of a short-term NAAQS would require substantial technical resources. Furthermore, the committee did not think that such a standard would be enforceable (see below).

4. CASAC questioned the enforceability of a 5-minute NAAQS or "target level." Although the Agency has not proposed an air monitoring strategy, to ensure that such a standard or "target level" would not be exceeded, we infer that potential sources would have to be surrounded by concentric circles of monitors. The operation and maintenance of such monitoring networks would be extremely resource intensive. Furthermore, current instrumentation used to routinely monitor sulfur dioxide does not respond quickly enough to accurately characterize 5-minute spikes.

The Committee appreciates the opportunity to participate in this review and looks forward to receiving notice of your decision on the standard. Please do not hesitate to contact me if CASAC can be of further assistance on this matter.

Sincerely,

George T. Wolff

George T. Wolff, Ph.D.
Chair, Clean Air Scientific
Advisory Committee

APPENDIX B

A. Additional Information About the Exposure Analyses

Tables B-1 and B-2, placed at the end of this appendix, provide a more full description of the results of the utility analysis (Rosenbaum et al., 1992) and non-utility analysis (Stoeckenius et al., 1990). Footnotes to Table B-2 give more details about some of the assumptions used to generate certain calculations presented in the main text.

B. Important Uncertainties Involved in the Exposure Analysis

Any nationwide exposure analysis must contain numerous assumptions and simplifications. These can result in either overstating or understating the estimates of exposures. A brief summary of major sources of uncertainty is presented in Table 3-4 and discussed below. The major sources of uncertainty are estimates of activity patterns, emission and dispersion modeling, and the use of peak-to-mean ratios to estimate 5-minute peak SO_2 concentrations. For a more complete treatment, see EPA (1986c,d), Burton et al. (1987), Stoeckenius et al. (1990), Burton and Stoeckenius (1988), and Rosenbaum et al. (1992).

1. Activity Pattern Uncertainties

The activity pattern data used in these analyses has undergone numerous revisions. The current analyses reflect the best information available at the time regarding the number of individuals estimated to be at high ventilation (Rosenbaum et al., 1992; Stoeckenius et al., 1990). However, more recent work has shown that some individuals at moderate activity may ventilate at > 35 L/minute, while others may not ventilate at that level, on average, even during "high" activity (Linn, 1991).

In addition, minute-by-minute ventilation estimates are now available. The Human Exposure Model used for these analyses assumed that an individual with asthma was at sufficient elevated ventilation for the hour if she had at least 10 minutes of high activity. This would lead to overestimates in hours where the 5-minute peak did not coincide with the elevated ventilation. However, some underestimation might occur during hours in which individuals might briefly be at elevated ventilation ($\leq$ 10 minutes) and experience a high ambient SO_2 peak.

The activity data used in the exposure analyses is not specific for individuals with asthma, which could affect the exposure estimates. The general population activity data used relied on a diary study of greater than 900 Cincinnati residents, who were followed over 3-day intervals in cool or warm seasons (see Johnson et al., 1993 for more information). The data as used in Stoeckenius et al. (1990) and Rosenbaum (1992) indicate that the general population spends 1.7% of waking hours at strenuous exercise, with peak hourly activity rates of approximately 3.5% (Stoeckenius et al., 1990, Fig. 2-2, exact numbers provided by Stoeckenius, personal communication).

In contrast, a study of a population-based sample of 136 Cincinnati residents with asthma followed over a 3-day period reported the prevalence of outdoor exercise was greater than for the general population: 3.3% of waking hours at strenuous exercise, with peak hourly activity rates of 7-9%, depending on day of week (Roth Associates, 1992, p.3-7, 3-12). In a smaller, 3-day study of 52 asthmatic residents of Los Angeles involved in the clinical studies conducted by the Linn group, survey participants spent 2.4% of their waking hours, on average, exercising outdoors (Roth Associates, 1988).

Finally, a more recent 7-day survey of 49 asthmatic residents of Los Angeles who had been clinical subjects for the Linn group, found that a group of individuals with primarily moderate to severe disease spent only 0.2% of their total waking time exercising outdoors at a fast breathing rate [or possibly 0.2% of hours, but it is unclear how much activity was needed to classify an hour at high activity (Linn, 1991, p. 22, 37, and Figure 4-1)].

One reason that the general population activity estimates are lower than some of the activity estimates for the asthmatic population might be because mild asthmatic individuals are encouraged to exercise as part of their therapy. This factor may not have been reflected in the Los Angeles surveys, because the sample groups for both these studies probably overrepresented the proportion of moderate to severe asthmatic individuals relative to that asthmatic population as a whole. For the 1991 study, in which high activity rates were extremely low, individuals with moderate to severe disease comprised approximately 70% of that group, in roughly equal proportions. Approximately 50% of the

1988 group was composed of individuals with moderate to severe asthma (Roth Associates, 1988, p.1-2).

The 1991 study (Linn, 1991) seems to suggest that a group composed of more severe asthmatics is generally less active outdoors, but when the results for this small group were examined according to the author's classification of asthmatic subjects, mild asthmatic subjects appeared to be no more active than severe asthmatic subjects (p. 37). Another reason why these results may be so low may be time scale differences: the 1991 study reported time at "fast" activity as a proportion of total waking time, while the other studies reported "high activity" as proportion of waking hours, with an hour being scored at high activity as long as subject was at elevated ventilation for at least 10 minutes in the hour.

In the past it has been assumed that individuals with asthma may be less active, on average, than the general population (EPA 1986d), but the existing data do not provide a basis for that assumption.

2. Dispersion Modeling Uncertainties

Uncertainties involving dispersion modeling could influence the results of both the utility and non-utility analyses, although the precise extent to which these uncertainties affect the analyses is difficult to estimate. The models used in these analyses to estimate ambient SO_2 concentrations were originally designed to predict design value concentrations for 3-hour, 24-hour, or annual averaging times. However, in these analyses the models are used to provide estimates, specific to time and location, of the ambient concentration of SO_2 for each hour in a year. The accuracy of these models when used for this purpose is not fully established, although an evaluation by Moore et al. (1988) reported that the dispersion model used in the utility analysis tended to over-predict slightly the average of the highest hourly concentrations (e.g., 25 highest) relative to those observed, when observations and predictions are allowed to be unpaired in time and location.

In addition, tests of Gaussian dispersion models indicate that stability classes (derived by averaging meteorological data over a year or more) often fail to capture much of the variability in meteorological parameters. For unstable weather classes this may result in differences of up to 40 percent in predictions of maximum concentration when compared to measurements (Irwin, 1987). Whether such meteorological variability would have much effect on predictions of exposures is unclear, given the findings of Moore et al. (1988) and the fact the exposure analyses did not rely solely upon stability classes, but also used actual meteorological parameters (from historical data) in estimating dispersion.

However, an important point to keep in mind when considering the impact of air quality emission and dispersion uncertainties is that the exposure estimates from the earliest EPA exposure analysis indicated that exposures (around utilities) were apparently the result of comparatively few ambient peaks of SO_2

[on the order of 10-20 expected exceedances for any given ring (EPA, 1986, Figure 3-3 and 3-4)]. If estimated exposures in the subsequent analyses also result from relatively few ambient peaks (data comparable to these reports are not currently available), then estimating the impacts of uncertainties on the exposure estimates will be more difficult. It is conceivable that small changes in the treatment of meteorological uncertainties, or other uncertainties (such as the peak-to-mean and emission modeling uncertainties discussed below) could lead to relatively large changes in exposure estimates.

Additional meteorological uncertainty is introduced when dispersion analysis is performed on a prototype source (utility analysis), or meteorological records from one particular area are applied nationwide (non-utility analysis). The utility analysis used meteorological data specific to the prototypical plant's location to model dispersion for all the sources in each of its 24 bins (a bin is a subset of sources modeled as resembling a prototype source). Such steps are necessary to reduce the computational complexity, but simplify meteorology by applying meteorological data from one source to the modeling of many sources.

Due to the large number of sources, in the non-utility analysis meteorological data from only one particular region was used to model all sources from a source category. However, efforts were made to diminish this uncertainty by choosing conditions applicable to the region expected to account for the largest proportion of exposures (e.g., meteorological data from the Pacific Northwest was used to model pulp and paper mills). These simplified treatments of meteorology could result in either over- or under-estimates of exposures in other regions of the country.

3. Peak-to-Mean Ratio Uncertainties

Another potential source of uncertainty is introduced through the use of peak-to-mean ratios. For present purposes, the peak-to-mean ratio is the ratio of the maximum 5-minute concentration for an hour divided by the hourly average (a peak-to-mean ratio of 2 indicates for that hour the maximum 5-minute concentration was twice the concentration of the hourly average). Peak-to-mean ratios for these analyses were chosen using a Monte Carlo simulation based on a frequency distribution derived from a collection of observed peak-to-mean ratios.

Both analyses rely heavily (non-utility analysis) or exclusively (utility analysis) on a distribution of peak-to-mean ratios derived from 18 months of monitoring around the Kincaid power plant, a tall, isolated coal-fired plant in Illinois. This distribution has an average ratio of 2.2, and, although 88 percent of the values are peak-to-mean ratios of 3.5 or less (Stoeckenius, 1990, Table 2-18), it does contain peak-to-mean ratios up to 11 to 1. The Kincaid power plant is in the 80th percentile of stack height (Burton and Stoeckenius, 1988). Thus, on theoretical grounds, use of this ratio would be expected to be conservative for the majority of the power plants in the nation.

However, using a single peak-to-mean ratio distribution introduces several uncertainties of undetermined magnitude. The data from one source is essentially generalized to all sources. The 18 months of data used to generate the ratio contained apparently only three observations of a 5-minute concentration above 0.5 ppm (Thrall et al., 1982, Figure 6), and the maximum concentration observed equaled 0.56 ppm; both of these factors might affect the applicability of the ratio to sources with more numerous high 5-minute peaks. However, the Kincaid analysis (Thrall et al., 1982, p. 27) noted a small but statistically significant tendency for peak-to-mean ratios to decrease with increasing hourly concentration. Thus, sources producing higher ambient concentrations might have lower peak-to-mean ratios; sufficient data is not currently available to test this hypothesis.

Peak-to-mean ratios are also highly sensitive to weather conditions. Thus, using a single peak-to-mean ratio from one location means that the assumption is made that the meteorological conditions of that area apply to all areas. Furthermore, choosing the peak-to-mean ratio from a distribution of ratios from all hours, rather than hours segregated by stability classes or other meteorological parameters, essentially uncouples the choice of the peak-to-mean ratio from the weather conditions for the hour used in the dispersion modeling.

It is difficult to determine what bias, if any, this would bring to the analysis. Unfortunately, the Kincaid data was not analyzed in relation to meteorological conditions. Certain weather conditions would be expected to result in high hourly concentrations and low peak-to-mean ratios, while others result in low hourly concentrations and high peak-to-mean ratios. Use of a distribution from all hours could therefore overstate exposures in some cases. However, if some sources have many hours with moderate hourly concentrations, and if typically moderate to high peak-to-mean ratios were observed, exposures for these sources could be underestimated.

Other expected uncertainties resulting from use of a single peak-to-mean distribution (e.g., whether monitor placement and instrument response time understated peak-to-mean ratios) are discussed in Burton and Stoeckenius (1988).

The same uncertainties listed above apply to the application of the Kincaid distribution to non-utility sources. However in these cases, which typically involve much lower emission release heights, use of the distribution is much more likely to overstate the probability of high exposures. The higher peak-to-mean ratios reported in Section III of this paper can probably be explained by two factors. First, the ratios reported in Section III do not examine all hours, but rather only those hours with high (> 0.75 ppm) 5-minute peaks. Second, the sources examined in Section III probably experienced substantial increases in their emissions within the hour, which contributed to the high observed peak-to-mean ratio. This second factor was partially taken into account for many sources in the non-utility analysis by assuming constant operation at maximum design rate.

The estimates for non-utility sources resulting from use of the Kincaid distribution were viewed as representing an upper-bound on possible exposures. A different peak-to-mean distribution with fewer extreme values (Stoeckenius et al., 1990, Table 2-18) was used to generate lower-bound estimates.

The uncertainties surrounding the use of dispersion modeling and peak-to-mean ratios in these analyses add considerable uncertainty to the final estimates. However, refining the methodology of these areas (for example, by using 5- to 10-minute rather than hourly meteorology data) would involve intensive remodeling and other efforts.

4. <u>Emission modeling Uncertainties</u>

It should be noted that the recent utility exposure analysis (Rosenbaum et al., 1992) and elements of the non-utility analysis (Stoeckenius et al., 1990) (refineries and some other sources, see below) estimated actual exposures, rather than potential exposures that could result if the source operates at its higher permitted emission limit. Potential emissions were evaluated in the previous EPA analysis (EPA, 1986). Thus, exposures could increase for many of the sources analyzed if they decided to increase emissions to the permitted limit (as was shown by the full-load figures for utilitites given in Section III.D.2). However, the objective of these analyses was to attempt to estimate the magnitude of current exposures to SO_2, not to predict the number of possible exposures.

Probably the largest single source of uncertainty in these analyses is in the emissions estimates used for the non-utility sources. For most non-utility sources, constant operation at the maximum hourly design rate was assumed, which almost certainly overstates actual emissions and exposures (and likely even overstates potential emissions as well). For batch processes of great variability, however (e.g., sulfite pulp and paper mills, copper smelters), it is conceivable that peak emissions within an hour may exceed the hourly design rates. These brief episodes may be very important in terms of actual exposures, but additional analysis would be required to determine whether the frequency and magnitude of such episodes for these sources would result in a greater number of exposures than the assumption of constant operation at the hourly design rate.

For other sources (refineries and additional sources with incomplete emissions information), annual emissions data was used. This would be expected to understate emissions and exposures, since these sources would undoubtedly emit at rates above their annual emissions rate for a substantial number of hours in the year, and probably these would be the hours contributing most to exposures.

In contrast, the emission estimates for utilities, which consisted of a Monte Carlo simulation using distribution of power plant loads specific to season and time of day would be expected to produce estimates of actual exposures with much less uncertainty. Some minor uncertainties about how fuel use and consumption are handled with this approach are discussed in EPA (1986d).

5. Other Uncertainties

Another important uncertainty affecting these results is the current inability of the models used to address the effects of complex terrain (which may affect the estimates for the more than 25 percent of U.S. power plants located in complex terrain, and to a lesser extent the estimates for non-utility sources located in complex terrain). In addition, the analyses did not attempt to consider the effects of overlapping sources, occurrence of multiple peaks in an hour, or some source types that might contribute some additional exposures (lead smelters, coke ovens, and possibly some small, < 25 MW, power plants). Each of these factors might increase exposure estimates by small amounts.

Some understating of exposures might have also occurred in the procedure used to estimate the affected area around different sources. Exposures may occur beyond the 20 km, the furthest distance typically modeled in the utility analysis (EPA, 1986d, p. 2-15), and within the distance (i.e., three building heights) that could not be modelled in non-utility analysis (Stoeckenius et al., 1990).

C. Conclusions

Some of the uncertainties discussed above might be relatively easy to address, while others might require intensive remodelling or data that is not readily available. Some assumptions or simplifications would have to be retained if the development of nationwide exposure estimates is to be a manageable task. These uncertainties make it difficult to arrive at precise estimates of the number of asthmatic individuals exposed to SO_2, and so the estimates of the total number of annual exposures to high peaks of SO_2 should be viewed with caution.

Nevertheless, despite the limitations, the recent exposure analyses have provided better insight into the potential magnitude of exposure to concentrated ambient peaks of SO_2 and the sources most likely responsible for such peaks than was previously available. The basic findings of these analyses (i.e., that exposures to high concentrations of SO_2 are restricted to the vicinity of certain SO_2 sources and that these exposures do not affect a large proportion of the nationwide asthmatic population in any given year, although a greater proportion of asthmatic individuals living close to certain sources may be exposed) would probably not change even if exposure estimates were to increase several-fold. Furthermore, improved treatment of some of these uncertainties, such as those resulting from the assumption of constant operation at maximum design rates used for many non-utility sources, could substantially decrease estimates of actual exposures, although not necessarily potential exposures.

Refinements of these analyses or additional ambient monitoring data could possibly indicate the need to reevaluate the relative importance of one source category versus another in accounting for high 5-minute peak ambient exposures. However, it is not expected that these refinements would alter the basic thrust of the assessment that exposures to high 5-minute peaks of SO_2 are likely to be experienced almost exclusively by asthmatics who are in the vicinity of a subset of SO_2 sources.

D. <u>Notes on Calculations Performed for the Text (Section III.D.2)</u>

All figures given in the text were obtained from Tables B-1 and B-2, with the exception of the number of asthmatic individuals exposed 1 or more times. For the utility study, this number was calculated from the number of asthmatic individuals exposed listed in Table B-2, which does not contain an approximately 5% correction described in Rosenbaum et al. (1992, p. 2). When this correction is applied to the Number of Asthmatics Exposed 1X or more times, 46, 000 (the actual load figures) becomes approximately 43,700. This number, when divided by the total asthmatic population listed as in the vicinity of utilities (3,896,000), yields 1.12% of the asthmatic population in the vicinity being exposed 1 or more times, which is precisely the figure given in Table B-1, which is taken from Rosenbaum et al. (1992).

For the non-utility analysis, to obtain the percentage of the asthmatic population exposed 1 or more times, the range of numbers in the column listed "Expected No. Asthmatics Exposed At Least Once Per Year" in Table B-2 is divided by the asthmatic population column. For example, the 2,000 - 22,000 estimated exposures for sulfite paper mills divided by the asthmatic population of 74,000, leads to estimates of 2.7 to 29.7 percent of the asthmatic population being exposed 1 or more times.

For the calculations concerning the concentration of risk within different "bins" of the utility analysis, bin Base 3A can be seen to account for roughly 75% of the total utility exposures, depending on tha scenario chosen (Table 3 of Rosenbaum et al., 1992). Table 3-3 of Burton et al., 1987 shows that this bin accounts for 64 out of the 1034 (726 + 308) total utility point sources considered.

For the non-utility analysis of industrial boilers, Table 2-14 of Stoeckenius et al. (1990) indicates that 3 bins, E-7, E-10, and E-12 (Table 2-14), contribute more than half of the total exposures from the industrial boilers that were analyzed.

Table B-1. Summary of Estimates of Expected Number of Exposures of Exercising Asthmatics to Elevated 5-minute Average SO_2 Concentrations for Utilities

	SO_2 CONCENTRATION THRESHOLD	
EMISSION RATE ESTIMATES	0.5 ppm	0.75 ppm
1987[1]	68,335 (1.12)*	Not analyzed
Title IV[2]	39,587 (0.65)*	8,970 (0.15)*
Lowest of: Title IV compliance with current stds., compliance with 5-min 5xx std. of 0.75 ppm	24,745 (0.41)*	3,903 (0.06)*
Lowest of: Title IV compliance with current stds., compliance with 5-min 1xx std. of 0.75 ppm	19,006 (0.31)*	2,571 (0.04)*

* Percentage of asthmatics in vicinity exposed 1 or more times.

[1]Burton et al. (1987); updated in Rosenbaum et al. (1992).
[2]Based on acid rain Regulatory Impact Analysis.

(Derived from Rosenbaum et al., 1992)

TABLE B-2. Non-Utility Source SO_2 Exposure Analysis Results

Source Category	Number of Sources	Total Emissions (10^3 tons/yr)	Total Population (thousands)	Asthmatic Population (thousands)[2]	Expected Exposure Events/Yr	Expected Exposures Per 100 Asthmatics	Expected No. Asthmatics Exposed at Least Once Per Year[5]
Industrial Boilers[1]	3,108	1,725	48,702[6]	2,028[6]	56,000[3]-201,000[4]	2.8-9.9	12,000-42,000
Petroleum Refineries	187	639	35,208	1,457	27,000[7]	1.8	6,000-17,000
Pulp/Paper Mills:							
Sulfite	23	60	2,230	74	10,000[8]-35,000[4]	13-47	2,000-22,000
Kraft	118	402	9,110	340	5,000[8]-18,000[4]	1.5-5.3	1,000-12,000
Copper Smelters	5	319	469	18	2,000-[15] 5,000[9]	11.1-28	400-3,000
Sulfuric Acid Plants[13]	74	152	27,418	990	6,000[15] -18,000[9]	0.61-1.8	1,000-12,000
Aluminum Smelters	21	96	3,042	127	8,000-[15] 22,000[9]	6.3-17	2,000-14,000
Utility Boilers[10]	2,700	16,524	98,793	3,896	72,000[11]-125,000[12]	1.9-3.2	46,000-80,000
TOTAL	6,236	19,917	224,976	8,930	186,000-451,000	2.0[14]-5.0[14]	70,400-202,000

Footnotes reprinted in Appendix B.
Exposure estimates for utility boilers do not reflect the 5 percent downward adjustment reported in Rosenbaum et al. (1992).

(Source: Stoeckenius et al., 1990)

Footnotes to Table B-2

1. Includes coal and oil fired industrial, commercial and institutional boilers.

2. Estimated from regional and metropolitan area asthmatic prevalence rates as reported in the 1983 National Health Interview Survey (NHIS, 1985).

3. Lower bound derived by assuming building downwash effects are negligible and that peak-to-mean concentration ratios are similar to those observed at the Scottish Rites monitor near downtown Billings, MT (site in urban area not directly influenced by any single major source). This value is based on extrapolation of sensitivity analysis results for one dispersion prototype (Bin E) to all other prototypes.

4. Based on stack height/building height = 1.5 assumption and use of peak-to-mean ratios characteristic of tall, isolated point sources as observed by Thrall et al. (1982).

5. Derived from expected exposure event results by assuming that ratio of number of individuals exposed one or more times per year to the number of exposure events is equal to: 0.21 for lower bound, based on sensitivity results for one industrial boiler prototype bin (Bin E); 0.64 for upper bound (except 0.21 used upper bound of industrial boiler category) based on calculations performed for the UARG utility boiler analysis. Lower bound for utility boilers is also based on 0.64. As pointed out in the UARG analysis, not all exposed individuals will experience the same health effect.

6. Individuals living within the vicinity of more than one source represented by different prototypes are counted once for each prototype. Thus,this total overestimates the actual number of people living within the vicinity of one or more boilers.

7. Assumes continuous operation at an emission rate equal to the annual average. Thus, may underestimate actual exposures resulting from periods of operation at elevated emissions. Exposures are based on use of peak-to-mean ratios developed by Thrall et al. (1982).

8. Based on extrapolation of sensitivity of industrial boiler exposure estimates to building downwash and peak-to-mean ratios as in (3) above to this source category.

9. Based on prototype source/building configurations and on peak-to-mean ratio distribution characteristic of tall, isolated point sources as observed by Thrall et al. (1982).

10. Includes all coal- and oil-fired utility boilers greater than 25 MW. For additional information concerning these results, consult the UARG SO_2 exposure analysis (Burton et al., 1987).

11. Result from UARG SO_2 exposure analysis adjusted to account for revised population activity profile. Based on estimates of actual plant load.

12. Based on comparison of exposures calculated under actual load vs. constant, full-load operation for three prototype plants.

13. Does not include plants associated with refineries (these are incorporated into the refinery category estimates).

14. Population weighted average.

15. As in (8) above but without adjustment for building downwash.

REFERENCES

Armstrong, B. (1985) Peak/Mean Ratios for Phelps Dodge Douglas, Inter-Office Memorandum thru David O. Chelgren, Manager, Compliance Unit, Arizona Department of Health Services, December 4, 1985.

Armstrong, B. (1986) Peak/Mean Ratios for Magma, Inter-Office Memorandum thru David O. Chelgren, Manager, Compliance Unit, Arizona Department of Health Services, January 20, 1986.

Ayres, J. G. (1986) Trends in asthma and hay fever in general practice in the United Kingdom 1976-83. Thorax 41: 111-116.

Balmes, J.R.; Fine, J.M.; Sheppard, D. (1987) Symptomatic bronchoconstriction after short-term inhalation of sulfur dioxide. Am. Rev. Respir. Dis. 136: 1117-1121.

Burton, C.S.; Thrall, A.D. (1982) A Brief Review of Peak to One-Hour Average Ratios Observed in the Vicinity of Power Plants. Systems Applications, Inc., San Rafael, CA.

Burton, C.S.; Stockenius, T.E.; Stocking, T.S.; Carr, E.L.; Austin, B.S.; Roberson, R.L. (1987) Assessment of exposures of exercising asthmatics to short-term SO_2 levels as a result of emissions from U.S. fossil-fueled power plants. Systems Applications, Inc., San Rafael, CA. Pub. No. 87/176, September 23, 1987.

Burton, C.S.; Stoeckenius, T.E. (1988) Uncertainties associated with use of peak-to-mean ratios to estimate peak 5-minute concentrations in the vicinity of power plants. Systems Applications, Inc., San Rafael, CA. Pub. No. 88/191, November 29, 1988.

Carr, W.; Zeitel, L.; Weiss, K. (1992) Variations in asthma hospitalizations and deaths in New York City. Am. J. Public Health 82: 59-65.

Cohen, J. et al. (1983) Analysis of SO_2 Controlled Human Data. Memorandum to John Haines, Ambient Standards Branch, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, N.C., September 6, 1983.

Eaton, W.C.; Parkes, C.D.; Rickman, E.E. (1991) Evaluation of the adequacy of current SO_2 measurement methods to measure 5-minute average concentrations. Research Triangle Institute. Pub. No. 4699-061-01F. February 1991.

Edmunds, A.T.; Tooley, M.; Godfrey, S. (1978) The refractory period afater exercise-induced asthma: its duration and relation to the severity of exercise. Am. Rev. Resp. Dis. 117:247-254.

EPA (U.S. Environmental Protection Agency) (1982a) Review of the National Ambient Air Quality Standards for Sulfur Oxides: Assessment of Scientific and Technical Information (OAQPS Staff Paper) Office of Air Quality Planning and Standards, Research Triangle Park, N.C. EPA-450/5-82-007. Available from NTIS, Springfield, VA; PB 84-102920.

EPA (U.S. Environmental Protection Agency] (1982b) Air Quality Criteria for Particulate Matter and Sulfur Oxides. Environmental Criteria and Assessment Office. Research Triangle Park, N.C. EPA-600/8-82-029. Available from NTIS, Springfield, VA; PB 54-156801/REB.

EPA (U.S. Environmental Protection Agency) (1986a) Review of the National Ambient Air Quality Standards for Particulate Matter: Updated Assessment of Scientific and Technical Information (Addendum to the 1982 OAQPS Staff Paper). Office of Air Quality Planning and Standards. Research Triangle Park, N.C., December 1986.

EPA (U.S. Environmental Protection Agency) (1986b) Second Addendum to Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982): Assessment of Newly Available Health Effects Information. Environmental Criteria and Assessment Office, Office of Research and Development, Research Triangle Park, N.C. EPA-600/8-86-020F.

EPA (U.S. Environmental Protection Agency) (1986c) Staff Assessment of Recent Comments on the Short-term Sulfur Dioxide Exposure Analysis, Strategies and Air Standards Division, Office of Air Quality Planning and Standards, Research Triangle Park, N.C., July 1986.

EPA (U.S. Environmental Protection Agency) (1986d) An Analysis of Short-term Sulfur Dioxide Population Exposures in the Vicinity of Utility Power Plants. Strategies and Air Standards Division, Office of Air Quality Planning and Standards, Research Triangle Park, N.C., September 12, 1986.

EPA (U.S. Environmental Protection Agency) (1994) Supplement to the Second Addendum (1986) to Air Quality Criteria for Particulate Matter and Sulfur Oxides (1982): Assessment of New Findings on Sulfur Dioxide Acute Exposure Health Effects in Asthmatics. Environmental Criteria and Assessment Office. Research Triangle Park, N.C.

Evans, R., III; Mullally, D. I.; Wilson, R. W.; Gergen, P. J.; Rosenberg, H. M.; Grauman, J. S.; Chevarley, F. M.; Feinleib, M. (1987) National trends in the morbidity and mortality of asthma in the US. Prevalence, hospitalization and death from asthma over two decades: 1965-1984. Chest 91(suppl.): 65S-74S.

Hackney, J. D.; Linn, W. S.; Bailey, R. M.; Spier, C. E.; Valencia, L. M. (1984) Time course of exercise-induced bronchoconstriction in asthmatics exposed to sulfur dioxide. Environ. Res. 34: 321-327.

Horstman, D. H.; Roger, L. J.; Kehrl, H. R.; Hazucha, M. J. (1986) Airway sensitivity of asthmatics to sulfur dioxide. Toxicol. Ind. Health. 2:289-298.

Horstman, D. H.; Seal, E., Jr.; Folinsbee, L.J.; Ives, P.; Roger, L.J. (1988) The relationship between exposure duration and sulfur dioxide-induced bronchoconstriction in asthmatic subjects. Am. Ind. Hyg. Assoc. J. 49: 38-47.

Irwin, J.S.; Rao, S.T.; Petersen, W.B.; Turner, D.B. (1987) Relating error bounds for maximum concentration estimates to diffusion meteorology uncertainty. Atmos. Envir. 21: 1927-1937.

Johnson, T.; Capel, J.; McCoy, M. (1993) Estimation of ozone exposures experienced by urban residents using a probabilistic version of NEM and 1990 population data. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Jorres, R.; Magnussen, H. (1990) Airways response of asthmatics after a 30 min exposure, at resting ventilation, to 0.25 ppm NO_2 or 0.5 ppm SO_2. Eur. Respir. J. 3: 132-137.

Kehrl, H.R.; Roger, L.J.; Hazucha, M.J.; Horstman, D.H. (1987) Differing response of asthmatics to sulfur dioxide exposure with continuous and intermittent exercise. Am. Rev. Respir. Dis. 135: 350-355.

Koenig, J. Q.; Marshall, S. G.; Horike, M.; Shapiro, G. G.; Furukawa, C. T.; Bierman, C. W.; Pierson, W. E. (1987) The effects of albuterol on sulfur dioxide-induced bronchoconstriction in allergic adolescents. J. Allergy Clin. Immunol. 79: 54-58.

Koenig, J. Q.; Marshall, S. G.; van Belle, G.; McManus, M. S.; Bierman, C. W.; Shapiro, G. G.; Furukawa, C. T.; Pierson, W. E. (1988a) Therapeutic range cromolyn dose-response inhibition and complete obliteration of SO_2-induced bronchoconstriction in atopic adolescents. J. Allergy Clin. Immunol. 81: 897-901.

Koenig, J. Q.; Mc Manus, M. S.; Bierman, C. W.; Shapiro, C. G.; Furukawa, C. T.; Pierson, W. E. (1988b) Chlorpheniramine-sulfur dioxide interactions on lung and nasal function in allergic adolescents. Ped. Asthma Allergy Immunol. 2: 199205.

Koenig, J. Q.; Covert, D.S.; Hanley, Q.S.; van Belle, G.; Pierson, W.E. (1990) Prior exposure to ozone potentiates subsequent response to sulfur dioxide in adolescent asthmatic subjects. Am. Rev. Respir. Dis. 141: 377-380.

Larsen, R.I. (1968) A New Mathematical Model of Air Pollution Concentration Averaging Time and Frequency (Presented at 61st Annual Meeting of the Air Pollution Control Association. St. Paul, Minnesota.

Lebowitz, M. D.; Holberg, C. J.; Boyer, B.; Hayes, C. (1985) Respiratory symptoms and peak flow associated with indoor and outdoor air pollutants in the southwest. J. Air Pollut. Control Assoc. 35: 1154-1158.

Linn, W. S.; Avol, E. L.; Shamoo, D. A.; Venet, T. G.; Anderson, K. R.; Whynot, J. D.; Hackney, J. D. (1984) Asthmatics' responses to 6-hr sulfur dioxide exposures on two successive days. Arch. Environ. Health 39: 313-319.

Linn, W.S.; Avol, E.L.; Peng, R.C.; Shamoo, D.A.; Hakney, J.D. (1987) Replicated dose-response study of sulfur dioxide effects in normal, atopic, and asthmatic volunteers. Am. Rev. Respir. Dis. 136: 1127-1134.

Linn, W.S.; Avol, E.L.; Shamoo, D.A.; Peng, R.C.; Spier, C.E.; Smith, M.N.; Hackney, J.D. (1988) Effect of metaproterenol sulfate on mild asthmatics' response to sulfur dioxide exposure and exercise. Arch. Environ. Health 43: 399-406.

Linn, W.S.; Shamoo, D.A.; Peng, R.C.; Clark, K.W.; Avol. E.L.; Hackney, J.D. (1990) Responses to sulfur dioxide and exercise by medication-dependent asthmatics: effect of varying medication levels. Arch. Environ. Health 45: 24-30.

Linn, W. S. (1991) Short-term patterns of activity and respiratory status in adult asthmatics: their relationship to health risks from community air pollution. Electric Power Research Institute, Project RP3215-01, Los Amigos Research and Education Institute, Inc., Downey, California.

Marks, G.; Mellis, C.; Peat, J.; Woolcock, A. (1992) β agonist usuage among adults with asthma in an Australian provincial town [abstract]. Am. Rev. Respir. Dis. 145: A693.

McManus, M.S.; Koenig, J.Q.; Altman, L.C.; Pierson, W.E. (1989) Pulmonary effects of sulfur dioxide exposure and ipratropium bromide pretreatment in adults with nonallergic asthma. J. Allergy Clin. Immunol. 83: 619-626.

Moore, G.E.; Stoeckenius, T.E.; Hanna, S.; Strimitas, D.; (1988) Air Quality Simulation Model Performance for One-Hour Averages. Sigma Research Corp., Lexington, MA, Pub. No. SYSAPP-88/003, May 23, 1988.

National Institutes of Health (1991) Guidelines for the Diagnosis and Management of Asthma. National Asthma Education Program: Expert Panel Report. Pub. No. 91-3042.

Neville, R. G.; Clark, R. C.; Hoskins, G.; Smith, B. (1993) National asthma attack audit 1991-2. Br. Med. J. 306: 559-562.

NCHS (1993) Prevalence of Selected Chronic Conditions: United States, 1986-88. National Health Survey, 1993. U.S. National Center for Health Statistics, Hyattsville, Maryland, February, 1993:DHHS Publication No. (PHS) 93-1510.

NHIS (1985) National Health Interview Survey, 1983. U.S. National Center for Health Statistics, Hyattsville, Maryland, October 1985.

Niinimaa, V.; Cole, P.; Mintz, S.; Shephard, R. J. (1980) The switching point from nasal to oronasal breathing. Respir. Physiol. 42: 61-71

Partridge, M. R. (1992) Education and compliance. In: Barnes, P. J.; Rodger, I. W.; Thomson, N.C., eds. Asthma: basic mechanisms and clinical management. New York, NY: Academic Press; pp. 723-727.

Roger, L. J.; Kehrl, H. R.; Hazucha, M.; Horstman, D. H. (1985) Bronchoconstriction in asthmatics exposed to sulfur dioxide during repeated exercise. J. Appl. Physiol. 59: 784-791.

Rosenbaum, A.S.; Hudischewskyj, A.B.; Roberson, R.L.; Burton, C.S. (1992) Estimates of Future Exposures of Exercising Asthmatics to Short-term Elevated SO_2 Concentrations Resulting from Emissions of U.S. Fossil-fueled Power Plants: Effects of the 1990 Amendments to the Clean Air Act and a 5-minute Average Ambient SO_2 Standard. Pub. No. SYSAPP-92/016, April 23, 1992.

Rote, D.M.; Lee, J.L. (1983) Discussion and Interpretation of Results of the Analysis of the St. Louis SO_2 Data: Final Report. Energy and Environmental Systems Division, Argonne National Laboratory, Argonne, IL.

Roth Associates, Inc. (1988) A study of activity patterns among a group of Los Angeles asthmatics. EPRI Research Project 940-5, November 1988.

Roth Associates, Inc. (1992) A Survey of Daily Asthmatic Activity Patterns in Cincinnati. EPRI Research Project 940-05, November, 1992.

Rubinstein, I.; Bigby, B. G.; Reiss, T. F.; Boushey, H. A., Jr. (1990) Short-term exposure to 0.3 ppm nitrogen dioxide does not potentiate airway responsiveness to sulfur dioxide in asthmatic subjects. Am. Rev. Respir. Dis. 141:381-385.

Saibene, F.; Mognoni, P.; Lafortuna, L.; Mostardi, R. (1978) Oronasal breathing during exercise. Pflugers Archiv. 378: 65-69.

Schachter, E. N.; Witek, T. J., Jr. ; Beck, G. J.; Hosein, H. R.; Colice, G.; Leaderer, B. P.; Cain, W. (1984) Airway effects of low concentrations of sulfur dioxide: dose-response characteristics. Arch. Environ. Health 39: 34-42.

Schwartz, J.; Gold, D.; Dockery, D. W.; Weiss, S. T.; Speizer, F. E. (1990) Predictors of asthma and persistent wheeze in a national sample of children in the United States: association with social class, perinatal events, and race. Am. Rev. Respir. Dis. 142: 555-562.

Sly, M. D. (1988) Mortality from asthma in children 1979-1984. Ann. Allergy 60: 433-443.

Smith, E. (1993) Analysis of Short-Term Air Quality Data. Memorandum to John Haines, Ambient Standards Branch, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC. July 6, 1993. Docket # A-84-25, IV-B-6.

Smith, N. A.; Seale, J. P.; Shaw, J. (1984) Medication compliance in children with asthma. Aust. Paediatr. J. 20: 47-51.

Smith, N. A.; Seale, J. P.; Ley, P.; Shaw, J.; Bracs, P. U. (1986) Effects of intervention on medication compliance in children with asthma. Med. J. Aust. 144: 119-122.

Stoeckenius, T.E.; Garelick, B.; Austin, B.S.; O'Connor, K.; Pehling, J.R. (1990) Estimates of Nationwide Asthmatic Exposures to Short-term Sulfur Dioxide Concentrations in the Vicinity of Non-Utility Sources. Systems Applications Inc., San Rafael, CA, Pub. No. SYSAPP-90/129, December 6, 1990.

Stone, S.L. (1994) Analysis of Short-Term Air Quality Data. Memorandum to John Haines, Ambient Standards Branch, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC. March 15, 1994. Docket # A-84-25, IV-B-10.

Thomas, H.C. (1987) U.S. EPA, Strategies and Air Standards Division. Memorandum to John Haines, Strategies and Air Standards Division. September 17, 1987. Docket # A-84-25, II-B-4.

Thrall, A.D.; Langstaff, J.E.; Liu, M.K.; Burton, C.S. (1982) On the Variability in Peak Sulfur Dioxide Concentrations Contained in Longer Term Averages. An Empirical Study of an Isolated Power Plant. System Applications, Inc., San Rafael, CA, Pub. No. 82262, October, 1982.

Van Essen-Zandvliet, E. E.; Hughes, M. D.; Waaklens, H. J.; Duiverman, E. J.; Pocock, S. J.; Kerrebijn, K.F. (1992) Effects of 22 months of treatment with inhaled corticosteroids and/or beta-2-agonists on lung function, airway responsiveness, and symptoms in children with asthma. Am. Rev. Respir. Dis. 146: 547-554.

Weinstein, A. G.; Cuskey, W. (1985) Theophylline compliance in asthmatic children. Ann. Allergy 54: 19-24.

Weiss, K. B.; Wagener, D. K. (1990) Changing patterns of asthma mortality: identifying target populations at high risk. JAMA J. Am. Med. Assoc. 264: 1683-1687.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT This paper presents a summary of the evaluation and interpretation of key new studies on the health effects associated with short-term sulfur dioxide (SO_2) exposures and also updates available information on the occurrence of short-term (5-minute) peaks of SO_2 in the ambient air and on the likelihood that the at-risk population will be exposed. This staff paper supplement is intended to help bridge the gap between the scientific review of recent health effects information contained in the 1994 SO_2 criteria document addendum supplement and the judgments required of the Administrator in determining whether new regulatory initiatives are needed to provide increased protection to asthmatic individuals whose health could be compromised if exposed to high 5- to 10 minute peak SO_2 levels. Factors relevant to this evaluation, as well as staff conclusions and recommendations on alternative regulatory approaches are presented in this paper.

The staff recommends that the Administrator consider three possible regulatory alternatives: 1) establish a new 5-minute NAAQS in the range of 0.6 to 1.0 ppm SO_2 expressed as the maximum 5-minute block average in 1 hour, with 1 to 5 expected exceedances; 2) establish a new regulatory program under section 303 of the Clean Air Act, with a target level in the range of 0.6 to 1.0 ppm SO_2 expressed as the maximum 5-minute block average in 1 hour, with 1 to 5 expected exceedances; and 3) retain the existing suite of standards but augment their implementation by focusing on those sources likely to produce high 5-minute peaks of SO_2.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sulfur Oxides Sulfur Dioxide Air Pollution	Air Quality Standards	

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