CHAPTER 5. BIOLOGICAL EFFECTS OF AIR POLLUTION

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Summary

Exposure of living organisms to sulphur dioxide, sulphuric acid, fly ash, other particulates, and oxides of nitrogen is discussed from the points of view of air pollution phenomenology, specific and nonspecific responses of plants, animals and man, and environmental and constitutional factors that influence the mode of response and the degree of effect. Some examples of dose/effect relationships are given. For sulphur dioxide and (black) suspended matter (as indices of pollution from the use of fossil fuels) both tolerable and unacceptable criteria are tentatively suggested for the purpose of planning and control.
In addition argument is given — from the biological, physiological and common sense standpoints — in support of the concept of clean air conservation.

I. Introduction

The effect of atmospheric pollutants upon living material is determined by a number of factors:

- physical and chemical properties of the pollutant;
- its concentration;
- duration of exposure;
- environmental conditions;
- susceptibility of the organism;
- locus and mode of uptake;
- metabolism and rate of elimination.

The latter is of particular interest in the case of human beings and many animal species: a great number of substances may pass through the body or can be eliminated, in their original form or as a detoxified metabolite. Vegetal life usually has no such facilities at its disposal, although a type of elimination of non-physiological substances may take place, e.g. by transporting sulphates into the roots after the leaves have been gassed with sulphur dioxide.

In view of the biochemical rules and probabilities that determine life's fundamental processes, it should be recognized that most pollutants can be characterized as "unknown" and strange to the natural system, either as substances *per se*, or in the concentrations encountered. This means that life in modern environments has to cope with a great number of chemicals that are irrelevant from the point of view of nutrition and energy demand.
Therefore those substances can be considered toxic or potentially noxious, and to get rid of them requires biological energy on the part of human, animal, and plant life. Detoxification and elimination processes happen to take place at the expense of an essentially limited potential of life's phenomena. Consequently pollution problems should be appreciated in terms of body burden and loading capacity, which can be assessed partially on the basis of objective, or of subjective and arbitrary criteria.

The toxicity of a substance can only be assessed if duration and pattern of exposure are known. Therefore a thorough knowledge of air pollution phenomenology is of fundamental assistance. Of a number of pollutants, such as sulphur dioxide (SO_2) and suspended particulates, it is known that their ground level concentrations per measuring station fluctuate according to a pattern that is reproducible over longer periods, namely an approximately normal (= Gauss) distribution of the logarithms of 24-hour averages over a year (vide chapter **3**, section **IV**)
In agglomerations with a spread of a great number of different sources of varying output, the geometric standard deviation of such a distribution of SO_2 data, for example, is in the order of 1.5. In the case of a measuring station near to a single source — such as the stack of an isolated power station — this figure will be in the order of five.
In practice the net result may be that the geometric mean of both distributions differs to an extent of a factor ten, although on the other hand the probability of excessively high concentrations over a few days per year may be of the same order in both instances.

Although the response of living material is theoretically dependent on the integral of a pattern of exposures, the exposure can in practice be fairly accurately characterized by the mean concentration and the number and level of peak concentrations of short duration. Although no exact relationship exists between extremes of exposures, for practical purposes one may assume that, within a definite range of exposures and with not too toxic substances, the degree of effect will be more or less consistent, depending on the constancy of the product of log concentration and log exposure time ($E \sim k.\ log\ C.\ log\ T$).

Substances that are capable of causing damage to living material and that originate from the burning of fossil fuel in power plants are SO_2, nitrogen oxides, fly ash and other suspended particles. A relatively small amount of sulphuric acid (H_2SO_4) may be emitted.

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Some part of the SO_2 emitted into the atmosphere will be converted into H_2SO_4. This process is dependent on the presence of catalytic particulates (fly ash, metal salts) and on the relative humidity of the plume and the ambient atmosphere. It is reasonable to assume that under normal conditions about 5 % (10 % at most) of the emitted SO_2 will be converted into H_2SO_4. Although the latter is precipitated fairly rapidly by growth of the hygroscopic droplets, these sulphuric acid aerosols should not be neglected as an important factor in the causation of damage to living and non-living material.

II. Effects on plants and vegetation

A. General

The effect of pollutants upon living organisms depends on several factors, as has been pointed out in the previous paragraph. In the case of plants an important role is played by the great differences in susceptibility existing between various species of both cultivated and wild plants, and even between varieties or individual specimens of some species, in exceptional cases. Moreover, the influence of environmental conditions such as climate, radiation or soil chemistry and moisture, is far more pronounced than in the case of man and the higher animals. These influences vary, however, according to the types of pollutants involved. In this respect the scope of the present survey is rather limited.

In cases of coal burning especially, particulate matter contributes to undesirable deposits on vegetables and fruits. Although direct injury is seldom caused, the harvested product must be cleaned before marketing. This has financial consequences for the grower. In areas with greenhouses and dutch lights, solid deposits may considerably reduce the amount of light passing through the glass coverage, thus diminishing growth and crop yields.

However, gaseous pollutants are of greater importance — particularly sulphur dioxide and, to a lesser extent, nitrogen oxides. Some countries like the Netherlands are in a fortunate situation from the agricultural point of view: natural gas, which is free of sulphur compounds, is available for heating purposes and electric energy production. For so long as this short-term source of energy is not exhausted it offers an alternative to coal or mineral oil as a fuel in areas where current sulphur dioxide concentrations might be particularly unacceptable.

B. Sulphur dioxide (SO_2)

Careful investigations of the influence of various environmental factors on the susceptibility of plants to sulphur dioxide have resulted in some firm conclusions. Meteorological and soil conditions play an important role as to the degree and amount of damage caused by certain concentrations of SO_2 present in the air over known periods of exposure.
A high humidity increases the susceptibility of plants: from 30 to 60 % relative humidity (R.H.) there is a gradual increase, and between 60 and 90 % R.H. a rapid increase. The influence of temperature is less pronounced.
So after fumigation with 7 mg/m³ (2.5 ppm) SO_2 for two hours, barley (the most susceptible cereal) can be damaged at an ambient temperature of 1.5° C and 75 % R.H. In the same experiment no damage occurred at 10.3° C and 45 % R.H., but this lack of effect was probably the result of the low humidity alone.

Figure 1 - Chambers for short term experiments with plants exposed to relatively high concentrations of test gases.

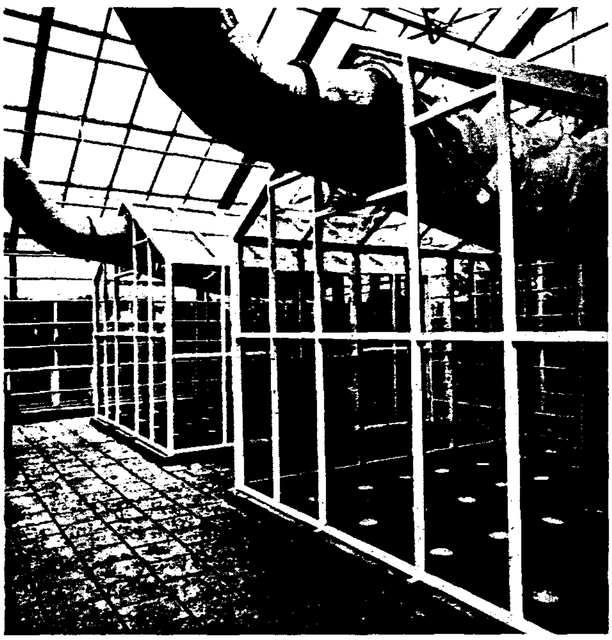

Figure 2 - Exposure chambers for the administration of very small gas concentrations to plants during a whole growing season.

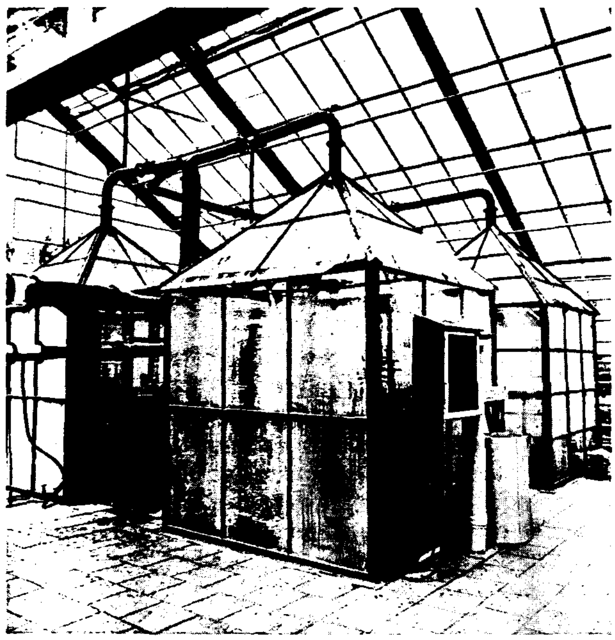

Figure 3 - Leaf damage in normally grown tomato plants, due to a six hour fumigation with 4.2 mg/m³ (1.5 ppm) SO_2.

The amount of sunlight has no clear influence upon the effect of SO_2; this in contrast to what has been observed in the case of plant damage due to peroxy-acetylnitrate (PAN), which is the product of a chain of photochemical reactions and an important constituent of atmospheres with an oxidizing (Los Angeles) type of pollution. So far as SO_2 under experimental conditions is concerned, the plants of lucern (alfalfa) appear to be most susceptible about four hours after sunrise, on both sunny and cloudy days. With spinach and radish the same phenomenon has been observed. Experiments concerning the influence of soil moisture on the effect of fumigation with SO_2 have shown that vine plants, for example, can be badly damaged if the soil is constantly kept moist, whereas, even after several fumigations with high concentrations (4.5—9 mg/m³ or 1.6—3.2 ppm) of SO_2, no damage has been observed to plants grown on a dry soil. Similar results have been obtained with tomato plants. In colza the resistance to SO_2 increases with the mineral nitrogen content of the soil.

Acute symptoms of SO_2 injury are clearly visible in the interveinal leaf tissues which collapse and later become desiccated and bleached, while the veins themselves remain green. With small doses of SO_2 no symptoms occur as a rule, because SO_2 is metabolized, in the leaves, into sulphates which are at least partly transported towards the roots. If small amounts of SO_2 are absorbed over longer periods, the leaves may become chlorotic.
Epiphytic lichens and mosses (bryophytes) are much more susceptible than higher plants. At an annual average concentration of SO_2 above 45 μg/m³ (~ 0.016 ppm) only some species, such as *Parmelia saxatilis*, may survive. Therefore lichens may be used as indicators for the presence of SO_2. As a concentration of 100 μg/m³. may. in the long term, adversely affect pine trees, landscape designers should be advised to be wary about planting conifers in a *Parmelia saxatilis* "desert".

Sulphur dioxide can act as a synergist in the causation of damage by ozone. This has been clearly demonstrated in American fumigation experiments using low concentrations of either pollutant, individually as well as in combination.

C. Nitrogen oxides

As a rule, the nitrogen oxides which are formed in the combustion process of conventional power plants will consist in part, of NO_2 at the point of maximum ground level concentration. In short term experiments this gas may cause the same symptoms as SO_2 if high concentrations (about 5.4 mg/m³ or 3 ppm) are used. In the outdoor atmosphere such concentrations of NO_2 rarely occur under normal conditions. In the Netherlands the former have only been found after, say, an accident at a chemical factory. At low concentrations (of about 0.2—0.5 mg/m³ or 0.1—0.3 ppm) visible effects on tomato plants only appear after a continuous fumigation for several months (Figure 4). However, growth and production may be seriously affected, and can lead to a decrease in yield as high as 22 %.
In some densely populated areas of the USA a concentration of 0.5 mg/m³ (or 0.3 ppm) NO_2 is registered quite regularly. In Western Europe the NO_2 levels are muche lower, and it seems improbable that the emissions from electric power plants will contribute

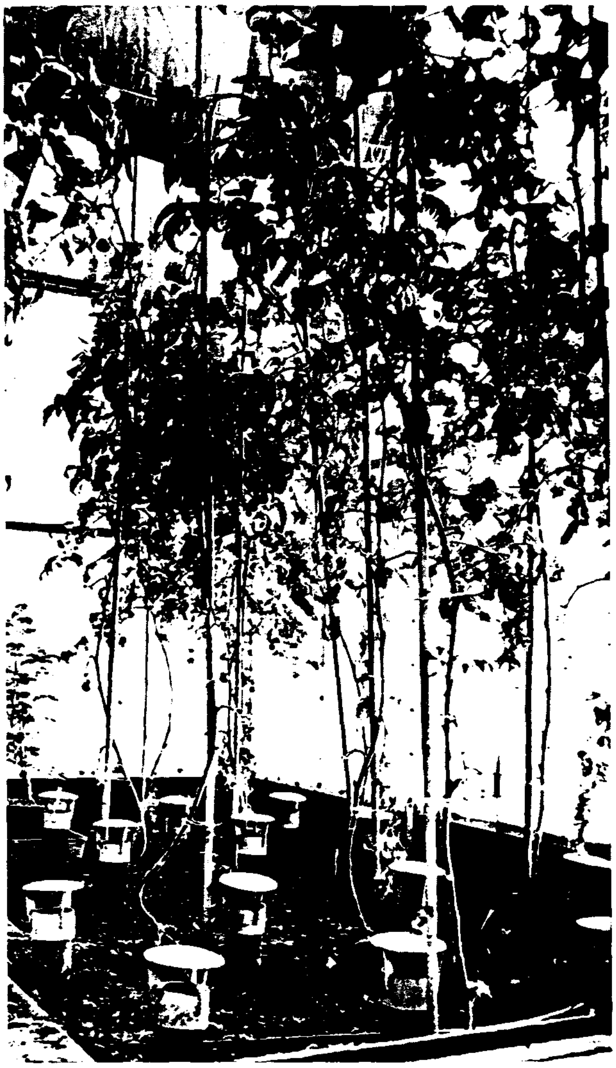

Figure 4 - Defoliation in tomato plants as a result of a four month continuous exposure to 0.25 ppm of NO_2.

Figure 5 - Control culture to the experiment illustrated by figure 4. Grown under the same conditions but without exposure to NO_2. Some normal old age effects are visible.

substantially to the buildup of ambient NO_2 levels that may be hazardous or adverse to plant life. Only if the atmospheric conditions are favourable for the formation of photochemical oxidants like ozone, does NO_2 act as a "catalyzer", contributing to the ozone-forming process.

III. Effects on man and animals

A. General

As mentioned already, man and his domestic animals have a reasonable capacity to metabolize substances that are "strangers" to the physiology of their systems. Thus they can cope with a stream of biologically irrelevant information. But there are limits, as has so clearly been demonstrated during so-called smog disasters — periods of a few days with adverse meteorological conditions causing cumulation of pollutants (for example, during the heating season). During such periods (and sometimes shortly afterwards), a lesser or greater number of particularly vulnerable people appear to be afflicted, as shown by increased mortality, sickness rates and functional impairment (cf. Greater London 1952 with 4000 excess deaths in a few days, at an expected death rate of about 300 per day during wintertime). As to the causation of the nonspecific health effects in cumulation periods with a reducing type of pollution, the following substances are suspected to play a role: sulphur dioxide, black suspended matter (soot), and other particulates — amongst which sulphuric acid aerosol and sulphates. Although not routinely measured, carbon monoxide (from open fires, stoves with stagnating chimney flow, traffic) could also have played a part during these periods.

On the one hand it is to be expected that under such circumstances sufferers from chronic bronchitis and those with impairments of the cardiorespiratory system would be the main potential victims. On the other hand it is surprising just how disastrous the effects have in fact been, when it is considered that they resulted from exposure to polluted atmospheres which in practice could only be characterized by such con-

centrations of SO_2 and particulates as have failed to demonstrate any unfavourable effect under comparable circumstances, like industrial exposures and experiments with human volunteers and animals. One should recognize the fact that SO_2, H_2SO_4, NO_2, CO, and particulates are the only measured indicators of an amalgam of pollutants that is, in effect, more toxic than can be deduced from the presence of only one or a few parameters.
Various substances may interact, or even separately potentiate their respective responses. In this respect it is very well known that small particles with a diameter of less than five microns can penetrate deep into the airways and lungs, where they may irritate and evoke responses of an obstructive nature, depending on the acid gases or liquids adhering to the particle surface. Mucus production and reflex constriction of the smaller bronchi and bronchioli, together with the increased airway resistance and impaired breathing in respiratorily crippled and sensitive people, is a typical result of exposure to these essentially nonspecific stimuli.

(should not be surprised if future investigations bring fresh facts to light that lead to new concepts in this field, as is the case with the latest ideas on the uptake and metabolism of SO_2 in the body. A few years ago SO_2 was only appreciated as an external agent that could irritate the mucous membranes of the airways when inhaled.
Modern investigations with tracer techniques and balance studies of uptake and output have shown that SO_2, being an easily soluble gas, is 90 to 100 % absorbed in the aqueous surface of the mucous membranes of the nose and throat (nasopharynx). From there it is transported through the tissues into the blood stream. In various organs an accumulation of labeled sulphur molecules can be measured. After

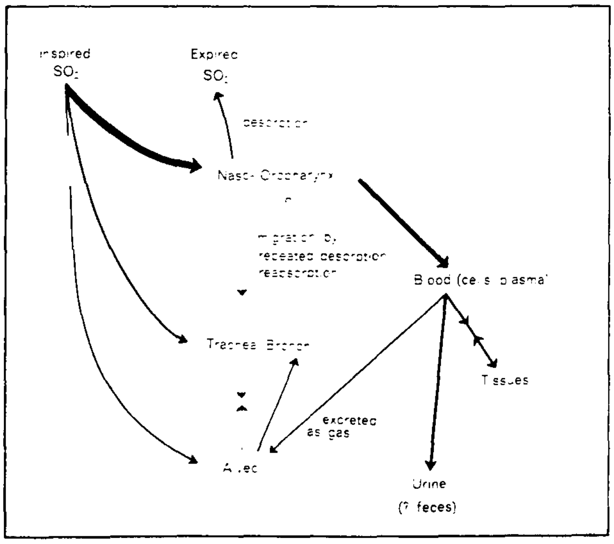

Figure 6 - Outline, based on experimental evidence, suggesting different paths taken by SO_2 after its removal from inspired air. Thickness of arrows is intended to indicate roughly relative amount of sulfur moving along each path. Whether SO_2 migrates along mucosal surfaces from nasopharynx or oropharynx to larynx and lower airways is unknown as is indicated by broken line.
Frank, N.R., Yoder, R.E., Brain, J.D., and Eyi Yokoyama: SO_2 (^{35}S Labeled) Absorption by the Nose and Mouth Under Conditions of Varying Concentration and Flow, Arch Environ Health **18** : 315-322 (March) 1969.)

some time SO_2 appears in the expired air and is thus excreted, in a proportion not yet quantified (vide Figure 6).
A great deal of the energy transport in the body is performed by (de-) hydration of sulphhydryl (HS-) groups. One may assume that inhaled and circulating SO_2 influences this system. This has in fact been shown in experiments in which SO_2 reduced the capacity of the total HS-system in the blood of test animals. That this mechanism does not directly result in catastrophic sequelae under experimental conditions can probably be explained by the fact that for energy transport a number of reliable systems normally act together to keep a balance by compensatory mechanisms. A loss of vital energy can thus be camouflaged in healthy organisms, where in ill or disabled people it would become readily apparent.

Considerable attention has been paid to the relation between mean and peak concentrations of SO_2 and (black) suspended matter on the one hand, and the mortality pattern in the population on the other. So far relatively well qualified and quantified dose/effect relationships have only been evaluated under exceptional circumstances, in which pollution levels over one or two days either raised current concentrations fourfold, or greatly exceeded definite thresholds. Such evaluations have also been attempted for morbidity parameters such as hospitalization, absenteeism, outpatient attendance and subjective responses of patients, mainly with reference to respiratory and cardiovascular symptoms.

As to the causation or promotion of adverse health conditions due to atmospheric pollutants, it is probably unrealistic to think in terms of specificity and direct cause and effect relationships. The observed symptoms and deteriorations of man's health are not a representative response to the influence of any one particular agent, and likewise, one substance may evoke different types of response (cf. SO_2, H_2SO_4, nitrogen oxides, particulates, and cigarette smoke, versus chronic bronchitis, lung emphysema, and lung carcinoma). It should be mentioned in passing that it is an established fact that inhalation of cigarette smoke is the main contributor to the causation, promotion and continuation of this type of disease. Compared with the detrimental effect of cigarette smoking, the influence of air pollutants from combustion processes in their normal emission concentrations, can probably claim only 10 % of the joint influence of both these features of modern civilization!

There are indications that, among children and young people in polluted areas, alterations of the functional condition of airways and lungs may appear in a degree which would not in itself be so serious, but that in the long term could facilitate the onset of recurring respiratory infections. One of the nonspecific — but very typical — effects that has been observed in animals in polluted atmospheres is an acceleration of the aging process, which can be described as an accelerated, uneconomic and regardless consumption of life's potentials, and even of life itself!

The fact that SO_2 and other gases can be registered by the olfactory and central nervous system at concentrations so small that they are sometimes far below the sensory threshold, has been demonstrated by investigators whose work is informed by the concepts of the prominent Russian physiologist I. Pavlov and of V. A. Rjazanov, the late hygienist. Unconditioned (= natural) as well as conditioned (= acquired) reflexes appear to be altered in the course of particular standard tests. The electroencephalogram (= record of the electrical activity of the cerebral cortex) appears to reflect subsensory registrations of changes in the composition of the atmosphere. With increasing concentration of the test gas an initial rise in the cortical activity can be observed, followed by a decline. Although these findings look spectacular, it has not yet been evaluated precisely what practical significance they have as regards the possible inhibition of brain function. But one should recognize the fact that human individuals, as well as the community as a whole, have increasingly to rely upon the integrity of their sensory and intellectual information processing system.

B. Sulphur dioxide (SO_2)

The threshold for smell detection of SO_2 lies at a concentration of about 3 mg/m³ (~ 1 ppm). Unpleasant irritation may occur at a level of 5—6 mg/m³ (~2 ppm). Nevertheless, the generally accepted threshold limit value (TLV) for pure SO_2 in industrial working conditions is 13 mg/m³ (5 ppm). One should note that a TLV refers to time-weighted concentrations for a 7 or 8-hour workday and a 40-hour workweek. Because of wide variation in individual susceptibility however, a small percentage of workers may experience discomfort at concentrations at or below the TLV, with a smaller percentage being affected more seriously by aggravation of a pre-existent condition or by development of an occupational illness.
Notwithstanding the relatively solid basis underlying the TLV, it is possible to register, among healthy volunteers in experimental conditions, an increase in airway resistance after only a short exposure to SO_2 concentrations at the TLV. Although the working mechanism of SO_2 is still under study (vide Figure 6), it is possible that reflex responses may play a role in the constriction of the smaller bronchi. On the other hand, irritation of the mucosa does induce an increased mucus production which is an especially deleterious effect in bronchitics, who are liable to react on exposure to concentrations much lower than the TLV, e.g. in the order of 3 to 6 mg/m³ (1 to 2 ppm) of SO_2.

Whereas in the outdoor atmosphere other pollutants like fly ash and black suspended matter are nearly always present, one should be aware of interactions between SO_2 and various other substances before attributing a recorded harmful effect to the influence of a single substance like SO_2. In practice the presence of soot and particulates seems to play an important role. Although the latter need not induce a response *per se*, it has been possible to record unwanted respiratory symptoms in bronchitic patients who were incidentally exposed to an atmospheric pollution that could be characterized by a level of about 1 mg/m³ (~ 0.4 ppm) SO_2 under presence of only 200 μg soot per m³.
Although such concentrations of these two substances do not, in practice, occur regularly in areas with single sources equipped with an appropriate control technique, one should avoid considering SO_2 as being a substance with such a low toxicity that it can be neglected. Especially since it has become clear that SO_2 is absorbed completely and rapidly into bodily organs and systems, the question as to the vital significance of this omnipresent pollutant should be answered, and rapidly.

C. Sulphuric acid (H_2SO_4)

A H_2SO_4 aerosol is, in terms of S-equivalent, far more irritating and harmful to the respiratory tract than is SO_2. The response and effect depend on the particle diameter, or, in other words, the deposition area in the respiratory tract. Particles in the order of 1 μm diameter or smaller are very active. At concentrations of about 400 μg/m³ irritation of the upper airways occurs. Exposure of bronchitic patients to H_2SO_4 concentrations of 250 μg/m³ may induce unpleasant irritation and shortness of breath. In healthy people a concentration of 120 μg/m³ over a limited exposure period would not give rise to clinical symptoms. Although the working mechanisms of SO_2 and H_2SO_4 are different, experiments have shown that both substances contribute equally in evoking the same type of response. So it is a question of simple addition.

It should be mentioned that other aerosols, like sodium chloride or finely dispersed metal salts, also have the capacity to stimulate an SO_2 effect. In the case of catalytic metal compounds in particular, it is a question of the real H_2SO_4 formation in the inspired air, or at the surface of the mucous membranes where the agent enters and induces the response.
This is of particular significance where a solitary source such as a power station is contributing, with its SO_2 emissions, to the formation of H_2SO_4 in a neighbouring area where considerable amounts of catalytically oxidizing substances are present in the atmosphere, as in the case of steel plants and metallurgical works.

D. Fly ash and other suspended particulates

Fly ash consists of a part of the incombustible minerals of the fuel, i.e. silicates and a great number of metal compounds. Other products, particularly of incomplete burning, may adhere to fly ash particles. For the time being fly ash as such is not a suspect material from the health point of view. It is possible that the metal compounds play a role as condensation nuclei and catalysts in the transformation of absorbed SO_2 into H_2SO_4. If these, extremely hygroscopic, particles are small enough to be inhaled (diameter $< 5\ \mu$m), fly ash may then play a role as a vehicle for the deposition of H_2SO_4 in the respiratory organs. Attention should be drawn to the presence of polynuclear hydrocarbons in soot from mineral oil combustion because of the interest some of these compounds have from the point of view of carcinogenesis in experimental animals. Although soot is not fly ash, it is thought that such carcinogenic hydrocarbons may well be adsorbed upon or absorbed in fly ash particles.

Apart from this no information concerning the direct influence of fly ash upon the health of man and animals is available. This must be considered a serious lacuna in the present state of knowledge.

As regards the influence of suspended particulates in general, it may be stated that, among bronchitis, an increase in respiratory distress has been observed during exposure to incidental cumulations of pollutants that could be characterized by daily mean levels of smoke in the order of 200 $\mu g/m^3$, which roughly corresponds to a total amount of suspended particulates of 400 $\mu g/m^3$. Such peak values of particulates can be encountered in areas that have a long term mean pollution level of about 75 $\mu g/m^3$ of OECD standard smoke or about 150 $\mu g/m^3$ of suspended particulates.
There wil probably be no harmful effects observed among sensitive people if the mean level of suspended particulates over the long term remains below about 70 $\mu g/m^3$, which roughly corresponds to 35 $\mu g/m^3$ of OECD standard smoke.

. **Oxides of nitrogen**

Oxides of nitrogen will increase in significance as an indicator of atmospheric pollution. Although they could, in this respect, be ranked with sulphur dioxide, the two can not be compared as regards the predictability of harmful effects on living organisms. Here nitrogen dioxide is of greatest importance. It irritates the mucous membranes, and in higher concentrations may cause irreversible damage to the lungs with immediately fatal consequences (lung edema).
Nitrogen dioxide is an oxidizing agent, and as such can denature tissue proteins, even at relatively low concentrations. It induces irreversible and stable chemical bonds which interfere with the vitality and adaptability of elementary structures on cellular and tissue level. Results of recent research indicate that long term exposure to concentration of NO_2 below 2 mg/m^3 (1 ppm) denatures the lung tissue of test animals (young rats). This process of deterioration can be interpreted as an acceleration of aging.

trogen dioxide plays an important role in the production of photochemical oxidation products which may cause eye irritation and, in severe cases, give rise to other complaints as well. A part of the irritating effect can be explained by the presence of formaldehyde and acrolein, as well as peroxyacetylnitrate (PAN).

IV. Biological and medical criteria for air quality standards

The issuance of air quality criteria is a vital step in a programme designed to assist the authorities concerned in taking responsible technological, social, and political action to protect the public from the adverse effects of air pollution. The designation of tolerable concentrations of pollutants is thus the result of a multidisciplinary choice in a complex of criteria which are qualitatively and quantitatively dissimilar. But quite apart from the importance one would like to attach to various types of criteria, one should realize that pollution is an evil that cannot be excused and which should be abated and prevented for its own sake.

Because a clean air policy depends in practice, on many more factors than just logic, common sense and good will, only relative, rather than absolute, criteria can be applied. For this very reason, however, one can never be too exhaustive in assessing whether measures to be taken do carry things far enough, for it is a feature of human nature in such problems to be content with little for the sake of convenience.
In the matter of multiple choices and decision making, unidisciplinary criteria may serve as guidelines. Air quality criteria (in the American terminology) reflect the latest scientific knowledge of use in indicating the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of an air polluting agent. Comprehensive evaluation and interpretation of criteria results in guides that indicate which effects are to be expected if exposure to pollutants exceeds definite concentrations and exposure times, and to what extent these effects will operate. Such guides are of fundamental importance, and yet all over the world people are engaged in study and evaluation of data that unfortunately are not yet appropriate to the subject in many instances.

There is as yet no agreement as to the interpretability of a number of qualitatively widely differing criteria, e.g. mortality and morbidity statistics versus Pavlovian methods and interpretations. Much depends on philosophy (pragmatism versus dogmatism), and guesswork in a field where knowledge is still lacking. Therefore only a very brief outline is given here, regarding the documents that describe the material in further detail.

There is general agreement that a single, 24-hour exposure of man, animals or plants to a concentration of SO_2 in the order of 200 $\mu g/m^3$ ($\sim$ 0.08 ppm) will not induce any harmful effect.
In a comparable manner long term exposure to a mean SO_2 concentration of 75 $\mu g/m^3$ ($\sim$ 0.03 ppm) will not result in any damage to man, animals or vegetation. Nevertheless it should be noted that even this relatively low level of SO_2 causes a so-called "desert" of epiphytic lichens and mosses.
Higher concentrations and longer exposures will result in a situation where harmful effects become detectable. As regards man and animals such a "sensitivity threshold" may be around 500 to 600 $\mu g/m^3$ ($\sim$ 0.2 ppm) for a short term exposure (24 hours) and around 150 $\mu g/m^3$ ($\sim$ 0.05 ppm) as the mean SO_2 concentration over a long period (years).
The transition from doses that are harmless to doses that increasingly lead to unwanted and deleterious effects is gradual and depends on the organism and the symptom under study, as well as on environmental conditions. But at exposures to 2000 $\mu g/m^3$ ($\sim$ 0.8 ppm) for 24 hours, and 300 $\mu g/m^3$ ($\sim$ 0.1 ppm) in the long term one has arrived at doses that induce deleterious effects which are unacceptable from the common sense point of view.
These figures apply to SO_2 as an index of pollution by combustion products from the use of traditional fossil fuels.

For a full appreciation of the gradation of this transition from harmless to deleterious exposures, one should realize that a harmful influence may already be acting on single sensitive individuals at concentrations of pollutants which are considerably lower than the level at which exposures begin to have a statistically significant effect on large population groups.

If one really intends to promote clean air in order to prevent unpleasant effects occurring, one should consider the above mentioned figures concerning a hypothetical "sensitivity threshold" as purely tentative. They hardly give a true picture, and as such they should be appreciated simply as upper limits which in practice should never be reached and which should be rigorously underbid by a policy that intends to guarantee a harmless and comparatively healthy environment based on either the best available knowledge or on qualified guesses.

For further information on the subject the reader is referred to the publications listed in the bibliography.

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