State of California
Air Resources Board

Amendments to Regulations for the 24-Hour Ambient Air Quality Standard for Sulfur Dioxide

Staff Report

Research Division

August 1991

State of California
AIR RESOURCES BOARD

STAFF REPORT: INITIAL STATEMENT OF REASONS FOR RULEMAKING

Public Hearing to Consider

AMENDMENTS TO REGULATIONS REGARDING THE STATE 24-HOUR AMBIENT AIR QUALITY STANDARD FOR SULFUR DIOXIDE

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State of California
AIR RESOURCES BOARD

Public Hearing to Consider

AMENDMENTS TO REGULATIONS REGARDING THE STATE 24-HOUR AMBIENT AIR QUALITY STANDARD FOR SULFUR DIOXIDE

STAFF REPORT

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INTRODUCTION

Sulfur dioxide is a highly irritating gas, harmful to the respiratory system. It is emitted primarily from the combustion of sulfur-containing fuels such as coal and oil. To protect public health, the California Air Resources Board has established ambient air quality standards for sulfur dioxide. The standards apply over two different averaging times. One is a one-hour standard to deal with short-term health effects. The other is a 24-hour standard that deals with longer-term health effects. In this report, the staff of the Air Resources Board recommends to the Board that the current 24-hour standard for sulfur dioxide be changed as shown under the heading "Recommendations." This staff report and the proposed regulatory action pertain only to the 24-hour standard for sulfur dioxide. The basis of the one-hour standard has not been reviewed and staff is not recommending any change to the standard at this time.

This staff report summarizes the basis for our recommendations. A Technical Support Document goes into greater detail concerning the health effects of, exposure to, and emissions of sulfur dioxide and the need to revise the standard. Both documents have been prepared by the staff of the Air Resources Board, with the assistance and review provided by the staff of the Department of Health Services (DHS).

Recommendations made in this report are based on findings made by the Department of Health Services. If our recommendations are adopted, they will do the following to the existing 24-hour standard for sulfur dioxide:

- Lower the numerical value of the standard from 0.05 parts per million (ppm) to 0.04 ppm;
- Change the basis for determining violations of the standard to "not to be exceeded" (rather than "equal or exceed"). This policy

regarding violations was called for by the Board in 1982 for all ambient air quality standards;

- Uncouple the standard from the current requirement of concurrent exceedance of either the total suspended particulate matter standard or the ozone standard;
- Change the "Most Relevant Effects" column of Title 17, California Code of Regulations, section 70200, Table of Standards, to refer to new health effects data, and add language to the "Comments" column regarding these health effects;
- Delete parts of sections 70100, 70200, and 70201 which discuss or define compliance of the 24-hour sulfur dioxide standard in combination with total suspended particulate matter and ozone; and
- Retain the current method for monitoring for sulfur dioxide, the Ultraviolet (UV) Fluorescence method.

The net effect of these proposed changes is to retain the current level of maximum allowable 24-hour exposure to sulfur dioxide and to rescind the language specifying concurrent exposure to ozone and/or suspended particulate matter. The text of the regulation with the proposed changes as described above is attached as Appendix B.

II.

RATIONALE FOR THE PROPOSED CHANGES

The ARB first established a 24-hour sulfur dioxide standard in 1969. The standard was revised in 1970, 1974, 1975, and most recently in 1977. The ARB staff regularly reviews the State ambient air quality standards to determine if the scientific bases of the standards are still sound. Frequently, new scientific information and research are published which indicate a need for reexamination of the standards.

New research studies published since the 1977 revision of the 24-hour sulfur dioxide standard require that the standard be reviewed to take account of this new scientific information. The new research studies provide additional evidence demonstrating respiratory health effects due to long-term exposure (24 hours or longer) to low levels of sulfur dioxide in the ambient air.

In addition, the fact that the current 24-hour sulfur dioxide standard is tied to the total suspended particulate matter (TSP) standard and oxidant (measured as ozone) standard presents difficulties in determining compliance with the standard. The TSP standard was superseded in 1983 by a PM10 standard (50 ug/m^3, particulate matter of 10 microns or smaller in size). However, the ARB must still measure TSP levels to determine attainment of the 24-hour sulfur dioxide standard even though PM10 is now the State's standard for particulate matter. In addition, since the ARB monitors for TSP on every sixth day, effectively the ARB can only determine violations of the 24-hour sulfur dioxide standard on every sixth day when the ozone standard is not violated. Monitoring for sulfur dioxide is done continuously at all sites that have sulfur dioxide monitors.

There are also problems with the sulfur dioxide/oxidant standard as well. The oxidant standard was revised in 1987 to an ozone standard (0.09 ppm, averaged over one hour). That change has not affected enforcement of the 24-hour sulfur dioxide standard, since the oxidant standard has been measured as ozone since the early 1970's. A greater impact on the combined sulfur dioxide/oxidant comes from difficulties arising from the Hazucha and Bates (1975) research study. This study demonstrated the combined sulfur dioxide/ozone respiratory health effects and served as the basis for the combined standard. The results of this study have not been replicated and the authors now believe that problems with their experimental methods may have influenced the results. In a February 24, 1989 letter to ARB regarding emergency episode criteria for oxidants, the DHS recommended rescinding the criteria for the combined sulfur dioxide/oxidant standard because of concerns about the validity of the Hazucha and Bates (1975) study.

With these issues in mind, the ARB staff requested the Department of Health Services to review the health effects literature for sulfur dioxide and provide findings and recommendations for the health effects associated with long-term sulfur dioxide exposure.

III.

CALIFORNIA AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE

The ARB has established two ambient air quality standards for sulfur dioxide: a one-hour averaged standard based on short-term health effects; and a 24-hour averaged standard based on long-term health effects.

A. ARB AUTHORITY FOR STANDARDS SETTING

California Health and Safety Code section 39606(b) authorizes the Air Resources Board (ARB) to adopt standards for ambient air quality to protect public health, safety, and welfare. The objective of ambient air quality standards is to provide a basis for preventing or abating the effects of air pollution. Ambient air quality standards establish the maximum allowable levels of air pollutants. However, standards should not be interpreted as permitting, encouraging, or condoning the degradation of present air quality which is superior to that stipulated in the standards. Standards shall be adopted in consideration of health, illness, irritation to the senses, aesthetic value, interference with visibility, effects of air pollutants on the economy and other relevant factors. Standards based upon health effects are to be based upon the recommendations of the Department of Health Services.

B. CURRENT 24-HOUR SULFUR DIOXIDE STANDARD

Currently, the 24-hour sulfur dioxide standard is a combination standard; it limits exposure to sulfur dioxide in combination with oxidant (measured as ozone) and suspended particulate matter. Specifically, the 24-hour sulfur dioxide standard is violated when the 24-hour averaged sulfur dioxide concentration equals or exceeds 0.05 parts per million (ppm) at the same time as either the oxidant standard of 0.10 ppm (measured as ozone and not to be equaled or exceeded) or the total suspended particulate matter (TSP) standard of 100 micrograms per cubic meter (ug/m^3) is violated.

Several changes have occurred since the combination 24-hour sulfur dioxide standard was established in 1977 that have complicated enforcement of the standard. As discussed above, these changes include the superceding of the TSP standard with a PM10 standard and difficulties with the scientific basis for the combined sulfur dioxide/oxidant standard.

C. ONE-HOUR SULFUR DIOXIDE STANDARD

The one-hour standard for sulfur dioxide is 0.25 ppm, not to be exceeded. This standard was originally established by the ARB in 1969 at a level of 0.50 ppm. It was revised in 1983 to its present level. The one-hour standard is not reviewed in this staff report (see section below).

D. DIFFERENT HEALTH EFFECTS BASES

While both the 24-hour and one-hour standards are based upon health effects, they are based upon different types of effects. The one-hour standard is based on bronchoconstriction in asthmatics and is designed to protect against adverse effects from short (5 to 10 minute) exposures to sulfur dioxide. In contrast, the 24-hour standard is based upon health effects from long-term exposure to sulfur dioxide including an increased incidence of respiratory disease and excess mortality from higher concentrations. Because the health bases of the two sulfur dioxide standards are different, studies used to set the 24-hour standard are not relevant to the one-hour standard, and vice versa.

E. RELATIONSHIP TO OTHER POLLUTANTS AND STANDARDS

Atmospheric reactions of sulfur dioxide yield other sulfur-containing air pollutants, primarily sulfuric acid and sulfates. Sulfuric acid and sulfates are primary constituents of PM10 (particulate matter of 10 microns or smaller in size) and visibility reducing particles. The ARB has established ambient air quality standards for sulfur dioxide, sulfates, PM10, and visibility reducing particles. The ambient air quality standards for sulfur dioxide, sulfates, and PM10 are based on respiratory health effects. The ambient air quality standard for visibility reducing particles is based on the aesthetic value of reduced visibility (frequently the most obvious form of air pollution).

IV.

HEALTH EFFECTS FROM EXPOSURE TO SULFUR DIOXIDE

Researchers have studied the effects of sulfur dioxide on the respiratory system in great detail over the last 40 years. They have studied the effects of sulfur dioxide using both animal and human test subjects. The health effects of sulfur dioxide on the respiratory system are well documented.

Studies in animals have shown that exposure to sulfur dioxide can cause a change in lung cell structure and function, that adversely affect a major lung defense mechanism, the muco-ciliary transport. This mechanism functions by trapping particles and substances in the mucus produced by goblet (mucus secreting) cells. The ciliated cells of the lung (cells with cilia, fine hair-like projections) then sweep the mucus, along with the particles, out of the lungs. Sulfur dioxide can cause an overproduction of mucus and goblet cells. It can also kill cilia. This all results in a decreased rate of transport of mucus and particles out of the lungs. This overproduction of mucus and goblet cells and the slowed muco-ciliary transport are symptoms frequently seen with the disease of chronic bronchitis in humans. Therefore these effects seen in animals may have serious health consequences for humans.

In studies with human subjects, sulfur dioxide exposure has been shown to adversely affect lung function. Its primary short-term effect is bronchoconstriction, a narrowing of the airways which results in labored breathing, wheezing, and coughing. Research studies have shown asthmatics to be particularly sensitive to the bronchoconstrictive effects of sulfur dioxide. In addition, since sulfur dioxide can be effectively absorbed in the upper airways (the nose and postnasal cavities), those individuals that breath primarily through their mouths (rather than the nose) bypass this protective mechanism. These "mouth-breathers" are also more sensitive to sulfur dioxide since a larger dose of sulfur dioxide reaches the deeper parts of the lungs. Exercise, through an increased respiratory rate, also can increase the dose of sulfur dioxide reaching the deep lung.

With regard to long-term health effects, the effects of sulfur dioxide exposure were dramatically demonstrated during the air pollution episodes seen in London in 1952, Donora, Pennsylvania in 1948, and the Meuse Valley, Belgium in 1930. During these air pollution episodes, sulfur dioxide and particulate matter levels rose during periods of stagnant air (inversions). The rates of respiratory disease increased dramatically during the air pollution episodes. Death rates of those with pre-existing respiratory disease or cardiac disease also increased. Since then, researchers have studied these episodes and other areas with sulfur dioxide pollution to determine the long-term effects of sulfur dioxide exposure. A conclusion of many studies was that sulfur dioxide exposure is associated with a greater incidence of respiratory disease and with a greater risk of mortality.

Since the 24-hour sulfur dioxide standard is based upon long-term effects, the DHS reviewed relatively new research studies that looked at human response to 24-hour or longer sulfur dioxide exposure. Their findings regarding the adverse effects of sulfur dioxide exposure are discussed below.

V.

FINDINGS OF THE DEPARTMENT OF HEALTH SERVICES

We requested the DHS to review the current scientific literature regarding sulfur dioxide and determine whether new research or other information indicates the current 24-hour sulfur dioxide standard should be revised. Since the one-hour sulfur dioxide standard has a different scientific basis and is meant to protect a sensitive population (asthmatics) from different health effects (bronchoconstriction), we are not reviewing it and did not ask DHS to review it at this time.

In response to the ARB request, the DHS has reviewed 48 studies on health effects of sulfur dioxide. The studies reviewed were primarily epidemiological studies since they were most appropriate for studying long-term health effects from relatively low doses of sulfur dioxide in ambient air. Based upon their review, the DHS has made findings and recommendations on sulfur dioxide-associated health effects, on a "low adverse effect" level for sulfur dioxide and on a "no adverse effects" level for sulfur dioxide. The DHS findings are not based upon the results of any one study but upon the "weight of evidence", contributions from the cumulative results of many studies.

The DHS also finds that the 24-hour sulfur dioxide standard can be uncoupled with concurrent measurements of suspended particulate matter based on the results of studies that show an association with sulfur dioxide exposure but not particulate matter. While DHS finds that the adverse health effects are probably not due to sulfur dioxide alone, they also find that the data are sufficient to warrant a standard not linked to particulate matter. In these studies sulfur dioxide is probably acting as a surrogate for the complex mixture of pollutants that exist in the atmosphere. As mentioned earlier, reactions involving sulfur dioxide produce sulfuric acid and sulfates. As a surrogate, sulfur dioxide is an effective and accurate measure for determining the respiratory effects that are associated with atmospheres of sulfur-based pollutants, of which sulfur dioxide is a major component.

With regard to the sulfur dioxide/oxidant standard, the DHS finds that because of difficulties in the experimental methodology, the results of the Hazucha and Bates (1975) study are weakened and that this weakens that basis of the standard itself. DHS does find that ozone may potentiate the effects of short-term exposure to sulfur dioxide but that these effects are relevant to the one-hour sulfur dioxide standard and not the 24-hour standard. Accordingly, the DHS recommends the repeal of the combined sulfur dioxide/oxidant standard.

The Findings and Recommendations of the Department of Health Services are attached as Appendix A. The DHS's Air Quality Advisory Committee (AQAC), an independent advisory group, has reviewed the DHS findings and concurred with their interpretation. In addition, the Department of Health Services asked an independent group of scientists with expertise in air pollution epidemiology to review the DHS findings. Their comments have been incorporated into the final DHS findings.

A. TYPES OF STUDIES ON WHICH STANDARDS ARE BASED

In making their recommendations, the DHS depended almost entirely on epidemiological studies. For determining long-term health effects due to relatively low levels of sulfur dioxide, epidemiological studies are the best source of information. There are two other types of health effects studies which the DHS relied upon, although to a much lesser degree, to arrive at their findings and recommendations. These are animal studies and controlled human studies.

Animal studies allow researchers to look at health effects in a manner that would not be appropriate with humans, such as tissue damage requiring pathological examinations. They also allow for researchers to control for confounding factors as much as possible. However, results from animal studies still must be extrapolated to the human condition in order to assess human health effects, a process that always adds uncertainty to the assessment.

Controlled human studies allow researchers to control the exposure conditions and eliminate confounding factors that may confuse the results. They are also conducted with the most appropriate species, that is humans themselves. However, in most cases, controlled human studies are appropriate only for determining the health effects of short-term exposure, since testing periods are usually limited. It is not practicable to keep people in exposure chambers for long periods of time. The one-hour sulfur dioxide standard is based on health effects derived from controlled human studies.

Epidemiological studies allow researchers to study human populations exposed under ambient conditions in their normal living environments, and the results are usually more representative of the general population. However, epidemiological studies sometimes suffer from imprecise exposure measurements, and unexpected confounding factors can confuse the interpretation of results. Nevertheless, for the basis of determining long-term health effects to relatively low levels of sulfur dioxide, epidemiological studies are the best source of information.

B. FINDINGS OF THE DHS REVIEW

The findings and recommendations of the DHS are based on the results of epidemiological studies that looked at 24-hour or longer exposures to sulfur dioxide in the ambient air. Following review of the epidemiological studies, the DHS grouped the studies into three categories in order to attain three objectives. First, DHS grouped those studies which show an association between sulfur dioxide exposure and adverse health effects (qualitative assessment) in order to determine the possible adverse effects caused by sulfur dioxide exposure. Second, DHS reviewed studies that possessed adequate exposure data to quantitatively assess the levels at which health effects occur. Third, DHS grouped those epidemiological studies which show sulfur dioxide effects without showing a particulate matter effect.

1. Health Effects from Sulfur Dioxide Exposure

Based on the information from the epidemiological studies, the DHS finds that long-term (24-hours or longer) exposure to sulfur dioxide is associated with adverse health effects. DHS finds that exposure to sulfur dioxide is associated with: a) an increased incidence of respiratory symptoms (e.g., coughing and wheezing) or respiratory disease; b) decreases in pulmonary function; and c) increased risk of mortality. The effects of increased respiratory symptoms and disease and decreased lung function were frequently seen in children as well as adults.

The DHS concluded that these effects probably are not caused by sulfur dioxide alone. Sulfur dioxide is probably acting as a surrogate for the complex mixture of pollutants that exist in the atmosphere. This is discussed in greater detail below (section 3.)

2. Quantitative Assessment of Sulfur Dioxide Effects

Some studies provided adequate information to enable DHS to identify a "low adverse effects level" for 24-hour average sulfur dioxide exposure. These studies were vitally important in providing the necessary information to establish the level of the standard for sulfur dioxide. Several studies found no association between sulfur dioxide exposure and health effects. DHS believes these studies show a lower boundary for effects attributable to sulfur dioxide and can be used to set a "no adverse effects" level for sulfur dioxide.

From their review of the epidemiological studies, DHS finds that adverse respiratory effects resulting in decreased lung function, increased incidence of respiratory disease, and increased risk of mortality can occur from 24-hour exposure to sulfur dioxide at levels of 0.06 ppm and above. Further, some of the studies indicate a sulfur dioxide threshold for effects, whereby "no adverse effects" are expected at sulfur dioxide concentrations of 0.04 ppm and below. Studies with adequate exposure data serve as the scientific basis for the recommendation to amend the 24-hour sulfur dioxide standard to a numerical value of 0.04 ppm, not to be exceeded.

3. Sulfur Dioxide Effects without Particulate Matter Involvement

In the past, epidemiological studies that found an association between sulfur dioxide exposure and respiratory effects have also frequently found an association with particulate matter levels. This is not surprising since sulfur dioxide is a precursor for sulfuric acid and sulfates, major components of particulate matter, and the combustion of fuels that produce sulfur dioxide also produce other organic particles. The 1977 revision to the 24-hour standard was based upon studies where health effects occurred in environments with elevated sulfur dioxide levels and where particulate matter levels were usually elevated as well.

In their review, the DHS reports the results of several recent studies where sulfur dioxide exposure was associated with respiratory effects but particulate matter levels were not. On the basis of these studies DHS finds that the 24-hour sulfur dioxide standard can be uncoupled from concurrent suspended particulate matter measurements. Does this mean that the respiratory effects of the study populations were due entirely to sulfur dioxide? Probably not. The DHS and the ARB staff believe that sulfur dioxide levels in these studies probably serve as a surrogate for the effects caused by the complex mixture of pollutants in the atmosphere, including sulfur dioxide, sulfates, acids, and suspended particulate matter. Does this mean that sulfur dioxide levels are a good indicator of safe and unsafe levels of the mix of sulfur-containing pollutants in the atmosphere? Definitely so, in the view of both agencies.

VI.

EMISSIONS OF SULFUR DIOXIDE

Approximately 544 tons of sulfur dioxide are emitted per average day in California. Of this total, 79 percent results from fuel combustion, both mobile and stationary sources, and 21 percent results from petroleum and industrial processes.

A. CURRENT EMISSIONS

The ARB lists in its 1987 emission inventory a statewide total of 544 tons of oxides of sulfur per average day. Although the emissions inventory lists oxides of sulfur (SOx), almost all is in the form of sulfur dioxide.

Approximately 62 percent of the statewide emissions of sulfur dioxide are from mobile sources. This includes on-road vehicles and other mobile sources such as ships and aircraft. All of these emissions are associated with the combustion of fuel.

The 38 percent from stationary sources is divided as follows: 17 percent is from the combustion of fuels; 13 percent is from petroleum process, storage and transfer operations -- nearly all of these emissions are from processes related to petroleum refining; 7 percent is from industrial processes; and 1 percent is from waste burning and other miscellaneous processes.

Four air basins account for approximately 80 percent of the SOx emissions in California. The emissions from the most populous of these air basins, the South Coast Air Basin, account for 25 percent of the total. The percentage contributions of the major source types differ from air basin to air basin. However, for the South Coast Air Basin, the distribution of SOx emissions among the major source types is very similar to the statewide distribution described above.

B. PAST EMISSIONS OF SULFUR DIOXIDE

Overall, emissions of sulfur dioxide declined throughout the period 1977 through 1987. This trend was due to dramatic reductions in sulfur dioxide emissions from stationary sources throughout the same period. There were several reasons for this decline. Some of the reductions resulted from ARB requirements for sulfur dioxide emission reductions needed to eliminate violations of the National Ambient Air Quality Standard for sulfur dioxide in Kern County caused by oil field steam generators. These reductions were accomplished through the use of emission control technology (scrubbers) and, to a smaller extent, fuel switching. However, the greatest reductions were the result of industry fuel switching from fuel oil to natural gas in combustion processes due to the rising price of oil in the late 1970's.

Mobile sources showed a general trend upward in sulfur dioxide emissions from 1977 through 1987. There was a slight dip in emissions in 1981, likely due to the recession. There was another drop in emissions in 1985 reflecting the adoption of low-sulfur diesel-fuel regulations in the South Coast Air Basin and in Ventura County. Overall, when accounting for both stationary and motor vehicle sources, sulfur dioxide emissions show a substantial decline throughout the period 1977 through 1987.

C. PROJECTED EMISSION TRENDS

Because of the expected growth in the state's population and economy, the ARB staff projects that sulfur dioxide emissions from most categories, with the exception of on-road motor vehicles, will increase through the period ending in 2010. Reductions of sulfur dioxide emissions from motor vehicles will be realized when low-sulfur diesel fuel is required statewide in 1993.

Stationary source emissions of sulfur dioxide are expected to climb to 262 tons per day (tpd) in 2010 from the 1987 inventory level of 207 tpd. Mobile source emissions drop from the 1987 level of 337 tpd to 301 tpd in 1995. However, thereafter mobile source emissions rise again reaching the 337 tpd level in 2010.

VII.

AMBIENT AIR CONCENTRATIONS OF SULFUR DIOXIDE

Due to the substantial reductions in sulfur dioxide emissions since the mid to late 1970's, sulfur dioxide levels in California have decreased dramatically. In the early 1970's it was not unusual for the 24-hour State standard to be violated 70 to 100 times a year in the South Coast Air Basin. As industries switched to natural gas for fuel, the number of violations decreased yearly. In 1977, the year the standard was last revised, there were still 22 violations of the 24-hour sulfur dioxide standard (primarily in the South Coast Air Basin) and 53 days when the 24-hour sulfur dioxide levels exceeded 0.05 ppm. It was not until 1981 that the combined 24-hour standard was attained everywhere in the state. However, 24-hour sulfur dioxide levels still exceeded 0.05 ppm until 1986, albeit very infrequently.

No area in California has violated any ambient air quality standard for sulfur dioxide during the most recent three calendar years for which we have data (1987-1989). Therefore, the Board did not designate any areas of California as "nonattainment" for sulfur dioxide during the most recent review of the sulfur dioxide designations (November 1990). Only two areas--Humboldt County and the portion of Kern County in the Southeast Desert Air Basin--are designated as "unclassified" for sulfur dioxide because ambient monitoring data have been insufficient to demonstrate attainment. The remainder of California is designated as "attainment" for sulfur dioxide.

These ambient concentrations reveal the dramatic reductions in sulfur dioxide that have occurred since the 1970's. However, since most of these reductions were due to market forces (high oil prices) causing a switch from fuel oil to natural gas, sulfur dioxide levels could rise again if low-sulfur natural gas became unattainable or uneconomical.

VIII.

MONITORING METHODS FOR THE SULFUR DIOXIDE STANDARD

The current standard method for determining compliance with the California ambient air quality standards for sulfur dioxide is the Ultraviolet (UV) Fluorescence method. Since this method is already listed in the California Code of Regulations, there is no need to amend this part of the Table of Standards. The Environmental Protection Agency's (EPA) reference method for determining compliance with the national ambient air quality standards for sulfur dioxide is the manual Pararosaniline Method. The ARB finds this method will give equivalent results for monitoring for California sulfur dioxide standard violations. Other equivalent methods may be used to monitor for the California sulfur dioxide standard violations if they can be shown to the satisfaction of the ARB to give equivalent results at or near the standard. The UV Fluorescence method is currently the most widely used method in California.

IX.

CONCLUSIONS

Based upon the ARB staff's review and the recommendations of the Department of Health Services, the staff concludes:

- At the request of the ARB staff, the Department of Health Services has reviewed 48 research studies, published since the 24-hour sulfur dioxide standard was revised in 1977, which concern the adverse respiratory health effects from exposure to sulfur dioxide.

- The DHS finds that epidemiological studies demonstrate an association between long-term exposure to sulfur dioxide (24-hour exposures or longer) and adverse respiratory health effects. These effects include decreased respiratory function, an increased incidence of respiratory symptoms and disease, and an increased risk of mortality.

- The effects seen in the epidemiological studies were probably not caused by sulfur dioxide alone; rather, sulfur dioxide serves as an effective and useful surrogate for other related pollutants (such as acid, sulfates, or particulate matter) in addition to itself.

- Exposure data from the epidemiological studies contained sufficient information to determine dose-response effects in the range of current or anticipated sulfur dioxide concentrations.

- The DHS finds that epidemiological studies indicate an association between sulfur dioxide exposure at or above levels of 0.06 ppm and adverse respiratory health effects.

- The epidemiological studies indicate a "low adverse effects" level at 24-hour sulfur dioxide concentrations of 0.06 ppm and higher.

- The epidemiological studies indicate a "no adverse effects" level at 24-hour sulfur dioxide concentrations of 0.04 ppm and below.

- The scientific basis of the combination sulfur dioxide/oxidant (measured as ozone) standard is weakened due to methodological problems that may have occurred in the study of Hazucha and Bates (1975), which served as the basis for the combination 24-hour sulfur dioxide/oxidant standard, and therefore make the results of the study problematic.

- Research has been published that reports a combined sulfur dioxide/ozone effect, but the data are more appropriate to short-term sulfur dioxide exposure and to the one-hour sulfur dioxide standard, not the 24-hour standard.

- The data from the epidemiological studies are adequate to support a 24-hour sulfur dioxide standard that is not coupled to ozone and particulate matter concentrations.

- The Department of Health Services' Air Quality Advisory Committee (AQAC), an independent advisory group, has reviewed the DHS findings and concurred with their interpretation of recent research results.

- In addition, the Department of Health Services asked an independent group of scientists with expertise in air pollution epidemiology to review the DHS findings. Their comments have been incorporated into the final DHS findings.

X.

RECOMMENDATIONS

The staff of the Air Resources Board, based on its independent review and the recommendations of the Department of Health Services, recommends that the Air Resources Board amend the 24-hour California ambient air quality standard for sulfur dioxide in Title 17, section 70100, section 70200, ("Table of Standards"), and section 70201, of the California Code of Regulations as follows:

- Lower the numerical value of the standard from 0.05 parts per million (ppm) to 0.04 ppm (section 70200, "Table of Standards");

- Amend the standard so that it is uncoupled from concurrent measurements of total suspended particulate matter and ozone;

- Change the basis for determining violations of the standard to "not to be exceeded" (rather than "equal or exceed");

- Amend the "Most Relevant Effects" column of section 70200, "Table of Standards", to read as follows,
  "a. Increased incidence of pulmonary disease and symptoms, decreased pulmonary function, and increased risk of mortality."

- Amend the "Comments" column of section 70200, "Table of Standards", to read as follows,
  "Effects may not be due to sulfur dioxide alone but also to suspended particulate matter, including sulfates and acids.";

- Amend section 70100 to remove those parts from the definition of "Total Suspended Particulate Matter" that pertain to determining compliance with the combination 24-hour sulfur dioxide standard;

- Delete section 70201. Determination of the 24-hour SO_2 Standard, which currently serves to inform how to use sulfur dioxide, ozone and TSP measurements to determine compliance with the combination 24-hour sulfur dioxide standard; and

- Retain the current monitoring method for sulfur dioxide when determining compliance with the 24-hour ambient air quality standard for sulfur dioxide. This is the Ultraviolet (UV) Fluorescence method. Since this method is already listed in the California Code of Regulations, there is no need to amend this part of the Table of Standards.

XI..

ENVIRONMENTAL IMPACTS

The proposed changes to the 24-hour ambient air quality standard for sulfur dioxide, alone, will have no negative environmental impacts. Ambient air quality standards establish the maximum allowable levels of air pollutants. The objective of ambient air quality standards is to provide a basis for preventing or abating the effects of air pollution. However, standards should not be interpreted as permitting, encouraging, or condoning the degradation of present air quality which is superior to that stipulated in the standards. Once a standard is adopted by the ARB, local air pollution control districts are responsible for the adoption of rules and regulations to control emissions from stationary sources to attain and maintain the standard. The ARB is responsible for adoption of emission standards for mobile sources. Once standards are attained and maintained, the air quality will be improved with corresponding benefits to the environment and public health and welfare. Since there are currently no violations of the the 24-hour sulfur dioxide standard and violations are not expected if the proposed changes are adopted, additional emission controls are not expected.

XII.

ALTERNATIVES TO THE PROPOSED CHANGES

Because the adoption of the proposed standard will not have any adverse environmental impact, alternatives which would reduce this impact need not be discussed. However, the alternatives which were considered in developing the proposed alternatives can be briefly characterized as: No Action; Proposing a less stringent standard; and Proposing a more stringent standard. If the "No Action" alternative were adopted the present combination 24-hour sulfur dioxide standard would remain in effect. As discussed previously under "Rationale for the Proposed Changes", there are problems with the current combination 24-hour sulfur dioxide standards which render it inaccurate and inadequate to protect public health. Although currently there are no violations of the 24-hour sulfur dioxide standard, sulfur dioxide concentrations may increase in the future; therefore, no action on the standard could result in an increased risk of adverse health effects.

A less stringent standard is also not adequate to protect public health. The DHS review finds that adverse health effects would occur if the numerical value of the standard were raised. Therefore a less stringent standard is not justified. A more stringent standard could be more protective however it might not provide additional benefits since the DHS review found no evidence for adverse health effects at a lower level of exposure. Therefore, the staff believes the proposed changes to the standard are sufficiently protective, based upon the health effects evidence available in the current scientific and research literature.

APPENDIX A

DEPARTMENT OF HEALTH SERVICES RECOMMENDATIONS

State of California

Department of Health Services

Memorandum

JAN 28 1991

B-4

To : James Boyd
Executive Officer
Air Resources Board
1102 Q Street
Sacramento, CA 95814

Date : January 24, 1991

Subject: Air Quality Standard for Sulfur Dioxide

From : Office of the Director
714 P Street, Room 1253
Sacramento, CA 95814
8/485-1248

Attached is a copy of the Department of Health Services' (DHS') recommendation for the 24-hour ambient air quality standard for sulfur dioxide (SO_2). Staff at the Air Resources Board (ARB) requested this recommendation pursuant to Section 39606 (b) of the California Health and Safety Code. This document has been reviewed by the DHS Air Quality Advisory Committee and by several additional scientists with expertise in air pollution epidemiology and SO_2 toxicity. The current version incorporates revisions suggested by the Committee and the other independent reviewers.

DHS is recommending that the current standard be revised in two ways: first, the 24-hour average concentration should be lowered from 0.05 to 0.04 parts per million (ppm) SO_2 and second, the standard for SO_2 should be uncoupled from concurrent particulate and ozone measurements. This recommendation is based primarily on recent epidemiologic studies indicating that daily ambient SO_2 concentrations are associated with increased respiratory morbidity, decreased pulmonary function, and increased mortality in populations in several countries. Such associations have been observed at 24-hour average SO_2 concentrations of approximately 0.06 ppm and above, but not when the concentrations have been 0.04 ppm or less. This recommendation therefore includes a margin of safety consistent with published data.

DHS will be submitting a recommendation for short-term exposures to SO_2 at a later date. DHS staff are considering recommending an averaging time shorter than one hour (the existing standard), but are waiting for collection of real-time SO_2 monitoring data by ARB staff.

If you have any questions about the attached recommendation, please contact Steven A. Book, Ph.D., Chief, Health Hazard Assessment Division, at (916) 324-7572.

for Kenneth W. Kizer, M.D., M.P.H.
Director

Attachment

cc: Steven A. Book, Ph.D., Chief
Health Hazard Assessment Division

RECOMMENDATION FOR THE 24-HOUR AMBIENT AIR QUALITY STANDARD FOR SULFUR DIOXIDE

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Resources Board by the Department of
Health Services

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1. RECOMMENDATION

The Department of Health Services (DHS) recommends that the 24-hour ambient air quality standard for sulfur dioxide (SO_2) be revised as follows:

a. the maximum allowable concentration should be 0.04 rather than 0.05 parts per million (ppm) SO_2; and

b. the standard should be independent of both particulate matter and ozone (or oxidant).

2. BACKGROUND

DHS last presented a recommendation concerning the 24-hour SO_2 ambient standard in 1977. At that time, DHS noted that it was reasonable to recommend a standard for SO_2 alone, even though the adverse health effects observed in epidemiologic studies were probably attributable to SO_2 and other pollutants, especially particulate matter. DHS remarked that, "[such adverse effects] will be of greatest concern in air basins, or in larger regions, where interactions with other pollutants might occur, i.e., where suspended particulate matter or oxidant standards are frequently exceeded" (DHS 1977, p. 1). Subsequently, the Air Resources Board (ARB) promulgated regulations coupling the SO_2 standard to exceedances of the standards for total suspended particulates (TSP) and oxidants. In this recommendation, DHS again advocates a standard for SO_2 that is independent of other pollutants, relying primarily on research published since 1977.

3. BASIS FOR RECOMMENDATION

The 24-hour SO_2 standard is based on epidemiologic studies of morbidity and mortality. These studies observe populations during ambient exposure conditions in nonexperimental settings. For this reason, the sample and response in an epidemiologic study are usually more representative of the general population than those obtained from small numbers of volunteers exposed to controlled concentrations of a specific pollutant. In addition, the epidemiologic studies considered here involve 24-hour (or longer) measurements of SO_2 and thereby obviate the need for extrapolation to longer averaging times. However, measurements of exposure and health endpoints typically are less precise than in chamber studies, and results are more easily confounded by variations in uncontrolled and unmeasured factors. Nevertheless, these studies provide both quantitative and qualitative information on the effects of SO_2.

Since no single epidemiologic study can satisfactorily address every concern regarding study design, sample selection, statistical methods, confounders, or omitted variables, DHS staff have attempted to view the studies together and develop a recommendation based on the weight of evidence. A large number of recent epidemiologic studies indicate that increases in 24-hour average exposures to SO_2 may result in increases in the incidence of respiratory symptoms and illness, decrements in lung function, and mortality. Section 4 reviews epidemiologic studies relevant to the recommendation of a 24-hour average standard for SO_2. The studies' results are summarized in Tables 1 through 3. Section 5 describes how we derived the range of SO_2 concentrations in which adverse effects have been observed. Table 4 provides a summary of the inferred concentrations of SO_2 associated with these effects.

Sulfur dioxide is a highly irritating gas that is soluble in water and is therefore efficiently absorbed in the upper respiratory tract. SO_2 is rapidly hydrolyzed to form ions of hydrogen, bisulfite, and sulfite, each of which may contribute to the irritant property of this gas, although hydrogen and bisulfite appear to be more influential than sulfite (Fine 1987). Penetration to the airways is enhanced by oral breathing and an increased respiratory rate, such as occurs with exercise (Bethel et al. 1983; Frank et al. 1969; Kleinman 1984). In experimental animals, SO_2 causes a variety of effects, including increased resistance to airflow and changes in mucus secretion, with such effects infrequently demonstrable at concentrations below 5 ppm (Sheppard 1988). The most important consequences of short, peak exposure to SO_2 are constriction of the airways and attendant respiratory symptoms, particularly among asthmatics and others who appear to be sensitive to the effects of SO_2.

In controlled laboratory experiments of human volunteers with asthma, short (5-10 minutes to one hour) exposures to SO_2 result in bronchoconstriction and increased lower respiratory symptoms at concentrations of 0.20 ppm and above (Sheppard et al. 1980, 1981; Bethel et al. 1983). At concentrations near 0.20 ppm SO_2, this effect is observed only with exercise or voluntary hyperventilation. However, this concentration is still substantially greater than those associated with adverse health effects in epidemiologic studies. In view of the experimental evidence, DHS staff believe that the effects observed in studies of human populations are unlikely to be due to SO_2 alone; nevertheless, as described below, the epidemiologic data are sufficient to warrant a standard that is not linked to particulate matter or oxidant.

There are numerous epidemiologic studies published since 1977 linking exposure to SO_2 with respiratory symptoms, decreased pulmonary function, and mortality. Although many of these investigations also indicate that particulate matter is associated with these outcomes, several studies appear to show an effect of SO_2 where one from particulate matter cannot be demonstrated. Furthermore, in some of the publications reporting an effect of both pollutants, SO_2 and particulates are strongly correlated, but in others the correlation of the daily levels of these pollutants is only weak to moderate. Thus, it is reasonable to infer an effect of SO_2 independent of particulate matter concentration.

The issues regarding the joint SO_2-oxidant standard are somewhat different. In 1975, Hazucha and Bates reported that the combined effects of ozone and SO_2 were greater than those of the individual pollutants in human volunteers exposed in an environmental chamber. This report formed the basis for DHS's suggestion that there might be interactive effects involving these pollutants in some California air basins. Several more carefully controlled studies have failed to confirm the findings of the 1973 publication (Bedi et al. 1979, 1982; Bell et al. 1977; Folinsbee et al. 1985). Although one paper (Kagawa 1983) ostensibly supports the results of Bates and Hazucha, the statistical methodology used in the analysis is questionable. Therefore, DHS staff suggest that the scientific basis of the joint 24-hour SO_2-oxidant standard has been substantially weakened. A recent report by Koenig et al. (1990) does show that sequential exposures to ozone (45 minutes) and SO_2 (15 minutes) cause bronchoconstriction in adolescent asthmatics, in contrast to the studies cited above (all of which involved participation by nonasthmatic volunteers). This study does not, in itself, support retention of the joint 24-hour ambient standard. Rather, DHS staff will utilize this information in the rationale for an appropriate safety margin in the one-hour SO_2 standard, which will be submitted at a later date.

4. REVIEW OF EPIDEMIOLOGIC STUDIES

a. Effects on Respiratory Symptoms and Disease

Several epidemiologic studies, in different geographic locations and with different population groups, indicate that exposure to ambient SO_2 (alone and in combination with other pollutants) is associated with an increased incidence of respiratory symptoms. This section describes studies relevant to the determination of a 24-hour SO_2 standard. Studies that provide either quantitative or qualitative evidence include Charpin et al. (1988) (respiratory symptoms among French children), Dodge et al. (1985) (respiratory symptoms and lung function in children in Arizona), and Bates and Sizto (1983, 1987, 1989, 1990) (respiratory admissions to hospitals in Ontario, Canada and emergency room visits in Vancouver). This section also reviews investigations that provide supporting evidence of an association between SO_2 and respiratory symptoms, but which cannot be used quantitatively. These studies, which either use much longer averaging times for SO_2 or report high correlation among pollutants, include those by Samet et al. (1981), Pönkä (1990), and Goren et al. (1988). Two epidemiologic studies are also described where no association between SO_2 and daily symptoms was found. Vedal et al. (1987) and Pershagen et al. (1984) provide a basis for describing a lower boundary for effects attributable to 24-hour averages of SO_2. Table 1 summarizes the study designs and results of the studies that relate SO_2 to respiratory morbidity.

Charpin et al. (1988) examined the effects of SO_2 on respiratory symptoms in children using a high SO_2 area near a coal power plant in France. The study involved 450 children aged 9 to 11 in eight communities, whose respiratory symptoms were logged in a daily diary for one month by their parents. Two separate analyses were undertaken. First, symptom scores were correlated with

Table 1. Summary of Sulfur Dioxide Effects on Respiratory Symptoms

Study	Population	Mean SO_2 Concentration (24-hr average, ppm)	Results
Charpin et al. (1988)	Children in coal basin in France	high: 0.06 (0.02-0.09) low: 0.02 (0.01-0.04)	Daily symptom scores related to SO_2 in high area, but not to PM. Low correlation between pollutants.
Dodge et al. (1985)	Children near smelter	high: 0.04 (± 0.1) low: 0.02 (± 0.07)	Higher prevalence of cough in high SO_2 area. Low correlation between SO_2 and particulates.
Bates et al. (1990)	Ages 1-14,15-60, 60+ in Vancouver, Canada	0.024 annual mean	Correlation for all age group between emergency room visits and SO_2. Moderate correlations between pollutants.
Samet et al. (1981)	All ages in Steubenville, OH	0.034 (± 0.03)	Emergency room visits related to SO_2, TSP.
Ponka et al. (1990)	Children and adults in Helsinki, Finland	0.02 (0.01-0.05) as mean of one-week average of 1 hr daily maxima	Upper respiratory illness in children and absenteeism in children and adults correlated with SO_2.
Goren et al. (1988)	Children in Israel	high: 0.011 low: 0.0016 as monthly average	Higher prevalence of respiratory symptoms and disease in high pollution area.
Vedal et al. (1987)	Children in Western Pennsylvania	0.02 (0.01-0.07)	No correlation of daily symptoms with SO_2, COH.
Pershagen et al. (1984)	Adults: COPD and sensitive individuals	0.01 (0-0.04)	No correlation of respiratory symptoms to SO_2.

Abbreviations: PM - particulate matter, TSP - total suspended particulates; COH - coefficient of haze; COPD - chronic obstructive pulmonary disease

SO_2 and particle readings in each city. This analysis showed that only in the two most polluted cities (mean 24-hour SO_2 levels = 0.06 ppm, with a range of 0.02 to 0.09 ppm) were the correlations statistically significant. The incidence of both cough ($p < 0.05$) and wheezing ($p < 0.01$) were significantly related to 24-hour SO_2 readings. Mean daily SO_2 levels in the other cities ranged from 0.01 to 0.04 ppm for the same period, and were not correlated with symptoms. In both the "high" and "low" polluted areas, the respirable particulate level (particulate matter approximately 3.5 microns or less in diameter) averaged over 24 hours was 56 $\mu g/m^3$, and was not correlated with daily symptom prevalence. Temperature was not correlated with symptoms during the one-month period of analysis. Since the particulate matter levels were similar in the two areas, this study suggests that SO_2 (or perhaps other sulfur compounds) was associated with cough and wheezing. In the second analysis, the prevalence of respiratory symptoms during two-week periods of either high or low pollution were compared within each city. For each city, symptom prevalence was higher during the higher air pollution period, although the differences were not statistically significant.

Dodge et al. (1985) examined respiratory symptoms in an area with moderate levels of SO_2 and low levels of particulate sulfate and fine particulates near an Arizona smelter. This study compares the health of 343 children in third through fifth grades, living in areas with "high" versus "low" SO_2 concentrations. The mean 24-hour average for SO_2 in the "high" pollution area was 0.04 (standard deviation (sd) ± 0.11) ppm versus 0.02 (sd ± 0.07) ppm or less for the other areas. The mean TSP and sulfate readings in the high pollution area were 52 and 10 $\mu g/m^3$, respectively. The point prevalence of cough, as reported on an intake questionnaire, correlated significantly with SO_2, but not with other air pollutants. However, based on annual questionnaires and lung function tests, neither the incidence of respiratory symptoms nor longitudinal growth of pulmonary function was correlated with SO_2 concentrations. Since the prevalence of parental smoking and that of gas stove use were not different across the study groups, these factors could not explain the observed difference in the prevalence of cough. However, other unmeasured differences between the study groups, such as socioeconomic status, could account for some of the differences. In this study, repeated exposure to low to moderate levels of SO_2 and sulfate were associated with a one-time ascertainment of cough, but not with longer-term effects on respiratory symptoms or growth in children's lung function. It is difficult to determine a level of effect from this study, however, because the time when the relevant exposure took place is uncertain. This study has particular relevance for the SO_2 standard since particulate matter, a potential confounder, was at low concentrations, and because in the arid Arizona climate it is unlikely that SO_2 was a surrogate for sulfuric acid or fine particulate sulfates.

In a series of studies of hospital admissions in southern Ontario, Canada, Bates and Sizto (1983, 1987, 1989) examined the daily effects of sulfur compounds (including both SO_2 and sulfates) and ozone. Summer and winter effects were disaggregated to reduce the impact of seasonal variations and influences. The 1983 study indicated an association in the summer months between hospital admissions related to respiratory disease and concentrations of SO_2 and ozone. This study took into account the potential confounding of temperature, humidity, and day of the week. The authors suggest that the mean level of SO_2 associated with an increase in admissions was 0.032 ppm, while that for ozone was 0.063 ppm. Unfortunately, the high covariation between these two pollutants makes it difficult to determine the extent of any independent impact of SO_2. Subsequently, Bates and Sizto (1987) incorporated additional years of data and the measurement of ambient sulfates. The correlation analysis of the daily data indicates that, during the summer, SO_2, ozone, and sulfate were related to both asthma and other respiratory-related hospital admissions. Summer SO_2 readings averaged 0.02 ppm and sulfate averaged 10.3 $\mu g/m^3$. Again, however, daily concentrations of ozone, SO_2, and sulfates were highly correlated, so it is not possible to isolate what effect, if any, SO_2 had on the trend in hospital admissions.

More recently, Bates et al. (1990) analyzed emergency room visits in Vancouver, British Columbia. The study involved emergency visits over a 28-month period from 1984 to 1986, including approximately 8,300 visits per year for acute respiratory conditions. The data for both asthma and other respiratory-related visits were correlated with several air pollutants for each of three age groups (ages 1-14, 15-60, and 60+). Smaller correlations among the pollutants were reported in this study, since Vancouver has much lower levels of ozone and sulfates (and most likely acid aerosols, as well) than southern Ontario. Specifically, the correlations between SO_2 and three pollutant measures -- ozone, sulfates, and coefficient of haze (COH), a measure of particulate air pollution -- were 0.23, 0.46, and 0.34, respectively. Analyses of these data indicate that, for the summer months, the more significant correlations appear for the age 15 to 60 subgroup, and indicate an association between nonasthma respiratory admissions and both SO_2 and sulfates. However, the seasonal September peaks in asthma visits that were observed could not be attributed to SO_2. At concentrations measured in Vancouver, ozone does not appear to be related to either asthma or other respiratory-related visits. In the winter, SO_2 is associated with respiratory-related emergency room visits across all three age groups, and is related to asthma admissions for the oldest subgroup. While this study provides greater evidence for a sulfur-specific effect than the Ontario studies, which were more subject to confounding from ozone, there is still uncertainty regarding the specific pollutant of concern and the concentrations that would produce the observed health outcomes. Nevertheless, the research indicates an effect of SO_2 and related sulfur compounds on asthma and other respiratory disease admissions at modest levels of exposure.

Pönkä (1990) investigated the association between weekly averages of air pollution and respiratory infections and absenteeism in children and adults in Helsinki, Finland. The mean of the one-week averages of one-hour daily maxima for SO_2 was 0.02 ppm, with a range of 0.01 to 0.05 ppm, while TSP ranged from 48 to 123 $\mu g/m^3$. Temperature was inversely correlated with SO_2 ($p < 0.0001$). All social classes and age groups were included. Among the health outcomes measured were upper respiratory tract infections diagnosed at communal health centers, upper and lower respiratory tract infections in children attending day care centers, and absenteeism due to febrile illness among day care children, schoolchildren, and adults. Weekly averages of SO_2 and temperature were both associated with upper respiratory illness in children, and with absenteeism in day care attendees and adults. After an attempt was made to standardize for temperature, only respiratory illness diagnosed at health centers remained correlated with SO_2. Of note, when weekly particulate matter concentrations were highest, there was no corresponding peak observed in the number of respiratory tract infections or absenteeism. However, this could have been due to strong seasonal patterns of illness. The use and reporting have been due to strong seasonal patterns of illness. The use and reporting of only weekly averages precluded the determination of a relevant 24-hr average level of effect.

Samet et al. (1981) examined the daily association between air pollution and emergency room visits in Steubenville, Ohio. The 24-hour averages for SO_2 and TSP (which were highly correlated: r = 0.69) were 0.034 (sd ± 0.03) ppm and 156 (sd ± 123) $\mu g/m^3$, respectively. Small but significant associations were observed between emergency room visits for respiratory disease and both SO_2 and TSP. Because of the high covariation between these two pollutants, an independent effect from SO_2 cannot be identified.

Goren et al. (1988) investigated the association between SO_2 and the prevalence of respiratory symptoms in two communities in Israel in 1982. Over 3,000 second and fifth grade schoolchildren were sampled in Ashdod (monthly average SO_2 of 0.011 ppm, with a 1/2-hour maximum of 0.32 ppm in 1982) and Hadera (monthly average SO_2 of 0.0016 ppm with a 1/2 hour peak of 0.16 ppm). Children's symptoms were documented using a questionnaire filled out by their parents. There was a significantly higher prevalence of several different respiratory symptoms (i.e., cough without cold, sputum without cold, wheezing, chest illness) and respiratory diseases (asthma, pneumonia) in Ashdod, the more polluted city. This difference appeared to exist after controlling for differences in other potential confounders, such as the type of home heating, crowding, father's educational level, and mother's smoking status. This study may be particularly relevant to southern California because of the similarity in climate. Unfortunately, 24-hour averages of SO_2 were not reported.

In two other studies, there was no association between low to moderate levels of SO_2 and respiratory symptoms (Vedal et al. 1987; Pershagen et al. 1984). In a study of children in western Pennsylvania, Vedal et al. (1987) examined the association between relatively low levels of SO_2 (mean = 0.02 ppm, range = 0.01 to 0.07 ppm) and peak flow (one measure of lung function) and respiratory symptoms. Based on responses to questionnaires about respiratory conditions over the previous year, children were divided into three groups -- those with persistent wheeze, those with chronic cough, and those without symptoms. Peak flow and symptoms were recorded for a nine-week period beginning in the fall of 1980. Neither SO_2 nor COH was significantly associated with either upper or lower respiratory symptoms (including wheeze) recorded in daily diaries.

Pershagen et al. (1984) analyzed daily symptom rates in a group of subjects with hospital-diagnosed chronic obstructive pulmonary disease (COPD) and a group of individuals deemed potentially "sensitive" to air pollution based on their responses to previously administered questionnaires. The latter group was subsequently classified into subgroups having either cough or other irritative symptoms. The mean SO_2 concentration was 0.01 ppm (range 0 to 0.04 ppm) and TSP levels were also quite low (mean = 20 $\mu g/m^3$; range 2 to 66). Simple correlation coefficients between ambient levels and symptoms were calculated for each of the three groups. No significant correlation was found between SO_2 and respiratory symptoms in any group. However, multiple regressions controlling for potential confounders were not performed, nor were there any controls for weekend or day-of-study effects. Nevertheless, these studies suggest the existence of a potential threshold for SO_2-related symptoms, below which the detection of any effect related to SO_2 exposure is difficult.

b. Changes in Pulmonary Function

Several epidemiologic studies indicate that exposure to ambient SO_2 may cause transient decrements in pulmonary function. This section describes such studies of children in Steubenville, Ohio (Dockery et al. 1982), children in Holland (Brunekreef et al. 1989; Dassen et al. 1986), and adults in Holland (van de Lende et al. 1975). One epidemiologic study is described (Vedal et al. 1987) which indicates no association between exposure to low levels of SO_2 and pulmonary function. Table 2 summarizes the results of the pulmonary function studies.

Dockery et al. (1982) examined pulmonary function in children in response to episodes of increased SO_2 and TSP in Steubenville, Ohio. Measurements of baseline pulmonary function (forced vital capacity (FVC) and forced expiratory volume in 0.75 seconds ($FEV_{0.75}$)) were recorded and then retaken four times within each of four separate periods between 1978 and 1980. SO_2 concentrations were highly correlated with TSP (r = 0.74). In three of the four periods, both FVC and $FEV_{0.75}$ declined significantly relative to a baseline measurement taken earlier in each of the periods. Such decrements in pulmonary function persisted for up to two weeks following high air pollution levels. The maximum 24-hour averages for these three periods were 0.11, 0.17, and 0.06 ppm for SO_2, and 422, 271, and 220 $\mu g/m^3$ for TSP. In the fourth period, when air pollution levels were the lowest (24-hour maxima were 0.07 ppm for SO_2 and 159 $\mu g/m^3$ for TSP), there was a slight but statistically insignificant reduction in lung function below baseline. However, the baseline lung examinations were performed when air pollution levels were among the highest in the period. In a second analysis of the data, regressions were estimated to determine the association of pulmonary function and air pollution. Both SO_2 and TSP, considered separately, were significantly related to lung function. The precise level of effects is difficult to determine from these results since, in two of the periods, lung function tests were preceded by either a very high SO_2 or TSP episode. Whether these peaks or repeated exposures to lower levels drive the results is not possible to determine. In addition, since children with pre-existing respiratory disease were apparently not excluded from the study, there may have been a subgroup of children particularly responsive to these pollutants. Nevertheless, the reported average magnitude of the decrement in FVC attributable to SO_2 exposure was 150 ml/ppm.

Supporting results have been reported by Brunekreef et al. (1989), Dassen et al. (1986), and van de Lende (1975). The Brunekreef et al. (1989) study examined pulmonary function changes over time of 1000 schoolchildren aged 6 to 12. Baseline lung function values were obtained three months prior to an air pollution episode in January 1987, in a rural part of the Netherlands. Lung function tests were repeated at the end of the episode and 2.5 and 3.5 weeks later. Baseline levels were corrected for growth rates to determine a new expected level of lung function and then differences between observed and expected levels of FEV_1 (forced expiratory volume in 1 second) and FVC were recorded. The 24-hour average SO_2 concentration was approximately 0.11 ppm at the beginning of the episode, falling to 0.06 ppm by the end. Particulate matter was below 100 $\mu g/m^3$ (24-hour average) during the episode and did not demonstrate any significant peaks. In this study, particulate matter was measured as "British smoke", a European method to measure the intensity of

Table 2. Summary of Sulfur Dioxide Effects on Pulmonary Function

Study	Population	Mean SO_2 Concentration (24-hr average, ppm)	Results
Dockery et al. (1982)	Children in Steubenville, OH	Maximum in 4 different periods of 0.11, 0.17, 0.06, 0.07	Association of SO_2 with decrements in pulmonary function. Correlation of SO_2 and TSP.
Brunekreef et al. (1989)	Children in the Netherlands	0.06-0.11	Association of SO_2 with decrements in pulmonary function.
Dassen et al. (1986)	Children in the Netherlands	high: 0.08-0.10 low: 0.04-0.06	Association of SO_2 with decrements in pulmonary function.
Van de Lende et al. (1975)	Adults in the Netherlands	high: 0.05-0.12 low: 0.02-0.04	Association of SO_2 with decrements in pulmonary function. High correlation with particulates.
Vedal et al. (1987)	Children in western Pennsylvania	0.02 (0.01 - 0.07)	No correlation of of daily lung function with SO_2, COH.

TSP = Total Suspended Particulates, COH = Coefficient of Haze.

blackening on a filter paper through which a specified volume of air is drawn. Total suspended particulates, however, did rise to a maximum of 280 $\mu g/m^3$ during the episode. There were statistically significant decrements in pulmonary function after the episode ($p < 0.001$). These decrements persisted into the second and third retests, with a maximum difference from baseline occurring approximately two weeks after the episode. Temperature did not appear to be a confounder in this case. In addition, the authors believed that acidic aerosols were low during this period.

The Dassen et al. (1986) study recorded several different pulmonary function tests in children following an air pollution episode in the Netherlands in 1985. Compared to pre-episode baseline lung function, pulmonary function decrements were associated with SO_2, TSP, and respirable particle concentrations in the 200-250 $\mu g/m^3$ range (0.08 to 0.10 ppm SO_2). In a third examination 25 days after the episode, SO_2 (0.04 to 0.06 ppm) and TSP (100 to 150 $\mu g/m^3$) did not appear to cause reductions in lung function. These findings are consistent with those of Dockery et al. (1982) and Brunekreef et al. (1989) regarding the magnitude of the decline in lung function, the general level of air pollution concentrations associated with an effect, and the duration of the decrement in pulmonary function.

Van de Lende et al. (1975) explored the association between air pollution and pulmonary function in adults living in the Netherlands. The study examined individuals during five days in 1969 when SO_2 concentrations ranged from 0.05 to 0.12 ppm, and particulate matter (measured as British smoke) from 40 to 140 $\mu g/m^3$. The same population was examined three years later on days with SO_2 concentrations from 0.02 to 0.04 ppm with British smoke ranging from 20 to 30 $\mu g/m^3$. There were significantly lower levels of lung function during the earlier period with higher air pollution. However, since regular measurements of air pollution were not carried out in 1969, the lower level of pulmonary function noted at that time could have been due to unmeasured peaks in air pollution prior to the pulmonary function testing (van de Lende et al. 1986).

In a study of children in western Pennsylvania, Vedal et al. (1987) (described above) examined the association between SO_2 and peak flow and respiratory symptoms. The investigators examined children exposed to relatively low levels of SO_2 (mean = 0.02 ppm with a range of 0.01 to 0.07 ppm). Peak flow measurements were recorded on a daily basis for a consecutive nine-week period. The analysis showed no association between these levels of SO_2 and peak flow. However, the authors noted that the subgroup with persistent wheeze tended to be sensitive to changes in SO_2, but no supporting analysis was provided.

c. Risks of Mortality

Several epidemiologic studies in different locations indicate that SO_2, acting alone or as a surrogate for other sulfur-related species, is associated with an increased risk of mortality. This section describes those studies relevant to the determination of the 24-hour SO_2 standard, including investigations in Athens (Hatzakis et al. 1986), France (Derriennic et al. 1989; Loewenstein et al. 1983), England (Chinn et al. 1981), and Poland (Krzyzanowski and Wojtyniak 1982). In addition, evidence of the association between air pollution and mortality in London during the winters of 1958 to 1972 is discussed. Table 3 summarizes the results of these studies.

Hatzakis et al. (1986) explored the relationship between daily mortality and air pollution in Athens, Greece from 1975 to 1982. Mean daily levels of SO_2 and British smoke were 0.03 (sd ± 0.02) ppm and 63 (sd ± 26) $\mu g/m^3$, respectively. The pollutants were moderately correlated ($r \approx 0.55$). Mortality was adjusted for seasonal patterns over time by calculating an observed minus predicted measure. Regression analysis was used to control for temperature, humidity, holidays, and annual, seasonal, monthly and weekly trends. SO_2 and excess all-cause mortality were correlated when all other independent variables were taken into account. Particulates, however, were not related to mortality. In addition, the effects of SO_2 were observed even when only daily averages below 0.06 ppm were considered. However, no effects were observed below 0.04 ppm. This study may be particularly relevant since the climate in Athens is similar to that in much of the more densely populated regions of California. DHS staff has calculated the potential effect on mortality in California using the results of the Hatzakis et al. study. For a 0.05 ppm daily increase in SO_2 over the range of concentrations in the study, there could be an excess of 0.44 to 2.63 deaths/day in a population of one million.

Derriennic et al. (1989) analyzed daily mortality for individuals over 65 years of age in Marseilles and Lyons, France between 1974 and 1976. Daily averages of SO_2 and suspended particulates were 0.03 ppm and 106 $\mu g/m^3$, respectively, but monthly SO_2 averages were above 0.07 ppm during certain times of the year. These two pollutants were moderately correlated ($r \approx 0.46$). Seasonal influences were statistically dampened in order to elicit more clearly any effect associated with daily variation in pollution levels. The authors noted that temperature, which was inversely correlated with SO_2, was correlated with respiratory mortality in Lyons and with cardiovascular mortality in Marseilles. The analysis (using correlation and multiple regression, controlling for temperature) demonstrated a statistically significant association between SO_2 and respiratory deaths in both cities, and between SO_2 and circulatory deaths in Marseilles. The authors argued that the SO_2 effects were independent of the impact of temperature, since the regression coefficient relating SO_2 to respiratory mortality was similar for the two cities, but in only one was temperature correlated with mortality. Similarly, the association of SO_2 with circulatory deaths in Marseilles (but not Lyons) may be explained by the high correlations in that city between SO_2 and temperature, and between temperature and mortality. No association between particulates and mortality was detected in either city. This study is supported by an earlier investigation by Loewenstein et al. (1983), who found a strong correlation between SO_2 and respiratory mortality (especially for the population above 75 years of age) in Paris over a 10-year period. DHS staff have also used the Derriennic et al. results to calculate that a 0.05 ppm increase in SO_2 could result in an increased risk of respiratory mortality to those over age 65 of 30.15 deaths/day per million people. If those over age 65 constitute 12 percent of the population (as in the entire United States), this could amount to excess mortality of 3.62/day per million people for the total population, which is close to the upper end of the range derived from the study by Hatzakis et al.

Chinn et al. (1981) investigated the association between mortality of people aged 45 to 74 and air pollution in London, England, and Wales. Mean SO_2 and British smoke levels were not provided explicitly, but visual inspection of the relevant graph in the text suggests mean pollutant concentrations of 0.06 ppm and 80 $\mu g/m^3$, respectively. Two age groups for both men and women

Table 3. Summary of Sulfur Dioxide Effects on Mortality

Study	Population	Mean SO_2 Concentration (24-hr average, ppm)	Results
Hatzakis et al. (1986)	Athens, Greece	0.03 (± 0.02)	See A
Derriennic et al. (1989)	Marseilles, Lyons France	0.03	See B
Chinn et al. (1981)	ages 45-74 in London & Wales	≈0.06	See C
Krzyzanowski el al. (1982)	Cracow, Poland	High: 0.04 Low: 0.02	See D
Martin and Bradley (1960) and others	London winters	≈ 0.07	See E

(A) Association between daily SO_2 (but not PM) and excess mortality when SO_2 ≥ 0.06 ppm.

(B) Association between daily SO_2 (but not PM) and respiratory mortality for those over age 65 in both cities.

(C) Correlation between SO_2 and mortality from chronic bronchitis in men ≥65 and women aged 46-65.

(D) Association between all-cause mortality and residence in "high" (central city) vs "low" (suburb) air pollution areas.

(E) Association between all-cause mortality and both SO_2 and British Smoke. High correlation between pollutants.

were analyzed: those aged 45 to 64 and 65 to 74. In addition to total mortality, several specific causes of death were considered, including hypertensive disease, influenza, and chronic bronchitis. There was little correlation between either SO_2 or British smoke and mortality, prompting the authors to suggest that this was a negative study. However, SO_2 was correlated with mortality from chronic bronchitis among men over 65 ($r = 0.22$) and women between 45 and 65 ($r = 0.26$).

Krzyzanowski and Wojtyniak (1982) examined the association between individual-specific daily mortality and air pollution over a ten-year period in Cracow, Poland. People living in the city center were defined as exposed to "high pollution" (mean 24-hour SO_2 of 0.04 ppm with the maximum several times higher; 24-hour average of particulates less than 10 microns in diameter (PM10) of 180 $\mu g/m^3$) versus those residing in the less polluted suburbs (mean concentrations were 0.02 ppm SO_2 and 109 $\mu g/m^3$ PM10). Age-adjusted, gender-specific mortality rates were calculated and regression analysis was used to control for covariates, including smoking, occupational status, and several socioeconomic factors. The investigators reported a significant statistical relationship between air pollution and all-cause mortality for men. Also, men exhibited a strong effect from the interaction of cigarette smoking and air pollution. Cause-specific analysis was not undertaken due to sample size problems (i.e., there were too few daily deaths to attain adequate statistical power), but respiratory disease was noted to constitute a large fraction of the central city mortality. There was no association demonstrated between air pollution and mortality for women. Although this study controlled for many differences that may exist between central city and suburban residents, there still is the possibility of geographic confounding. In addition, because of the high correlation between pollutants, the authors were not able to identify which might be responsible for the estimated effects.

Additional information is provided by the analyses of the daily measurements of air pollution and mortality in London during the winters of 1958-1959 to 1971-1972 (Martin and Bradley; 1960; Mazumdar et al. 1982; Ostro 1984; Schwartz and Marcus 1990). In the latter years of this data set, the 24-hour averages for the winter were approximately 0.07 ppm for SO_2, and 65 $\mu g/m^3$ British smoke. Although these analyses involve several different statistical methods, the following general conclusions can be drawn: (1) a strong relationship exists between air pollution and daily mortality in London, which holds both for the entire data set and for individual years (the later years exhibited almost a 10-fold decrease in air pollution concentrations); (2) no indication of a threshold (i.e., "no-effects level") is evident at the lower concentrations of air pollution experienced in London; and (3) the high degree of covariation ($r \approx 0.9$) between SO_2 and British smoke precludes the determination of an independent effect of either pollutant. The magnitude of effect implied by the London data is within the range of that indicated by Hatzakis et al. (1986). The results of Schwartz and Marcus (1986, Table 3) suggest that a 0.05 ppm increase in the 24-hour average concentration of SO_2 could result in approximately 0.8 to 0.9 excess deaths/day in an exposed population of one million people.

5. DERIVATION OF THE RELEVANT RANGE OF SO_2 CONCENTRATIONS

a. General Considerations

As noted above, a subset of the epidemiologic studies described above form the basis for the DHS recommendation for a 24-hour SO_2 standard. The studies involve different cities, seasons, populations, methods, health effects, and potential confounders. However, as noted in Section 3, it is improbable that the health effects cited above are purely the result of exposure to SO_2 alone. Thus, in these epidemiologic studies, it is likely that SO_2 is serving as an surrogate for a complex mix of pollutants including sulfate and nonsulfate particulates.

b. Determination of the Level of Effects

DHS believes that the weight of evidence indicates that there is a significant probability of risks to public health associated with SO_2 concentrations of 0.06 ppm and above. This recommendation is based on a subset of the epidemiologic studies described in Section 4. In formulating this recommendation, DHS staff relied only on those studies that provided a relatively clear indication of the relevant concentrations of SO_2 associated with health effects. Studies were not explicitly used to derive the concentration range of interest if they had either too many uncertainties in method or design, problems with confounding or omitted variables, lack of control for seasonality or weather, an indeterminate level of effects, or an SO_2 averaging time substantially longer than 24 hours. Throughout the following discussion, we assume that the level of effect is between the mean and the maximum of the range reported in studies using regression analysis to estimate a dose-response relationship. Table 4 displays the studies that provided quantitative information for the recommendation and the levels of effect inferred from these studies.

The Charpin et al. (1988) study indicated an association between respiratory symptoms and air pollution in cities with a range of SO_2 concentrations of 0.06 to 0.09 ppm. The same study indicated no association for cities with a range of 0.02 to 0.04 ppm SO_2. Since the particulate levels were similar for the "high" and "low" pollution areas, this study appears to indicate effects related more to SO_2 concentrations than to particulates.

The studies on lung function support this general range for the level of effects. Dockery et al. (1982) found an association between decrements in lung function and air pollution when the SO_2 concentration was between 0.06 and 0.11 ppm. However, SO_2 and particulate matter were highly correlated. This study suggests that for Steubenville, the effect may be more associated with the pollutants represented by the particulate measurement, possibly due to a different mix of sulfur compounds than in the Charpin et al. (1988) study. The Dassen et al. (1986) study generates a similar effects range. This study indicates that lung function decrements were associated with SO_2 concentrations between 0.08 and 0.10 ppm. The study found no association when SO_2 dropped to 0.04 to 0.06 ppm. Likewise, van de Lende et al. (1975) indicate an association of air pollution and lung function decrements on days with SO_2 concentrations between 0.05 and 0.12 ppm. No association was observed when SO_2 dropped to 0.02 to 0.04 ppm. Finally, Brunekreef et al. (1989) found an association between pulmonary function changes and SO_2 concentrations between 0.06 and 0.11 ppm.

Hatzakis et al. (1986), who specifically tested for a threshold level, found an association between daily SO_2 and mortality in Athens continuing down to

SO_2 levels of 0.06 ppm. Particulate matter was not significantly associated with mortality in this study. Derriennic et al. (1989) found associations between mortality and SO_2, but not particulates, in two French cities. The actual effect level suggested by this study is unclear, but SO_2 levels above 0.06 ppm were observed for significant periods of time in both cities. Finally, Chinn et al. (1981) reported an association between SO_2 and mortality from chronic bronchitis. Again, the specific level of effect is difficult to determine. However, visual observation of the data suggests a mean SO_2 level of 0.06 ppm, with a maximum of 0.11 ppm.

Additional information on the effects level is supplied by the negative studies of Vedal et al. (1987) and Pershagen et al. (1984). These two studies found no association between respiratory symptoms and air pollution when SO_2 levels were between 0.02 and 0.07 ppm.

Charpin et al. (1988), Van de Lende et al. (1975), and Hatzakis et al. (1986) all reported health effects when SO_2 levels were 0.06 ppm and above. It is also of note that in the Charpin et al. and Hatzakis et al. studies, as well as that of Bates and Sizto (1990), SO_2 was associated with adverse health outcomes, while particulate matter was not. This suggests that SO_2 is an important surrogate for the mix of pollutants or may be itself a contributor to adverse health outcomes. However, the potential for health effects related to PM10 should not be ruled out because of possible measurement problems. Specifically, in all four of these studies, particulates were measured as either British smoke or COH. These measures may not accurately account for the more important species relating to subsequent health impacts, such as acid sulfates. For example, recent research by Thurston et al. (1989) indicated that mortality in London between 1958 and 1972 might be more associated with sulfuric acid aerosols than with British smoke, per se.

In summary, the above evidence suggests that a variety of adverse health effects have been observed in diverse populations in different geographic locations when 24-hour SO_2 concentrations are approximately 0.06 ppm or greater. No such effects have been detected when 24-hour SO_2 concentrations are 0.04 ppm or less. Thus, a 24-hour average SO_2 concentration of 0.04 ppm is likely to be protective of public health in California with an adequate margin of safety. However, in stating this position, DHS recognizes the potential for lending a false sense of precision to these numbers. It must be borne in mind that the studies on which this recommendation is based used fixed-site monitors and thus an exact dose or level of effect cannot be ascertained. Furthermore, we assumed, as noted above, that in most of these epidemiologic investigations, the level of effect lies somewhere between the mean and the upper end of the SO_2 concentration range reported. Nevertheless, taken together, the subset of epidemiologic studies with data adequate to estimate a range of concentrations associated with health effects are remarkably consistent, and provide a reasonable basis for this recommendation.

TABLE 4. Summary of Relevant Studies and Inferred Levels of SO_2 Effect.

Study	Effect	Inferred SO_2 Level of Effect (ppm)
Positive Studies		
Charpin (1988)	Respiratory symptoms	0.06-0.09
Dassen (1986)	PFT	0.08-0.10
Dockery (1982)	PFT	0.06-0.11
Van de Lende (1975)	PFT	0.05-0.12
Hatzakis (1986)	Mortality	0.06 threshold
Chinn (1981)	Mortality	~0.06
Derriennic (1989)	Mortality	0.05-0.07
London data	Mortality	~0.07
Negative Studies*		
Charpin (1988)	Respiratory symptoms	0.02-0.04
Vedal (1987)	Respiratory symptoms, PFT	0.02-0.07
Pershagen (1984)	Respiratory symptoms	0.01-0.04
Dassen (1986)	PFT	0.04-0.06
Van de Lende (1975)	PFT	0.02-0.04

* Includes "no effects" findings from otherwise positive studies.
PFT = pulmonary function test.

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APPENDIX B

PROPOSED REGULATION ORDER

1. Amend section 70100, Title 17, California Code of Regulations, to read as follows[1]:

Article 2. Ambient Air Quality Standards

70100. Definitions.

*** [(a)-(j) no change]

(k) Total Suspended Particulate Matter. Total suspended particulate matter refers to suspended atmospheric particles of any size, solid and liquid, except uncombined water. Total suspended particulate matter is to be measured by the high volume sampler method or by an equivalent method. ~~for purposes of monitoring for compliance with the 24-hour Sulfur Dioxide (SO_2) standard.~~

*** [(l)-(s) no change]

NOTE: Authority cited: Sections 39600 and 39601, Health and Safety Code. Reference: Sections 39602 and 39606 (b), Health and Safety Code.

1. Section 70100, Definitions., includes 20 definitions for pollutants or terms describing standards or pollutants. Only those definitions proposed to be amended are shown.

2. Amend section 70200, Title 17, California Code of Regulations, to read as follows[1]:

70200. Table of Standards***

Substance	Concentration and Methods**	Duration of Averaging Periods	Most Relevant Effects	Comments
	* *	*	* * * *	* *
Sulfur Dioxide (SO_2)	0.25 ppm** flour-escence method	1 hour	a. Bronchoconstriction accompanied by symptoms, which may include wheezing, shortness of breath and chest tightness, during exercise or physical activity in persons with asthma.	The standard is designed to protect against adverse effects from short-term (5-10 min.) peak exposures.
	0.04 ~~0.05~~ ppm** flour-escence method, ~~with oxidant, (ozone) equal to or greater than the state standard, or with total suspended particulate matter equal to or greater than the state 24-hour suspended particulate matter standard. ****~~	24 hours	~~a. Will help prevent respiratory disease in children~~ ~~b. Higher concentrations associated with excess mortality.~~ a. Increased incidence of pulmonary disease and symptoms, decreased pulmonary function, and increased risk of mortality.	a. Further studies on co-carcinogenic role are necessary. b. Does not include effects on vegetation, ecosystems and materials. c. May ~~not include a margin of safety.~~ Effects may not be due to SO_2 alone, but also suspended particulate matter, including sulfates and acids.
Visibility Reducing Particles	In sufficient***** amount to produce extinction of 0.23 per kilometer due to particles when relative humidity is less than 70 percent. Measurement in accordance with ARB Method V.	8 hour (10 AM-6PM Pacific Standard Time)	Visibility impairment on days when relative humidity is less than 70 percent.	This standard is intended to limit the frequency and severity of visibility impairment due to regional haze and is equivalent to a 10-mile visual range when relative humidity is less than 70 percent.

Visibility Reducing Particles (Applicable only in Lake Tahoe)	In sufficient***** amount to produce extinction of 0.07 per kilometer due to particles when relative humidity is less than 70 percent. Measurement in accordance with ARB Method V.	8 hour (10 AM-6PM Pacific Standard Time)	Reduction in scenic quality on days when the relative humidity is less than 70 percent.	This standard is equivalent to a 30-mile visual range when relative humidity is less then 70 percent.

* * * * * * * * *

* Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

** These standards are violated when concentrations exceed those set forth in the body of the regulation. All other standards are violated when concentrations equal or exceed those set forth in the body of the regulation.

*** Applicable statewide unless otherwise noted.

~~****The 24-hour suspended particulate matter standard referred to is that adopted by the Board in 1969, of 100 ug/m³ as measured by high volume sampler.~~

**** ***** These standards are violated when particle concentrations cause measured light extinction values to exceed those set forth in the regulations.

NOTE: Authority cited: Section 39600, 39601 (a) and 39606 (b), Health and Safety Code.
Reference: Sections 39014, 39606 (b), 39701 and 39703 (f), Health and Safety Code.

1. The Table of Standards, section 70200, includes standards for nine pollutants. Only those standards proposed to be amended are shown.

3. Repeal section 70201, Title 17, California Code of Regulations, as follows:

~~70201. Determination of 24-hour SO_2 Standard.~~

~~In connection with measurements taken to determine compliance wit- the 24-hour SO_2 standard established section 70200:~~

~~(a) The SO_2 concentration, the oxidant concentration, and/or the total suspended particu-~~
~~monitoring station.~~

~~(b) A single sulfur dioxide average concentration is to be determined over a fixed, continuous 24-hour interval beginning and ending on the hour. The 24-hour interval shall be the same as that used for the determination of total suspended particulate concentration. A midnight to midnight 24-hour period is recommended.~~

~~(c) If the average concentration of oxidant equals or exceeds the State standard of 0.10 ppm during any clock-hour interval of the 24 hour interval in the average concentration of sulfur dioxide is deemed to have been violated.~~

~~(d) If the 24-hour interval over which sulfur dioxide and total suspended particulate are measured includes any portion of two calendar days, any violation is to be assigned to that day which contains the larger portion of the hours of the 24-hour interval, or to the first day if if encompasses twelve hours from each day.~~

~~(e) If the sulfur dioxide standard is violated concurrently with both the total suspended particulate matter and oxidant standards on the same day, only one violation of this standard will be deemed to have occurred.~~

~~NOTE: Authority cited: Section 39601, Health and Safety Code. Reference: Section 39606, Health and Safety Code.~~