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AN AIR THAT KILLS -- MAN'S ALTERATION OF THE CHEMICAL CLIMATE

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ABSTRACT

Over the past several centuries the problems of air pollution have developed from local to regional to global in scale, ultimately threatening serious alteration of the world's climate. A chronicle is presented here of the discovery of air pollution by coal smoke, acid rain, radioactive fallout and persistent organochlorine pesticides, and also of the implications of ozone-depleting chemicals and carbon dioxide build-up for climatic change.

Keywords: acid rain, air, carbon dioxide, climate, radioactive fallout, history, ozone layer, pesticide, pollution, smoke.

INTRODUCTION

Over the past three hundred years scientists have gradually established that plants photosynthesize while both plants and animals respire, so that the balance of nature is maintained by the interactions of the global cycles of carbon dioxide and oxygen through the atmosphere and the biosphere. This overall picture of the normal metabolism of the planetary ecosystem was perceived as long ago as 1772 by Joseph Priestley (1).

Over the same time span, other investigators have been concerned with what might be termed pathological manifestations of the biospheric metabolism mediated through the atmosphere, and it is these that I wish to consider here. Although I shall deal chiefly with problems deriving from the combustion of fossil fuels, other problems of similar magnitude will be examined briefly.

LOCAL PROBLEMS

The earliest concern about deleterious interactions between atmosphere and biosphere was felt in the cities, where air pollution became a problem as soon as coal came into general use in large urban areas such as the city of London (2). There the first recorded complaint was registered in 1257 by Queen Eleanor, wife of Henry III (3). The '80's of that century saw the setting up of two commissions to look into the fouling of the air by lime-burning and smelting.

By the mid-seventeenth century problems had become far worse and stimulated John Evelyn to write his celebrated tract, the "Fumifugium", in 1661 (4). In it he pointed out that smoke from "sea-coale", brought to London by ship from Newcastle, was a serious cause of ill health and mortality, particularly from lung disorders. In this he was supported by John Graunt, whose 1662 study of the bills of mortality in London became the foundation for the study of statistics and demography (5). Evelyn also inveighed against the dirt and corrosion caused by "smoake", and the loss of both bees and flowers from the city. He noted too that in 1644, when Newcastle was blockaded, the London air became so much improved that gardens and orchards yielded crops larger by far than any seen before or afterward. In his view local industries were the major cause of trouble, and he urged their banishment to five or six miles from the city.

The "Fumifugium" was reissued a century later, in 1772, and the editor took occasion to remark that the situation in London had worsened considerably since Evelyn's time. He also suggested a series of remarkably modern-seeming measures to ameliorate the pollution: tall smokestacks to disperse the smoke to distant parts, aided by better chimney construction to send the smoke higher in the air, improved methods of combustion -- by charring or coking the coal to make a smokeless fuel, inducements for industry to relocate outside London, and laws to prevent new industries from locating within the city. Earlier suggestions that Londoners ought to go back to wood as a source of fuel were by that time economically impractical, and the substitution of anthracite for bituminous coal did not become generally popular. In fact, substantial improvement of the London air did not come about until the late 1950's, after the great smog of 1952 -- which I experienced -- killed upward of four thousand people in a week.

Thorough scientific study of the mortality induced by urban air pollution has only been undertaken within the past century, and particularly in the years since World War II. Perhaps the most important investigation is that of Lester Lave and Eugene Seskin, who in 1977 estimated that a 10 percent reduction in pollution by sulfur oxides and particulates might reduce the United States death rate by about half a percent (6). They also suggested that full implementation of present clean air legislation would bring benefits in health improvement conservatively estimated (by medical expenses and foregone earnings) at $16 billion, as against abatement costs of about $9.5 billion. Their statistical study could not of course demonstrate a conclusive, causal connection between air pollution and human health, but they made a conscientious attempt to satisfy the nine criteria for causality in epidemiologic studies that were set up by Sir Austin Hill in 1965. Another important analysis is that by Mendelsohn and Orcutt (7).

Man is not the only sufferer from air pollution, nor the most sensitive. Among the candidates for that distinction certain primitive plants -- the lichens -- are perhaps the strongest contenders. They are extremely sensitive to sulfur dioxide, and their absence from the city of Manchester was ascribed to air pollution by Grindon as long ago as 1859 (8). Nowadays they are widely used as test organisms in the detection of low levels of sulfur dioxide and general air pollution.

REGIONAL PROBLEMS

The earliest case of regional, indeed international, air pollution known to me was reported by John Evelyn (4). He remarked that French farmers had complained that smoke from the coastal districts of England was injuring their vines in flower. Smoke, including fine particulates derived from sulfur oxides and condensed hydrocarbons, also causes haze, noted again by Evelyn in London. Since World War II such haze has increased greatly over the eastern half of the United States, both in area and duration, to the point where it has become a major factor limiting visibility (9).

A more serious problem is that of acid rain. It was first discovered in Manchester in 1852 by Angus Smith (10), who in 1872 extended his investigations to many parts of England and Scotland, rural as well as urban (11). It was later studied by Crowther and Ruston in 1911, in and around the city of Leeds in England (12). They, like Smith, observed a marked decline in the deposition of organic matter, nitrogen, sulfur, chloride and acidity as one moved from the city center to its periphery. They also conducted biological experiments with acid Leeds rain and with sulfuric acid of similar strength, demonstrating a check to seed germination and plant growth, inhibition of various aspects of the nitrogen cycle in the soil, and a lowering of the protein content of timothy grass. It appears, however, that the acidity of Leeds rain -- like that of other British cities where coals high in chlorine are burned -- is owing to hydrochloric rather than to sulfuric acid, which in contrast prevails in the English countryside (13, 14).

The spread of acid rain (and snow) over the countryside on a regional basis was first documented in 1955, by Barrett and Brodin in Scandinavia (15), by Henry Houghton in New England (16), and by Gorham in the English Lake District (17). By great good fortune, the Scandinavian network for the study of precipitation chemistry expanded to cover the whole of Europe and remained in existence, so that by the mid-1960's it was clear that the problem was both growing worse and spreading. In the late 1960's, Svante Odén pointed out that acid rain was causing serious ecological damage in Scandinavia, especially to lakes and streams but possibly also to forests (18). In the early 1970's Gene Likens and his associates noticed the same phenomena in the eastern United States (19).

The damage to sensitive lakes and streams -- those on coarse, granitic soils lacking in lime -- is rapid and severe, leading within a few years or a few decades to a loss of biological diversity at all levels of the food chain, and the progressive disappearance of fish populations (20). Smallmouth bass are sensitive and vanish early, whereas the more tolerant yellow perch are among the last to go.

Damage to forests is far less easy to demonstrate because it is likely to occur much more slowly, but it is potentially far more serious if it does occur. Again, the sensitive ecosystems are those on coarse granitic soils such as those of the Laurentian Shield. These soils undergo a very slow acidification by the natural ecological process of leaching (21), which can be accelerated by acid rain. Soil nutrients such as calcium, potassium and phosphorus are likely to be lost faster than they can be replaced by soil weathering, and the cycle of nitrogen -- the major soil nutrient limiting tree growth and forest productivity -- may well be inhibited over the long term (22). In areas economically dependent upon forest products there is a potential for serious losses over a period of several decades to a century or two. And although there has been up till now no conclusive demonstration of declining forest productivity in response to acid rain (23), all our experience of forest ecology leads us to expect it over the long run. If neglected, the acidification could eventually become irreversible, so we should take care to prevent it.

Acidification on such a broad regional scale cannot possibly be reversed by liming as practiced on agricultural soils. Some of the remedies in such a case lie in the application of better fossil-fuel technology: coal-washing, stack-scrubbers for flue gases, innovative techniques of coal combustion in fluidized beds; or in the use of alternative energy sources: sun, wind, water or biomass power from cornstalks or cattails. Many of these remedies will have environmental problems of their own to be solved, in the form of waste waters, sludges, diversions of land from other uses, etc. There is one remedy, however, that carries no environmental penalty whatever, and that is energy conservation. If we conserve wisely the energy that now we waste carelessly, there need be no appreciable impact upon human welfare.

GLOBAL PROBLEMS

Since World War II we have succeeded in elevating our air pollution problems not only from a local to a regional scale, but also in certain cases -- only one of them coal-related -- to truly global proportions. Our first such experience was with radioactive fallout, fortunately much reduced following agreement by the earliest nuclear powers (but not France and China) to cease testing nuclear weapons in the atmosphere. Hiroshima, and subsequent detonations of what were euphemistically described as nuclear "devices", spread round the world a rain of toxic radioisotopes -- strontium-90, cesium-137 and carbon-14 among them -- and these posed a threat both to our body cells in the form of cancer, and to our hereditary germ plasm in the form of genetic mutations. In both cases it seems likely that there is no safe threshold below which radioactive fallout does no harm, either to us or to the other inhabitats of the planetary biosphere. And we should remember that radioactive materials are also emitted -- albeit on a very much smaller scale -- by coal-fired power plants (24).

It was on a regional scale that fallout posed the greatest threat to humanity, in a way that was quite unexpected and surprising. As it turned out, I played a part in uncovering this particular threat, because after the great London smog I moved to the English Lake District in time to experience the fire at the Windscale reactor that exposed the local inhabitants to twenty thousand curies of iodine-131 and a few hundred curies of strontium-90 and cesium-137. That incident stimulated me to look for fallout in the surrounding vegetation; however, the fallout I found came not from Windscale but from the world-wide distribution of radioactive material that resulted from atmospheric detonations of nuclear weapons (25). I reasoned that mosses and lichens, depending on the atmosphere for their mineral nutrients, would be excellent scavengers for fallout, and so indeed it turned out -- they were far more effective than rooted higher plants (26). This explained for me why Norwegians were finding much more strontium-90 in reindeer than in sheep, because reindeer feed on mosses and lichens in preference to grasses and herbs. I then predicted that if someone took a look at reindeer-herders in Lappland they would get a nasty shock, because the Lapps would prove to be highly radioactive. And so it turned out; within a few years it was reported that the Lapps were far more radioactive than the inhabitants of Helsinki, and indeed some were exceeding the guidelines for cesium-137 in human populations (27). No one seemed to care about what might be happening to the reindeer, or indeed the lichens! Fortunately, since the test-ban treaty the levels of fallout radioactivity have been declining steadily and substantially.

Moreover, out of this gigantic experiment -- which incidentally violated the first rule of good experimentation, which is to set up adequate controls -- we did manage to extract some benefit. The diverse array of radioisotopes released into the atmosphere proved to be of considerable value in tracing the pathways of various elements through their geochemical cycles in our soils and waters, and in tracing those same elements through the food webs of the biosphere. It was indeed an ill wind that did blow us a little good along the way, although not enough to make scientists desire a return to testing in the atmosphere.

Our second experience of global air pollution came also after World War II, with the local and regional use of persistent synthetic pesticides in the form of chlorinated hydrocarbons such as DDT, not to mention the industrial polychlorinated biphenyls or PCBs. These proved to have an extraordinary ability to concentrate (by several orders of magnitude) along food chains, and to kill fish and birds at the ends of those food chains in substantial numbers (28). They are now globally distributed from the equator to the poles, partly because they are often coated upon fine particles of talc for aerial application, and sufficient talc escapes into the upper air to become a ubiquitous contaminant of atmospheric dust (29). These organic molecules also vaporize slowly from soil and water surfaces, and are carried down again by rain and snow, so that they are subject to a global process of recurrent distillation over the entire surface of the earth (30). It is well to remember that large amounts of chlorinated hydrocarbons continue to be used both for disease control and for agriculture, largely in Third World countries. The effects of chronic, low-level doses of these materials to animal and human populations over a lifetime are at present unknown, but will prove a fascinating study for epidemiologists as the children born after World War II come to the end of their life-span.

MAJOR ALTERATIONS OF THE ATMOSPHERE

The two global problems already discussed involve what might be termed contamination of the atmosphere, in ways that are not likely to have a major impact upon its function. The next two problems both involve the possibility of serious alteration in the way that the atmosphere functions and interacts with the biosphere.

The first such problem concerns the possibility of depleting the stratospheric ozone layer that screens us from excessive exposure to ultra-violet radiation from the sun -- the cause of sunburn, skin cancer, and other kinds of damage to living organisms. Ozone is a very reactive molecule formed from oxygen in the upper atmosphere, and it can readily be converted back to oxygen catalytically by oxides of nitrogen and by chlorine atoms. We now have the ability to accelerate the injection of these materials into the stratosphere in four ways, all discovered within the past ten years.

Three of them have to do with oxides of nitrogen. These are being generated increasingly in our agricultural soils as the enormous amounts of nitrogen fertilizer now in use are transformed by soil microbes. Some of the resulting gaseous oxide emissions will inevitably reach the stratosphere and react with the ozone there, as suggested by Paul Crutzen in 1970 (31). A year later Harold Johnston suggested that a fleet of supersonic transports

(SST's) could also generate enough oxides of nitrogen in stratospheric flight to threaten seriously the integrity of the ozone layer (32). The worst threat, however, would come from the immense amounts of such oxides that would be generated in the fireballs of a nuclear war (33).

A different sort of threat was suggested in 1974 by Molina and Rowlandson, who indicted the chlorofluoromethanes (freons) that we use as refrigerants and especially as propellants in aerosol spray cans (34). They reminded us that the very inertness and lack of chemical reactivity that led to their use in aerosol sprays allows freons to diffuse the long distance from the ground to the stratosphere. There they are no longer inert, and break apart under the stress of high-energy ultra-violet radiation to release the chlorine atoms that can react with stratospheric ozone.

The severity of the threat to the ozone layer is very difficult to assess. Most estimates of depletion are of the order of a few to as much as 10 or 15 percent over the course of a few centuries. What consequences there will be for the biosphere are even harder to estimate, but they appear sufficient to deserve our serious consideration and a great deal of further research, especially as there are implications of possible climatic alteration as well as damage from ultra-violet radiation.

The second and far more serious threat to global climate comes from our rapidly rising use of fossil fuels. The combustion of coal, oil and natural gas is on the way to doubling the levels of atmospheric carbon dioxide, which in turn is expected to cause a warming of the climate beyond present limits owing to the so-called "greenhouse effect". According to Plass (35) this particular story began with the French scientist Fourier, who in 1827 likened the atmosphere to a pane of glass beneath which the earth is warmed. The role of carbon dioxide in this process was foreshadowed by the Englishman Tyndall in 1861 and worked out in detail by the great Swedish chemist Svante Arrhenius in 1896. The process is as follows: incoming shortwave radiation from the sun is radiated back to space at long wave-lengths that are readily absorbed by carbon dioxide. By this means the escape of radiant heat from the earth is retarded, and the atmosphere is warmed.

Forty-two years after the time of Arrhenius, in 1938, G.S. Callendar suggested that fossil fuel combustion was releasing carbon dioxide into the atmosphere faster than it could be taken up by the vast reservoirs in the oceans and in the biosphere of living plants and animals. This phenomenon he believed to be the cause of a recent trend toward warmer climate (36). Eleven years later he suggested that forest clearance and cultivation might also be releasing carbon dioxide by the destruction of tree biomass and the oxidation of soil humus (37). The most recent estimates suggest that together these two mechanisms might well bring about an appreciable climatic warming sometime in the next century. It could amount to as much as two to four degrees celsius on average, and two to three times as much at the poles. There the warming might suffice eventually to melt the arctic pack-ice and the western antarctic ice-sheet, raising sea-levels by twenty feet or so (38).

The overall effect of atmospheric enrichment in carbon dioxide might be to increase somewhat the worldwide productivity of green plants. However, there would also be marked shifts in the patterns of climate and weather, and major displacements of agriculture. These cannot readily be predicted, but by analogy with the mid-postglacial period of warm climate several thousand years ago we might perhaps anticipate a drier climate and less productive agriculture in the American midwest and in the grain belt of the Soviet Union (38). Other areas might become able to produce more food than before, but many would lack the technology, trained personnel and capital to do so.

The uncertainties connected with the "greenhouse effect" are undoubtedly very great, but that does not relieve us of the necessity to introduce the issue into current decision-making on energy policy. The consequences of inaction -- if world climate were to change appreciably -- could so profoundly affect human society that we cannot ignore them; if we wait until the effects are demonstrated to everyone's satisfaction they will most likely be irreversible. Prudence dictates that we give the matter the most serious consideration, and probably also that we begin now to take steps to reduce both our combustion of fossil fuels and our clearance of the world's forests.

THE ROOTS OF OUR PROBLEMS

The underlying causes of all these derangements of normal atmosphere/biosphere interactions are easy to identify, but difficult to deal with because they are not only technological but also social and political. First is the rapid development over the past two centuries of our industrial technology, with its ever-increasing demand for energy which can only be satisfied presently by combustion of fossil fuels. The population explosion, and its implosion into large conurbations, acts as a potent multiplier for per capita increases in the use of energy and materials. Taken together, the result is that we human beings are beginning to operate on Nature's own scale in altering both the physics and chemistry of the earth's surface and of the atmosphere above it.

Unfortunately the physics and chemistry utilized by technologists are sciences far simpler and better understood than the biological, ecological, and social sciences that must deal with the consequences of technological development. We are, indeed, a band of sorcerer's apprentices, far from understanding the full, long-term implications of our increasingly potent manipulations of the planetary life-support system upon which we all depend.

WHAT WE MUST DO

In spite of all our complex problems there are several ways -- admittedly far from easy -- in which we may arrest our present course of environmental change and degradation. We must stabilize world populations as soon as possible. At the same time we must set realistic ceilings on the consumption of energy, particularly from fossil fuels. Renewable sources such as sun, wind, and water power must be increasingly exploited, along with the renewable energy in crops grown especially for their biomass.

We must be more selective in our technologies, realizing that some -- like the SST -- are wasteful and dangerous; and that decentralization has much to recommend it. As E.F. Schumacher told us, "Small is beautiful" (39). We must expect continual unpleasant surprises, but gear ourselves to avoid or ameliorate them by better assessment procedures and by massive research programs on the side-effects of technology. And as we attempt to arrange a more equitable sharing of global resources with the poorer countries of the Third World, we must also try more vigorously to resolve our differences with the Soviet Union, so that many of our and their best brains can be shifted from their destructive tasks of weapon design to the constructive tasks of building a better world for all the inhabitants of Spaceship Earth.

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