TOXICITY OF AIRBORNE CHEMICALS: AIR QUALITY STANDARDS—A NATIONAL AND INTERNATIONAL VIEW

6546

H. E. Stokinger

Department of Health, Education, and Welfare, National Institute for Occupational Safety and Health, Cincinnati, Ohio

Past reviews in this annual appearing under the broad title "Toxicology" have dealt respectively with selected organic and organometallic substances (1), selected inorganic substances of both industrial and environmental concern (2), and Soviet toxicology, including their general principles for establishing tolerance limits for environmental chemicals and their toxicologic methods of handling complex environmental problems (3). The present review will provide (*a*) a critical comparison of the philosophic bases of the American and Soviet air quality standards accounting for the intercountry differences in the limits of certain substances, (*b*) a critical discussion of the scientific background (criteria) of the air quality standards of a half-dozen of those airborne substances of greatest present-day concern for human exposures in both in-plant and urban communities in the USA, and (*c*) a presentation of the reasons for differences in the limits of the air quality standards for the two.

STANDARDS FOR LIMITING EXPOSURES TO AIRBORNE SUBSTANCES

Control of exposures to airborne chemicals in American industry has been achieved by compliance with Threshold Limit Values (TLVs) recommended largely by the Threshold Limits Committee of the American Conference of Governmental Industrial Hygienists (4a, 4b), for now more than a quarter of a century. Control of similar exposures of urban populations has been attempted by so-called air quality standards, more recently by "emission" standards, an engineering procedure calculated to limit industrial chemical effluents at their source.

The TLVs represent time-weighted average concentrations of airborne substances associated with industrial operations and manufacture, designed to protect the health and well-being of nearly all workers repeatedly exposed during a 7- or 8-hour workday and 40-hour workweek (4), not only for their working lifetime, but after retirement. Because of the time-weighted averaging of the air concentrations, the TLVs represent guides in the control of health hazards. Hence, the limits should not be considered fine lines between safe and dangerous concentrations. For another reason also, incorporated in the TLVs are "safety factors" of varying magnitudes (depending on the seriousness of the response) that add in most instances a comfortable "cushion" in the form of several-fold decrements from (*a*) borderline effects, if the limit is based on human experience, or (*b*) "no-effect," if based on animal data. Exceptions to the time-weighted averaging practice are a certain number (ca 6% of the approximately 500, 1971 limits) of substances for which the TLV represents a "ceiling" value, a maximal value that should not be exceeded. Ceiling TLVs are attached to those substances that have the potential of causing (*a*) intolerable irritation, (*b*) chronic or irreversible change, (*c*) narcoses of sufficient degree to increase accident proneness, impair self-rescue, or materially reduce work efficiency (4). Thus, the basis for limiting exposures to airborne substances in industry is first and foremost for the protection of the health and well-being of the worker. Limits are also established for nonhazardous substances, such as "inert" dusts, mists, and vapors in the interest of good housekeeping and reduction of nuisance. Some TLVs of substances common to both industrial and community atmospheres are given in Table 1.

Air quality standards for industry and community.—Table 1 offers a side-by-side comparison of the official (and certain unofficial) air standards in the USA and in the USSR as promulgated by the appropriate agencies of the respective governments. The pollutants in industrial air listed in Table 1 have been limited to those for which the corresponding limits have been set for community air. In the USA six Air Quality Standards (AQS) for community air were promulgated in April 1971 (6), each of which is extensively documented. By comparison, the USSR has standards for 114 substances (8b), the documentations for which were not available at this time. Without such documentation it is not possible to discover the basis for the differences in the respective air standards of the two countries. For example, on what basis did the Soviets select the low AQS for carbon monoxide of 1 mg/m^3? (Table 1).

The standards for industrial air far outnumber those for community air, the USA having somewhat over 500 (4), the USSR somewhat under 500 (8a). Setting of a standard is tantamount to determining compliance with that standard and all that is entailed. Air pollutant control in factories is far more manageable, for each factory has a limited number and furthermore knows what the pollutants are, a situation far from true in respect to community air.

It is evident from Table 1 that the pollutants of concern are not identical in both countries. For example, the Soviet list for industrial air contains no limit for ethylene or iron oxide, no AQS for community air for hydrocarbons, iron oxide, particulates, or photochemical oxidants. The omission of an AQS for hydrocarbons and photochemical oxidants is understandable, if motor vehicle traffic density and ultraviolet intensity, prime factors for development of these pollutants, are low in the USSR. The USSR limits for hydrogen sulfide and lead may indicate pollutants of present or future concern, or merely a philosophy of "preparedness" in the event of future need, as is readily interpretable from their large list of 114 pollutants. The USA has withheld an official AQS and an emission standard for lead on the basis that future unleaded gasolines will reduce community air concentrations to levels of no physiologic significance; hydrogen sulfide has been relegated to a low priority.

USA, USSR differences in permissible limits.—Comparison of the limiting values for the same pollutants in the USSR and the USA reveals still further international differences (Table 1). In general, the USSR standards tend to be lower, both for industrial and community air, than the corresponding standards in the USA. Most notable in this respect is the industrial standard for carbon monoxide (CO), 20 vs 55 mg/m^3, although the standard permits excursions to 50 mg/m^3 for periods not exceeding 1 hour, to 100 mg/m^3 for 30 minutes, and to 200 mg/m^3 for 15 minutes, with the additional stipulation that, when such excursions occur, interruption of exposure should be no less than two hours. The excursion permitted by the State of Pennsylvania, USA, approximates 400 mg/m^3 for 15 minutes, and assumes sufficient recovery periods for recuperation between exposures, with the further requirement that the TLV for the 8-hour workday shall not be exceeded. The USA industrial standard of 55 mg/m^3 has proved, since its issuance in 1965, entirely satisfactory for U. S. workmen, provided there are no significant concomitant exposures to other pollutants (carbon dioxide, motor exhaust, or excessive heat). Hence, it would appear that the Soviet standard contains a very large factor of safety.

A similar conclusion can be reached for the USSR standards for community air, particularly, again, for CO; the 1 mg/m^3 as a 24-hour average concentration is extremely low, when it is realized that man creates for himself a CO environment (14) greater than that exogenously obtained from 1 mg/m^3 in the ambient air. The remainder of the USSR standards are in line with those recommended elsewhere, but with larger safety factors.

A major distinction in the USA standards for community air is the establishment of so-called primary and secondary air standards (6)—the primary standard having its prime concern for the health of man; the secondary standard, for his welfare, the things he sees, feels, and owns, and doesn't like to see degraded, injured, or destroyed. Not all air pollutants have both standards, because many affect health only, and do not affect his senses or possessions. Of the six ambient air pollutants listed in Table 1, only two, particulates and sulfur dioxide, have both. The secondary standards, both more stringent than the primary, indicate that lower concentrations are required to protect man's environment than his health. It is not clear why secondary standards were not also set for photochemical oxidants

TABLE 1. AIR QUALITY STANDARDS FOR INDUSTRY AND COMMUNITY

Air Pollutant	TLV or MPC for Industrial Air			AQS for Community Air			
	mg/m^3			mg/m^3			
	USA (4) TLV	USSR (8a) MPC	Int'l[b]	USA (6)		California (7)	USSR (8b)
				Primary[a]	Secondary[a]		
Acrolein	0.25	0.7	—	0.025		—	0.03
Carbon monoxide	55	20	—	10 (8-hr. max.) (ne) 40 (1-hr. max.) (ne)		10 (12-hr. av.)	1 (24-hr. av.) 3 (max.)
Ethylene	1,100	—	—	—	0.05 rural (8-hr. max.) (5) 0.1 residential 0.15 commercial 0.2 industrial	—	3 (24-hr. av.)
Fluoride, as HF	2	1	1–2	—	0.0035 (24-hr. av.) (5)	—	0.005 (24-hr. av.) 0.2 (max.)
Hydrocarbons	—	—	—	0.16 (3-hr. max.) (ne)		—	—
Hydrogen sulfide	15	10	10–15	—	—	0.05 (1-hr. av.)	0.008 (max. & 24-hr. av.)
Iron oxide	10	—	—	—	0.1 rural (24-hr. max.) (5) 0.15 residential 0.2 commercial 0.25 industrial	—	—

TABLE 1 (*Continued*)

Air Pollutant	TLV or MPC for Industrial Air			AQS for Community Air			
	mg/m³			mg/m³			
	USA (4) TLV	USSR (8a) MPC	Int'l[b]	USA (6)		California (7)	USSR (8b)
				Primary[a]	Secondary[a]		
Lead	0.2	0.01	—	—	—	0.0015 (30-day av.)	0.0007 (24-hr. av.)
Nitrogen oxide	C9	5	5–9	0.100 (annual arithmetic mean)		0.45 (1-hr. max.)	0.085 (24-hr. av.)
Particulates	—	—	—	0.075 (annual geometric mean) 0.260 (24-hr. max.) (ne)	0.060 (annual geometric mean) 0.150 (24-hr. max.) (ne)	0.060 (annual geometric mean)	
Photochemical oxidant (ozone)	0.1	0.1	0.1	0.160 (1-hr. max.) (ne)		0.20 (1-hr. av.)	
Sulfur dioxide	13	10	10–13	0.080 (annual arithmetic mean) 0.365 24-hr. max.) (ne)	0.060 (annual arithmetic mean) 0.260 (24-hr. max.) (ne) 1.300 (3-hr. max.) (ne)		0.05 (24-hr. av.) 0.5 (max.)

[a] Primary and secondary air quality standards as legally defined in Part 410.2 of (6). Essentially, a *primary* standard is based on health effects; a *secondary* standard, on nonhealth effects, such as vegetation damage, soiling, reduction in visibility, etc.; i.e. protection of the public welfare as opposed to public health.

(ne) Not to be exceeded more than once per year.

mg/m³—Milligrams of substances per cubic meter of contaminated air at 25°C and 760 mm Hg pressure.

C—Ceiling or maximal value as opposed to time-weighted average value, corresponding to the USSR, Maximum Permissible Concentration (MPC).

[b] From Joint ILO/WHO Committee on Occupational Health, 6th Report, *Permissible Limits of Occupational Exposures to Airborne Toxic Substances*, Geneva, June 1968. Present international limits are derived only from those substances whose limits differ by no more than a factor of 2 in USA and USSR.

that injure foliage (e.g. tobacco leaves) at far lower levels (0.04 mg/m^3) than those established (0.160 mg/m^3) for health reasons. Similarly, nitrogen dioxide is corrosive to metal surfaces at far lower levels than 0.1 mg/m^3, the standard set for health protection.

Table 1 also lists the AQS for California as illustrative of the provision that a State may establish its own official standards provided they meet the requirements of the federal standards. California, the first state in the nation to develop AQS (1959), has, on November 19, 1970, officially adopted seven standards. The inclusion of a standard for hydrogen sulfide and lead, not established by the federal government, points up the frequent need for local authorities to establish standards for pollutants special to their particular environment.

There also exist unofficial air standards, "Community Air Quality Guides" (5) developed by an expert committee of the American Industrial Hygiene Association which began issuing the Guides in 1968 and periodically issues additional Guides. Ten Guides are available to 1971 : aldehydes, carbon monoxide, ethylene, iron oxide, ozone, particulates, phenols and cresols, sulfur compounds, one on Rationale, and another on Regional Planning. A characteristic feature of some of these Guides is a differential limit according to population density based to some extent on feasibility, i.e. the lower the density, the lower the limit (Table 1).

The limited number (about two dozen) of international industrial air standards can be dispensed with by the brief comment appearing in the legend to Table 1. No close agreement between the USSR and USA standards could be made at the international meeting in Geneva in 1968 because the documentations providing the bases for the differences were not available from the Soviet Maximum Permissible Concentrations (MPC) Committee, which compares to that of the U.S. TLV Committee (4b).

Air standards in other countries.—The International Labor Organization has assembled (1968) lists of official standards for the air of workplaces (TLVs, MPCs, MAKs, etc.) of 19 countries (9). Only a few of the highly industrialized nations of the world do not now have official industrial air standards (Italy, France, Czechoslovakia, and the Scandinavian countries—Sweden, Norway, Denmark, and Finland). Whether official or unofficial, the standards adopted by the non-Communist countries have been the threshold limit values of the USA used for the most part as maximal values and with modifications for certain few substances when found by test that a TLV was unsuited for the work conditions of a particular country (e.g. Italy, Japan, and the Federal Republic of Germany). Czechoslovakia, Hungary, Yugoslavia, and Poland have adopted "compromise" standards for those substances for which large differences between the USSR and the USA standards exist. For example, the Czechoslovakian standard for trichloroethylene is 250 mg/m^3, that of the USSR 10 mg/m^3, that of the USA 535 mg/m^3.

A similar list of air standards for community air of ten sponsoring countries has been assembled by the World Health Organization following an interregional symposium held in Geneva, October 1970 (10). Like the industrial standards, the number and type of the community standards of each nation tended to reflect the degree of concern for those pollutants characteristic of the nation. Following USSR with 114, Israel with 44, Czechoslovakia, 18; Italy 13; West Germany, U.S., and The Netherlands, 6; France and Sweden, 2 and 1 respectively; Japan, oddly one of the most highly air-polluted nations of the world, had but 3.

Documentation of the standards. The bases of all U.S. air standards are fully set forth and documented with references to the scientific literature. For the more than 500 Threshold Limit Values for industrial air the documentations are in a single bound volume now in its third edition (4b). The far more extensive documentation and background information available on each of the six community air standards include occurrence, properties, background levels, pollutant emission or formation and control, toxicologic effects in animals and man, sampling and measurement, and epidemiologic appraisals. Documentation for each standard is available as a separate document (11). Documentation for the USSR standards is distributed throughout the Soviet scientific literature. The Czechoslovak committee on MACs (maximal allowable concentrations) published a summary documentation of its MACs for 93 substances most commonly encountered in Czech industry, with a comparison of air standards in other countries (12).

DISTINCTIONS BETWEEN AIR QUALITY STANDARDS FOR INDUSTRY AND COMMUNITY

Comparison of the limiting concentrations of the TLVs for industrial air with the AQS for community air reveals, on first glance, outstanding discrepancies in the permissible limits, if the basis, protection of human health, is the same in both cases. Protection of human health, however, is not the sole basis, as the following examination shows.

The bases for AQS for community atmospheres in contrast with those of the TLVs are multifold. Depending upon the type of air pollutant, not only is the protection of human health and well-being considered, but foliage and crop damage, soiling, visibility reduction, corrosion, among other factors, may ultimately be the prime determinants of AQS. Depending upon the specific basis on which the AQS ultimately rests, it may be seen (Table 1) that differential factors between AQS and TLVs may range from one-half (ozone) to one-hundredth (nitrogen dioxide, sulfur dioxide, iron oxide) to one-thousandth (lead) or more (hydrogen fluoride). Obviously, such great differentials cannot have as their basis solely the differing susceptibilities of exposed population groups, large though they often are.

Before identifying the basis for differences in AQS and TLVs for each air pollutant in Table 1, it is most important to understand why the working population can tolerate higher levels of air pollutant exposure than the population at large. First, the working population is drawn, by and large, from essentially normal, healthy, adult individuals, certainly those who are to be exposed to potentially noxious fumes, dusts, mists, and vapors. This is far from true of the community dweller in the home. The urban dweller is a composite of all ages, with all the ranges in susceptibilities of the very young and the indispositions and debilities of the very old, including in particular, as far as air pollutants are concerned, diseases of the cardiorespiratory system, chronic obstructive pulmonary disease, chronic bronchitis, emphysema, and other related diseases associated with aging. Such individuals are not in the work force because of age or infirmity. Second, separated out from the work force likely to be exposed to respiratory irritants by virtue of job selection, are the intrinsic and extrinsic asthmatics, for whom the susceptibility factor is estimated to be 5- to 10-fold, depending on the pollutant. Clearly, this and similar job-selective processes make for a worker group with far greater capacity for exposure without response to air pollutants than the population at large. The factors expressing the differential susceptibility between diseased and healthy populations vary widely according to extent of the disease and age of the diseased. The factor for age alone is widely variant, from several-fold positive (increased susceptibility) from infancy and youth, to several-fold negative (increased resistance) in old age, at least for effects of respiratory irritants on the lung, amounting to a factor of 2- or 3-fold.

Basis of AQS-TLV Differences

In this section, the scientific basis for the differences in the limiting concentrations of the standards for community and industrial air will be presented for some of the more prominent air pollutants given in Table 1. Because the basis for the differences varies markedly from pollutant to pollutant, each will be discussed separately.

Carbon monoxide (*CO*).—This ubiquitous pollutant of all urban atmospheres, arising as it does from incomplete combustion of fossil fuels and carbonaceous materials, coal, mineral oils, wood, and tobacco particularly, also is a constant endogenous metabolite of man (14). In individuals not otherwise exposed to CO, each molecule of heme destroyed results in one molecule of CO. As there is continuous red cell destruction, a normal adult forms about 0.42 ml CO/hr. Obviously, one who inhales tobacco smoke or is exposed to ambient CO will form additional amounts, as the chief scavenger of either endogenous or inhaled CO is hemoglobin, forming carbon monoxyhemoglobin (COHb). Although the scavenging power of human hemoglobin for CO is about 210 times that for O_2, release of CO through the lungs readily occurs because the differential in partial pressure of CO in the lungs is essentially infinite in a nonCO-containing atmosphere. This excretory mechanism has been partly compromised, however, since the time man first sat by his cooking fire to the present when exogenous sources such as the unvented oil-burning spaceheater, coal-burning power stations, gasoline-driven vehicles, and tobacco smoke inhalation have increased the CO partial pressure of his environment. For industrial workers, metal refinery workers, garage mechanics, tunnel and border-crossing attendants, submarine crews, et al, this increase may be of such a degree as to break down completely homeostatic mechanisms requiring exposure limits to prevent unpleasant responses such as sleepiness, headache, and nausea.

Before setting forth the basis of AQS-TLV differences for CO, the importance of the duration of exposure to the response to CO should be emphasized. Because the partition coefficient for CO between alveolar air and pulmonary blood is such as to delay transfer of the CO-laden air to the circulating hemoglobin where it is bound as COHb, it is essential in any estimation of the response to know how long the exposure was experienced as well as the concentration of the exposure. At 100 ppm CO, for example, six to seven hours of inhalation at normal breathing rates are required to attain an essentially steady state value of COHb (16). Hence, short exposures of a few minutes duration as in a traverse through automotive vehicular tunnels, where CO concentrations may attain 100 or 200 ppm, will have no adverse physiologic effects from CO per se, even in individuals with severe cardiorespiratory difficulties.

Those individuals with such difficulties as well as those with the different forms of chronic obstructive respiratory disease, or indeed, anyone who has reduced oxyhemoglobin saturation, will be the ones to respond to, and have to be protected from, levels far below those readily tolerated by the industrial worker, if exposure is of several hours duration, cyclicly repeating, or continuous as is the CO exposure pattern of community air. Recognition of these considerations has been taken in arriving at definitive boundaries for CO exposure for such individuals in the recommendation that community air quality values be set at levels that will not exceed one-half of 5 to 6% COHb prior to tobacco smoke consumption. This provides for susceptibles a time-based margin of safety before reaching the critical 5 to 10% COHb range for such individuals (5). Recent data indicate that the rate of uptake of CO at levels less than 100 ppm, as well as the rate of formation of COHb, parallels those found for levels greater than 100 ppm as reported by Forbes et al (15). Thus the basis for the AQS-TLV differences rests on the greater ease of attaining critical levels of anoxia in individuals already having reduced oxyhemoglobin saturation. The AQS of 10 mg/m^3 CO as an 8-hour maximum is intended to prevent reaching these critical levels in such individuals.

Support for the validity of the TLV of 55 mg/m^3 CO for healthy adult workers has been reported (17); no untoward effects were observed in sedentary males exposed at twice the TLV for 8 hours, as determined by lack of impairment in manual dexterity following exposure.

Sulfur dioxide (SO_2).—This air pollutant is ubiquitous wherever fossil fuels, coal, oil-shale, and petroleum are burned. Burning releases SO_2 and SO_3 to the atmosphere in a ratio between 25:1, to 100:1, the latter ratio being more common. Other sources are the roasting and smelting of ores, petroleum refining, and paper-pulp manufacture. These sources produce more localized sulfur oxide pollution.

The chief effect of SO_2 on normal man is upper respiratory tract irritation resulting in reflex bronchoconstriction and increased pulmonary flow resistance. At concentrations in the range of 0.3 to 1 ppm, SO_2 can be detected by the average individual by taste rather than odor. The odor threshold is about 0.5 ppm. Accordingly, neither the annual mean nor the 24-hour maximum primary or secondary U.S. standard permits SO_2 to be detected by odor, and the 3-hour maximum is just at the point of bare detection by some sensitive individuals.

The justification of the industrial TLV of 5 ppm rests on the following considerations. Complaints of discomfort among some uninured workers at 10 ppm, but not at 5 ppm, is a partial basis. Moreover, no chronic, systemic effects were observed in oil refinery workers in Persia exposed for from 1 to 19 years when daily exposures were commonly as high as 25 ppm, and on occasion were as high as 100 ppm (18). Some basis for these findings may be found in a report showing that virtually all SO_2 gas is absorbed by the nasal mucosa when inhaled by human volunteers at an entering average level of 16 ppm (19). On the other hand, paper-pulp workers in Norway exposed at SO_2 levels of from 2 to 36 ppm showed an increased frequency of cough, expectoration, and dyspnea on exertion, and lower maximal expiratory flow rate (20). Inasmuch as the negative findings were made under conditions of very low humidity (Persian oil fields), whereas positive findings were made at far higher humidities (Norway), one can reasonably conclude that SO_2 at high humidities needs to be controlled to lower levels to be without effect. General confirmation of this observation is seen in the greater frequency of bronchitis associated with SO_2 pollution in highly humid London and Milan than in other SO_2-polluted cities without such humidities. Thus, with adaptation (inurement) of workers repeatedly exposed to SO_2 playing such a large role, coupled with the lack of chronic systemic effects at levels below 10 ppm, the industrial air standard of 5 ppm seems appropriate and has stood the test of time (15 years).

For community air the primary SO_2 standard, like the standard for CO, must take into consideration primarily two groups of individuals, the so-called cardiorespiratory "cripples" (those with chronic obstructive pulmonary disease, COPD, and cardiorespiratory difficulties) and the asthmatics, both groups being unable to sustain any protracted exposures without immediate extreme discomfort (asthmatic attack) or death. Unfortunate for the choice of the primary AQS for SO_2, the laboratory studies on animals are only partly relevant, and those done on man were performed on healthy volunteers (11). The basis for the primary standard, therefore, had to be derived from epidemiologic data on urban smog episodes (Denora, Pennsylvania; New York City; Chicago; London; Rotterdam; Ruhr). These data were of two kinds; excess mortality or morbidity (increased number of visits to emergency clinics) associated with rise in SO_2-smog levels. The most recent of such studies (21) reported an excess of 10 to 20 deaths per day in New York City on days when SO_2 levels rose from 0.2 ppm (0.57 mg/m^3) to 0.4 ppm (1.14 mg/m^3) or greater. Statistical evidence indicated the mortality was associated with increased levels of SO_2 and was independent of weather conditions. The report did not identify the cause of death, however; the assumption was that they were diseased individuals and not careless motor vehicle drivers and thus died of causes unrelated to air pollution. In another typical study (22) the hospital admissions for respiratory tract "irritation" rose when the SO_2 level rose from 0.11 ppm to 0.19 ppm (0.3 mg/m^3 to 0.5 mg/m^3), some of whom were presumably asthmatics. In such individuals an "attack" can be precipitated at the SO_2 odor detection limit (ca 0.5 ppm; 1.3 mg/m^3).

Using the above-quoted general population response levels of SO_2 ranging *from about* 0.5 *mg/m*^{3} *to greater than* 1 *mg/m*^{3}, *the primary* AQS of 0.08 mg/m^3, as an annual mean with a 24-hour maximum of 0.365 mg/m^3, becomes a reasonable standard for preventing exacerbation of COPD and asthmatic attacks. On this basis, the reason for the wide AQS-TLV differences becomes apparent.

For the secondary standards for community air providing protection of the public welfare, the levels of SO_2 that *minimize* its effects on materials and vegetation are the determinants. The levels critical to the development of this standard are the following. On materials, corrosion rate at a mean SO_2 level of 0.12 ppm (0.34 mg/m^3) was about 50% greater than at the least corrosive site (0.03 ppm; 0.08 mg/m^3) (11). Electrical equipment of all kinds is especially susceptible, but building materials—limestone, marble, slate, and mortar, statuary and art works are deteriorated and discolored. Certain textile fibers—cotton, rayon, and nylon are harmed and dyed fabrics fade at annual average SO_2 levels of 0.09 ppm (0.256 mg/m^3). Although vegetation varies widely in susceptibility to acute SO_2 injury, levels of 0.3 ppm (0.85 mg/m^3) as an 8-hour maximum, if not exceeded, will prevent acute damage. (This maximum corresponds to an annual average of between 0.03 and 0.05 ppm). However, these SO_2 concentrations may react synergistically with either ozone or nitrogen dioxide to produce acute injury in some sensitive varieties.

From these criteria, it is clear why the secondary SO_2 air standards are (*a*) lower than the primary; and (*b*) consequently far more stringent than the corresponding standard for workroom air.

Nitrogen dioxide (*NO_2*).—This pollutant with a TLV-AQS difference of almost 100-fold has the same value for both primary and secondary ambient air quality standard (Table 1). No AQS have been set for other oxides of nitrogen, principally because they react in such a way in air as to produce NO_2. The chief reason for the lack of a secondary standard is that the primary standard for the protection of human health is sufficiently low to protect public welfare also.

The AQS of 100 μg/m^3 (0.05 ppm) as an annual arithmetic mean was arrived at on the report of greater incidence of adverse health effects (acute bronchitis) in infants and children of school age in areas where the mean 24-hour NO_2 concentration varied from 118 to 156 μg/m^3 (0.063 to 0.083 ppm). Other reports of increased incidence of acute respiratory disease in family groups have appeared when the mean 24-hour NO_2 concentration was between 117 and 205 μg/m^3 (0.062 and 0.109 ppm) and the mean level of suspended nitrates was 3.8 μg/m^3 or greater (11). Because the NO_2 effects on the generation of oxidant smog, by interaction with "nonmethane" hydrocarbons, the effects on vegetation, and on metal surfaces (corrosion) occur at levels either at or above those producing adverse effects on health, it is clear why both the primary and secondary standards are the same.

The approximately 100-fold higher TLV (a ceiling 0.05 ppm, 8 hours daily, 40 hours per week) is explicable on the basis of long industrial experience in the USA and abroad where measured exposure concentrations five- to seven-fold the TLV resulted in no adverse effects in workers exposed daily for several years (4b). The TLV is a ceiling or maximum limit as a result of animal experimentation indicating that NO_2 may act as a mild tumor-accelerating agent in lung-tumor susceptible mice.

Hydrocarbons.—The designation of this class of air pollutants refers to those organic structures of carbon and hydrogen that exist in the atmosphere in the gas phase. This excludes the polycyclic aromatic hydrocarbons that are scheduled as a separate AQS. Although 26 nonaromatic hydrocarbons have been quantitatively identified in the ambient air of Riverside, California, the unsaturated hydrocarbon, ethylene, proves to be the sole gaseous hydrocarbon of air pollution concern (11). The concern, however, is not for reasons of public health (although many of the health effects associated with photochemical smog are indirectly related to ambient levels of these hydrocarbons) but for reasons of public welfare; injury to sensitive plants (tobacco, peas, orchids, carnations) has been reported (11) in association with ethylene concentrations of from 1.15 to 575 μg/m^3 (0.001 to 0.5 ppm) during an exposure of from 8 to 24 hours. The AQS of 160 μg/m^3 as a 3-hour maximum reflects the need to control hydrocarbons for the protection of sensitive vegetation.

No industrial air standard exists for hydrocarbons as a group; rather, TLVs have been established for individual hydrocarbons. For ethylene, the TLV has been set at 1,000 ppm (1,100 mg/m^3), the standard for simple asphyxiants and "inert" gases and vapors. Thus, the lack of human health effects makes the huge TLV-AQS disparity of 14,500 fold obvious.

Photochemical oxidant (*Ozone*).—Discussion of the air standards for this group of pollutants is not concerned with explaining the basis for the difference, for there is little; rather, explanation for the similarity of the industrial and community standards is in order.

Photochemical oxidant represents a group of oxidation products resulting from the interaction of oxygen, nitrogen dioxide, and ultraviolet light on air-borne gaseous hydrocarbons discussed in the previous section. Ozone (O_3) is the dominant constituent (up to 90%) of oxidant smog which is defined as a substance that oxidizes a selected reagent not oxidizable by oxygen. Within this definition are included besides O_3, free radical oxygen forms, both free and combined with carbon moieties of unmeasured and varying amount, peroxyacyl nitrates (PAN homologues) to the extent of about 0.6% of total oxidant, and certain oxides of nitrogen, NO, and NO_2.

Oxidant at sufficient concentration affects adversely the health of man in brief or protracted exposures, affects vegetation, attacks fabrics, and polymers such as rubber, and fades dyes and coloring materials. Exposure of populations to ambient air containing an oxidant level of about 250 $\mu g/m^3$ (0.13 ppm, maximum daily value) has caused an increase in the number of asthmatic attacks in about 5% of a group of asthmatics (11), a value associated with a maximum hourly average of 100 to 120 $\mu g/m^3$. By comparison, pure O_3 exposures of nonasthmatic human volunteers at 590 $\mu g/m^3$ resulted in nose and throat irritation after eight consecutive hours, and 980 $\mu g/m^3$ three hours per day gave decreased forced expiratory volume ($FEV_{1.0}$) after eight weeks, but 390 $\mu g/m^3$ (0.2 ppm) was without measurable effect after 12 weeks of 3-hour daily exposures. These were the data that served as the criteria for the AQS for O_3 of 160 $\mu g/m^3$ for a 1-hour maximum. Although leaf damage to certain sensitive plants (bean, peanut, tobacco, carnation) occurs from exposure to smog, O_3, or PAN at levels somewhat lower than those affecting human health (20–100 $\mu g/m^3$), oddly, no secondary standard was set for photo-oxidants; presumably the economic burden of reducing the primary standard to protect areas where such vegetation is not likely to grow, balanced off the risk to the vegetation.

Particulates.—As defined in the official document (11) atmospheric particulates are either solid or liquid matter suspended in air (hence called aerosols) and obviously, thus comprise a wide variety of substances with one common feature, a submicron size, i.e. less than 1 μm. This characteristic permits their suspension in air for periods of several months, under suitable meteorologic conditions. (The dust cloud from the Krakatoa eruption, estimated to rise 100,000 feet, completely circled the globe 3¼ times before final dissipation, requiring two years before the world's sunset cleared).

Because of their widely diversified nature, air-borne particulates impinge themselves on the polluted environmental scene in eight manners:

(*A*) *Effects on health.* As far as is now known, the effects at current levels of particulates are limited to the respiratory tract by serving as nuclei for carrying toxic gases to the deeper recesses of the respiratory tract that otherwise, because of their solubility, would never reach sensitive sites. Excess mortality and increase in illnesses have been observed in New York City at a smokeshade index of 5-6 cohs (coefficient of haze) when the SO_2 level was high. The lowest particulate levels associated with health effects showed increased death rates in Buffalo at annual geometric means of 100 $\mu g/m^3$ and above. Further evidence for the role of particulates is the decrease in sputum volume with decrease in smoke pollution (11).

(*B*) *Effects on visibility.* Air-borne particles in smog reduce visibility by scattering and absorbing light. Impingement on public welfare is reflected in restrictions on aircraft operations which occur at particulate loadings of from 75 to 300 $\mu g/m^3$.

(*C*) *Effects on materials.* Particulates may damage surfaces by chemical attack per se or by corrosivity of adsorbed substances (SO_2, NO_2) or by soiling. Steel samples corroded three times faster at a site where annual particulate concentrations averaged 176 $\mu g/m^3$.

(*D*) *Effects on vegetation.* Although the effects of general particulate pollution are not documented, the effects of specific dusts are known. Cement-kiln dusts, for example, cause moderate damage to bean plants when dusted at the rate of 470 $\mu g/cm^2/day$ for two days and then exposed to natural dew. Some dusts (iron oxide) may be beneficial to some plant species.

(*E*) *Particles as odor sources.* If sufficiently volatile and odorous, particles can serve as sources of (generally unpleasant) odors, e.g. motor exhausts, street paving asphalts, trash burning).

(*F*) *Effects on direct sunlight.* At concentrations ranging from 100 to 150 $\mu g/m^3$, where large smoke turbidity factors persist, particulates reduce direct sunlight up to one-third in summer and two-thirds in winter in the middle and high latitudes. The color of sunsets is also changed by particulates.

(*G*) *Effects on public concern.* Public awareness and concern for air pollution increases at levels of particulate concentration up to and above 200 $\mu g/m^3$ particularly in the presence of other pollutants that affect the sensibilities.

(*H*) *Effects on climate near the ground.* The scatter and absorption of sunlight by air-borne particulates reduces the amount of sunlight reaching the ground. Total sunlight is reduced 50% for each doubling of the concentration above 100 $\mu g/m^3$. Reduction is most pronounced on ultraviolet radiation.

As a result of these several partial criteria of particulate effects, a primary standard of 75 $\mu g/m^3$ as an annual geometric mean and a secondary standard of 60 $\mu g/m^3$ were officially set (Table 1). No similar TLV was set; industrial air standards relate to specific particulates, such as specific mineral and organic dusts, e.g. metal oxides and oil mists. TLVs range from 2 $\mu g/m^3$ for beryllium dusts to 100 $\mu g/m^3$ for dusts and fumes of cadmium and thallium, to 1,000 $\mu g/m^3$ for certain of the metal oxides. TLVs for those organic dusts that are readily metabolized to less toxic substances are even higher.

Lead.—It may seem odd at first glance (Table 1) that no official air quality standard for lead has been set in the USA where the per capita number of motor vehicles far outnumbers that in USSR. Two reasons seem probable. By the time the criteria document was to be prepared, it became apparent that the petroleum industry was working toward the elimination of leaded gasolines. At this time also, the philosophy of control of air pollution changed; control at the source replaced control in the air, i.e. engineering procedures replaced the biologic and medical. California, however, saw fit to set an official standard of 1.5 $\mu g/m^3$, about double that in the USSR.

SUMMARY

Official air quality standards for industry and community have been tabulated, and compared on a national and international basis. In these comparisons, it was felt important to identify clearly the bases for the often large differences between the standards for community air and those for industry, lest the side-by-side comparison of the limiting values prove inexplicable and, in turn, result in widespread, uninformed condemnation of the industrial air limits.

LITERATURE CITED

1. Gerarde, H. W. 1964. *Ann. Rev. Pharmacol.* 4:223–46
2. Roush, G., Jr., Kehoe, R. A., Ibid, pp. 247–64
3. Medved, L. I., Kagan, Ju. S. 1966. *Ann. Rev. Pharmacol.* 6:293–304

4a. *Threshold Limit Values for Substances in Workroom Air.* 1971. Am. Conf. Govt. Industrial Hygienists: Cincinnati, Ohio

4b. *Documentation of the Threshold Limit Values for Substances in Workroom Air.* 1971. Am. Conf. of Govt. Industrial Hygienists, 3rd Ed. Cincinnati, Ohio

5. *Community Air Quality Guides.* Am. Ind. Hyg. Assn., Southfield, Michigan
6. *National Primary and Secondary Ambient Air Quality Standards.* 1971. Federal Register 36, No. 84, 8186–8201, Washington, D.C.
7. *Ambient Air Quality Standards.* 1970. California Air Resources Board

8a. *Maximum Permissible Concentrations of Harmful Substances in the Air of a Working Area.* 1970. Moscow, USSR

8b. *Maximum Permissible Concentrations of Pollutants in the Ambient Air.* 1971. Moscow, USSR

9. *Permissible Limits for Toxic Substances in the Working Environment and Criteria for Their Assessment.* 1968. Occupational Health and Safety Branch, I.L.O. Geneva, Switzerland
10. Air Quality Criteria and Guides. 1970. *Rep. Interregional Symp., World Health Organ.,* Geneva
11. *Air Quality Criteria Documents.* 1970. Nat. Air Pollut. Contr. Admin., Washington, D.C. Documents available: Sulfur dioxide, Carbon monoxide, Hydrocarbons, Oxidants, Nitrogen dioxide, Particulates
12. *Documentation of MAC in Czechoslovakia.* 1969. Czechoslovak Comm. MAC, Praha
13. Stokinger, H. E. 1957. *Arch. Ind. Health* 15:181–90
14. Coburn, R. F. 1967. *Acta Med. Scand.* (Suppl. 472) 269–82
15. Forbes, W. H., Sargent, F., Roughton, F. J. W. 1945. *Am. J. Physiol.* 143:594–608
16. Smith, R. G. 1968. *J. Occup. Med.* 10:456–58
17. Stewart, R. D., et al 1970. *Arch. Environ. Health* 21:154–64
18. Anderson, A. 1950. *Brit. J. Ind. Med.* 7:82–86
19. Speizer, F. E., Frank, N. R. 1966. *Arch. Environ. Health* 12:725–29
20. Skalpe, I. O. 1964. *Brit. J. Ind. Med.* 21:69–73
21. Glasser, M., Greenburg, L. 1971. *Arch. Environ. Health* 22:334–43
22. Brasser, L. J. et al 1966. *Rep.* G-300 *Res. Inst. Pub. Health Eng.* Delft, Netherlands