Air Conservation Report Reflects National Concern

The role of scientists in the formulation of public policy is examined in the light of present knowledge.

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President Johnson, in his 1965 State of the Union message, proposed that "we increase the beauty of America and end the poisoning of our rivers and the air that we breathe." To that end, he said, "we will seek legal power to prevent pollution of our air and water before it happens. We will step up our efforts to control harmful wastes. . . . We will increase research to learn more about the control of pollution. . . ."

What steps the Congress may take to implement the President's call for action would be difficult to predict. But this much seems certain: Mr. Johnson's concern, as expressed in his message, is a manifestation of a growing national concern for the beauty, the cleanliness, the healthfulness of the environment.

That concern was expressed by the federal government during the preceding administration in the Clean Air Act of 1963, and has been expressed in recent years by many state and local governments, by newspapers and magazines, and by scientific bodies, including the American Association for the Advancement of Science.

This growing awareness, however, is not a guarantee that the problems posed by continuing pollution of the air will be solved quickly or intelligently. Yesterday, perhaps the greatest difficulty in the effort to improve the quality of the air was public apathy; tomorrow the greatest difficulty may be excessive fear. But both apathy and fear, in this instance at least, are the result of ignorance; what is clearly needed, if policy-making bodies are to respond intelligently to the problems of air pollution, is the assistance of a scientific community armed with knowledge.

The AAAS Committee on Science in the Promotion of Human Welfare, in its report of July 1960, said that scientists "should accept the obligation to determine how new advances in our understanding and control of natural forces are likely to affect human welfare, to call these matters to public attention, to provide . . . objective statements of the facts and of the consequences of alternative policies that are required as the basis for informed decisions on the relative merits of proposed courses of action." Six months later, anticipating the present public concern, the committee cited air conservation as an illustration of the thesis "that the accelerating progress of science is creating social issues of unprecedented magnitude."

Soon thereafter the committee appointed a 12-member Air Conservation Commission, which met for the first time early in 1962. Its deliberations spanned the next 2 years and culminated in a report that deals with air conservation, pollution control, pollutants and their effects, meteorology, law, economics, public health, public opinion, and government. The commission designed the report in three parts, so that it would be useful to scientists in a wide variety of disciplines and to interested laymen. The first part, written for the broadest possible readership, is directly responsive to the commission charge and deals with air conservation and public policy. The second part is a concise report on the present state of scientific knowledge. Seven rather technical chapters, of interest principally to scientists and specialists in other disciplines, make up the third part.

Here we attempt to present in condensed form the information contained in the first two parts of the report.

The Principal Pollutants

Air pollutants are produced wherever energy conversion takes place under human direction. From the smallest hearth fire to the latest factory, all contribute their share. The pollutants are even more numerous than the sources. However, a few groups of substances comprise the vast bulk of emissions to the atmosphere resulting from man's activity.

The single product of energy-conversion processes that occurs in greatest abundance is the product of least concern here—water. Only in very rare instances can it qualify as a pollutant.

Next in quantity among the waste products from our use of organic fuels is carbon dioxide. It is naturally abundant in the atmosphere, and man is well adapted to living with widely varying concentrations of it. However, carbon dioxide normally remains in the gaseous state for a long time. Liberation of this gas has been so great that we have already increased the global concentration by a substantial figure—around 5 percent. The increase has had no known effect on any living organism. But carbon dioxide is intimately involved in the mechanism that maintains the overall temperature of the earth. Although so many factors are involved in this overall atmospheric heat balance that it is impossible to evaluate the effect of any given increase in atmospheric carbon dioxide, it is possible that a continued increase over a long period would change the global climate.

The complete combustion of carbonaceous fuels produces carbon dioxide; the incomplete combustion, characteristic of many processes involving energy conversion, yields carbon monoxide. In American cities the primary source of this gas is the automobile. Atmospheric carbon monoxide begins to be hazardous to most humans at concentrations of about 100 parts per million, if the level is maintained for several hours. Particularly susceptible individuals may be affected at lower concentrations. Although the toxic level

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appears very high by comparison with that of the other pollutant gases, it has been reached occasionally in areas where traffic is heavy, and more frequent occurrences may be expected unless emissions from automotive vehicles can be controlled effectively.

In addition to substances emitted in massive amounts there are various materials that normally occur in much lower concentrations. But some of these other materials are much more toxic. Sulfur dioxide and the sulfuric acid that forms when the sulfur dioxide comes in contact with air and water seldom reach levels above a few parts per million. However, the present consensus is that these two substances have been centrally involved in all the air-pollution disasters of recent history, including the London smog of 1952, in which some 4000 persons died. (Many scientists believe that factors as yet undiscovered contributed materially to these deaths, but most today would identify sulfur dioxide and sulfuric acid, perhaps combined with soot or other particulate agents, as the major causative agents). Sulfur dioxide results primarily from the combustion of coal or oil, both of which contain substantial percentages of sulfur in various chemical forms. To some extent in the combustion itself, and to a greater extent in the external atmosphere, sulfur dioxide is converted by the action of atmospheric oxygen and water to sulfuric acid. Sulfur dioxide by itself is extremely irritating to the upper respiratory tract in concentrations of a few parts per million. Sulfuric acid appears as a fine mist that can be carried deep into the lungs, where it attacks sensitive tissues. In addition, the droplets of sulfuric acid carry absorbed sulfur dioxide far deeper into the system than the free gas alone could penetrate, thus spreading the effect of this irritant over the entire respiratory tract.

Hydrogen sulfide can result from a variety of industrial and other processes, but it usually enters the atmosphere as a result of the accumulation of industrial wastes in stagnant waters. Here bacterial action reduces the sulfur-containing compounds to hydrogen sulfide, which is relatively insoluble in water. It has the well-known odor of rotten eggs, and it is highly objectionable. In high concentrations it is also rapidly lethal. However, few cases are known in which concentrations of hydrogen sulfide in the open atmosphere exceeded the level of mere nuisance.

Only two of the six or seven existing oxides of nitrogen are normally considered to be pollutants: nitric oxide and nitrogen dioxide. Only an industrially advanced community is likely to suffer serious pollution from them. Nitric oxide is the primary product formed when combustion takes place at a sufficiently high temperature to cause reaction between the nitrogen and oxygen of the air. Such temperatures are reached only (i) in highly efficient combustion processes or (ii) when combustion takes place at high pressure. A great deal of nitrogen is fixed in the second way in the cylinders of the typical automobile. Electrical power plants and other very large energy-conversion processes also fix nitrogen in this fashion. However, for most cities the largest single source is automotive vehicles.

Nitric oxide is generally emitted as such to the atmosphere. However, a complex of processes, some of them photochemical, may convert a substantial portion of the nitric oxide to nitrogen dioxide, a considerably more toxic gas and the only important and widespread pollutant gas that is colored. As a result of its reddish brown color, nitrogen dioxide can significantly affect visibility.

In addition to the inorganic gases listed above, nearly any other objectionable inorganic gaseous material used in industry may become a pollutant if it escapes into the atmosphere. However, these other gases are not the general emissions of what might be called the metabolic processes of civilization, and they are likely to be restricted to a few locations. Consequently, only one of them deserves separate attention. Hydrogen fluoride, because of its extreme toxicity for some living organisms, is likely to be an acute problem at any place where materials containing fluorides are processed. Hydrogen fluoride is apparently taken up from the air by nearly all plants, and certain plant species are damaged by concentrations of less than 1 part per billion.

Furthermore, since vegetation tends to concentrate the fluoride that it receives, continuing low atmospheric levels of fluoride can produce levels of fluoride in forage that are toxic to grazing cattle; there are claims, as yet unproved, of concentrations dangerous to humans in leafy vegetables. The manufacture of phosphate fertilizer, the smelting of certain iron ores, and the manufacture of aluminum are all sources of hydrogen fluoride gas and of some particulate fluoride.

The organic gases are very numerous. The chemical process industries inevitably release into the atmosphere some of almost everything they manufacture. However, only a few general classes need separate consideration, since a number of the organic materials that can be identified in the atmosphere appear to have no adverse effects whatever.

Probably the simplest organic substance of significance as an air pollutant is ethylene. Aside from its participation in the "smog" reaction, discussed below, it is a potent phytotoxicant (plant-damaging agent) in its own right. Ethylene, like the bulk of other simple hydrocarbons, arises in part from industrial sources, but it comes primarily from the exhausts of automotive vehicles.

The higher members of the series to which ethylene belongs, the olefins, appear to have no direct effect upon vegetation or animal life. However, when these (together with several other classes of organics) are exposed to sunlight in the presence of nitrogen dioxide or nitric oxide, an extremely complex reaction sequence ensues. The end products appear to be ozone, aldehydes, and a variety of organic compounds containing nitrogen. This mixture, in adequate concentrations, produces two distinct types of damage to plants, and irritation of the eyes and mucous membranes in humans (and possibly in other animals). This reaction was first noticed in Los Angeles, and is therefore popularly referred to as the "Los Angeles smog reaction." The substances necessary for occurrence of the reaction can be produced by the right combination of industries, but they are present in almost ideal concentrations in automotive-vehicle exhaust. Consequently, the presence of this type of pollution is characteristic of areas having a high density of automotive traffic.

Some of the aldehydes characteristic of the Los Angeles smog also arise from other sources. Formaldehyde and acrolein, which are particularly irritating to the eyes and nose, are found in the smoke of poorly operating incinerators and in smoke from stockyards and from a number of other sources.

Aside from the gases and vapors listed above, large quantities of more or less finely divided particulate matter are put into the air, or formed there, as a result of human activities. The largest single particulate ingredient in nearly all urban atmospheres is dust.

In many cities the next most prevalent substance among the airborne particulates is soot, which is very finely divided carbon clumped together into long chains and networks. Soot results from inefficient combustion of carbonaceous fuels, hence represents not only an air pollutant but also a waste of fuel. Because the individual particles are so fine, they present an enormous surface per unit weight. This surface is extremely active, and it can adsorb a large variety of substances from its environment. Soot generally carries with it a substantial load of heavy hydrocarbons that are formed simultaneously with it in smoky flames. These hydrocarbons include organics known or suspected to cause environmental cancer on sufficiently prolonged contact. Soot can also act under some circumstances in the same manner as sulfuric acid mist; that is, it can adsorb vapors that would normally be removed in the upper respiratory tract and carry them deep into the lungs. In addition to all the known or suspected physiological effects, soot is a nuisance, both because it obscures visibility and because it is dirty. The fall of combined soot, dust, and other particulate materials on a single square foot (0.09 m^2) of horizontal surface in a city may easily exceed a pound (0.45 kilogram) per year.

There are two additional classes of particulate matter that are not of peculiarly urban origin but that have a substantial impact upon human well-being and thus have come in for a great deal of interest recently. These are (i) the economic poisons, and (ii) radioactive material.

The economic poisons include insecticides, herbicides, and other chemicals used by man. A number of these are normally disseminated through the air, and some portion of them may well find their way to considerable distances from the intended site of application. Many of them are toxic to man and can harm other life forms not intended as their targets.

There are three major sources of radioactive gases and particles. The first is research; this is generally not an important source of contamination except in case of major accidents. The second is nuclear power plants; these almost continuously give off some gaseous materials. There is no evidence to date that the accumulation of these in the atmosphere is a major hazard. The nuclear power industry is said to be one of the most carefully controlled of all industries on the face of the earth. However, an accidental discharge can distribute highly toxic concentrations over a rather large area. The final source is, of course, nuclear weapons. This is a special category, not because of any chemical or physiological difference in the compounds involved, or difference in their effects, but because the political, economic, and military considerations governing their use are so special.

Transport of Pollutants

Once a pollutant or a group of pollutants from a given source has been ejected into the air, its movement with the air will depend upon a number of factors. Particles larger than approximately 1 micron in diameter are significantly affected by gravity. They tend to settle out from the air that carries them and eventually are deposited, the distance from the source usually depending on the particle size. The movement of pollutants is affected, also, by turbulent diffusion, which tends to disperse them.

Less important over short distances, but of crucial importance on the large scale, are the effects of aggregation and growth. Particles in a pollutant cloud tend to increase in size, sometimes by collisions that form larger aggregates and sometimes by the condensation of vapors on them, with or without chemical reaction. This process may occur in and under water clouds, where the water droplets may form on the particles, increasing their size, or falling raindrops may collide with the particles, carrying them to the ground.

When wind speeds are high, pollutants are rapidly removed from the point of origin, and, within a short distance, turbulent diffusion usually dilutes them below the concentrations at which they have a significant effect. However, under some conditions turbulence can bring the plume from a stack to the ground, in great loops, at a point quite close to the source and before extensive dilution has occurred; this results in brief exposure to extremely high concentrations.

Whereas horizontal travel of pollutants is largely controlled by wind velocity, the primary factor regulating the vertical dispersal of pollution is the vertical profile of temperature. The rate of change of temperature with height is referred to as the lapse rate. Normally, in the lower atmosphere the temperature decreases with increasing altitude. According to well-established physical law, if a parcel of air is carried from a low altitude to a high one, it will expand with the decreasing pressure and its temperature will decrease, provided there is no heat exchange with its surroundings. By the same token, if the parcel of air is taken to a lower altitude without gaining or losing heat, its temperature will increase. For a given altitude change, the corresponding temperature change is constant and determinable. This rate of change is referred to as the adiabatic lapse rate.

If the actual lapse rate is greater than this theoretical rate, a parcel of surface air that begins to rise will continue to do so. This situation is called unstable. If, on the other hand, the temperature change with height is less than the adiabatic rate, surface air that begins to rise will tend to sink back to the surface; this is called a stable lapse rate. If there is no temperature change with altitude, or if the temperature increases, the atmosphere will be especially stable. The difference between this and the unstable situation is one of degree, not of kind. An increase in temperature with altitude—an inversion—is not a unique phenomenon.

During unstable conditions, there is a great deal of vertical mixing in addition to whatever horizontal dispersion the wind may induce; the dilution of pollutants takes place in three dimensions. On the other hand, under conditions of high stability, vertical dispersion will be greatly inhibited; if these conditions are accompanied by low winds, a layer of highly polluted air may build up over a large area, such as an entire city or an entire basin.

The Fate of Pollutants

For virtually every known pollutant there are natural processes that tend to remove it from the atmosphere, thus preventing mankind from smothering in its own by-products.

Reference was made earlier to the tendency of particulate pollutants to coagulate, to increase in size, and to fall to earth. Rain and snow carry large amounts of both particulate and gaseous pollutants out of the atmosphere and into the soils and the waters of the earth. Trees and grasses act like the fibers of an enormous filter mat to collect particles and some gases.

The oxygen of the air combines with many pollutants, either directly or indirectly, gradually changing them into forms more readily removable. In many cases sunlight plays a role in this reaction. Frequently the result is the formation of particulate matter from gases. These particles can then enter the cycle of filtration, aggregation, and washout, and thus be removed from the atmosphere. It is noteworthy that the sulfuric acid droplets that are believed by many to have contributed to the death toll in London, and the photochemical smog characteristic of the West Coast of the United States, actually are steps in the atmosphere's own process of self-purification. The misfortune is that these intermediate products have marked physiological effects and that they frequently form in heavily inhabited areas.

A few miscellaneous substances do not participate in photochemical oxidation reactions sufficiently rapidly to be removed by that mechanism. The outstanding examples are methane, and a few of its relatives, and carbon monoxide. These are ultimately destroyed by oxidation, entirely in the gas phase, and become carbon dioxide, but the rate of destruction is not known. Carbon dioxide appears to be removed most effectively by direct solution in the ocean, which is the ultimate point of disposal of most of the soluble inorganic substances. The power of the ocean ultimately to consume such materials by dilution is enormous. However, our rapid production of carbon dioxide seems to be outstripping the ocean's ability to remove it from the atmosphere. It appears that roughly a third of the carbon dioxide put into the air by combustion processes remains there; as noted earlier, this may have an effect on the world's weather. Growing plants remove carbon dioxide also, but they return it to the atmosphere when they die or decay.

Thus, the atmosphere has tremendous powers to dilute, disperse, and destroy a large variety of substances that man elects to discharge into it. Pollution occurs when, on a local scale, these processes cannot keep up with the rate of discharge, and when the wastes come in contact with a susceptible receptor, such as man or his fellow inhabitants of the biosphere.

Control of Air Pollution

The first and most obvious solution, historically, to the problem of a "dirty" industry is to move it out of town. But the town often has promptly grown out until it has encompassed the industry. Attempts have been made to segregate industry in areas generally downwind of the residential portion of the city. But sometimes the pollution from the workers' automobiles has added as much pollution as the industry would have had it been close to the population center, and sometimes the wind simply blows from the opposite direction.

Another widely used technique, particularly in the power industry, is the erection of enormously tall stacks, in which air velocities are usually very high. Pollutants are discharged high into the atmosphere and their vertical velocity tends to carry them still higher, so that the dispersive processes in the atmosphere may dilute the effluents below the concentration of physiological significance before they reach the ground. This technique has considerable merit but is not complete proof against an occasional very high concentration's reaching the ground in a downdraft.

In most industries it is at least theoretically possible, and in many cases it is economically feasible, to remove the bulk of the pollutants from the effluent stream before its discharge into the atmosphere. Devices exist for the removal of nearly all particulate pollutants and for removal of the bulk of the gases if they are at sufficiently high concentration. However, some industries have, typically, an enormous total volume of effluent containing the impurities at rather low concentrations. The actual discharge in terms of tons per hour may be quite large, but the concentration in the effluent air stream can be so low that efficient removal of the pollutants is extremely expensive.

In some cases it is possible to avoid emission of pollutants into the atmosphere by simple modifications of the processes in use. The main obstacle frequently is tradition.

A final and little-explored approach is simply better collaboration with nature. As noted earlier, air pollution is the result of man's conversion of energy. This energy conversion is fundamentally for the purpose of opposing or overcoming nature. This opposition to nature has become so much a part of man that he now sometimes chooses the more difficult way simply because it is in greater opposition to nature. Thus, he builds houses in hot climates without the large roof overhang that would decrease the air-conditioning load necessary to make the house habitable. He builds houses with enormous windows in cold areas, and the amount of fuel burned is thus increased.

Political, Economic Factors

Society generally solves its problems, if it does solve them, by first going through a period of trial and error, then settling down to a rational study, which leads to the formulation of workable policies. One obvious role of the scientist is to assist in disseminating information through which the trial-and-error stage in his community can be avoided or minimized, thus shortening the time between the initial recognition of an air pollution problem and the formulation of policies, programs, and (usually) laws to meet it. Law is public policy particularized and systematized. In general, demand for a statute on the part of a majority of the public is not necessary for its enactment, though it is useless to enact a statute that is opposed by the majority.

In different geographical areas people will attach different degrees of importance to the various values affected by air pollution. An approach through esthetics is seldom fruitful, unless esthetics is coupled with other values.

It is extremely tempting to try to motivate people to act in support of air conservation by appealing to them on grounds of health. This is an area in which the public is sensitive. There also generally exists a department of public health covering a given geographical area, a department that has most of the machinery for carrying out a program of air conservation. But caution must be used. First, scare tactics are unwarranted, and they seldom produce the desired result. Second, it is extremely difficult to demonstrate a clear health effect of air pollution. In the most acute cases such an effect is obvious. However, unequivocal proof of chronic effects is still wanting and may not become available for many years. While it is true that recourse to the police power may be had even in the absence of unequivocal proof, action based entirely upon the contention that pollution is a health hazard is extremely vulnerable if a legal protest is made.

Particularly with cost-conscious individuals, the economic approach is most likely to carry weight. While a great deal of study remains to be made before we can precisely evaluate the cost of dirty air, that there is a cost is now clearly proved. The best available estimate is of the order of $65 per capita per year for the entire United States. It can also be demonstrated that an industry establishing itself in a particular area saves money if there is a well-designed air pollution statute already in effect. Controls can always be built in more cheaply than they can be added—if pollution-control measures are available for the industry at all. This is a strong argument for taking action before a serious pollution situation exists.

An economic approach also suggests some interesting alternatives to a flat prohibition of emission of pollutants—ways to recover the cost of pollution to the community from individual industries in which the cost of control may exceed either the margin of profit on the product or the damage caused. Such an economic approach has not yet been tried, possibly because legislatures have shied away from a law that explicitly permits air pollution.

State or federal statutes are less likely to control pollution directly and are most likely simply to facilitate such control. Examples are statutes declaring that cities, counties, or larger geographical areas may organize to control pollution, and others establishing offices for research, development, training, and consultation, and for aid to local areas in defining their problems and in drafting their own legislation. Since statutes are confined to the jurisdiction of the legislative bodies enacting them, while air pollution knows no such boundaries, there is increasing need for legislation covering entire "airsheds" with uniform control ordinances.

Legislation to accomplish pollution control directly often specifies legal limits to the emission of pollutants. In this connection, at least two cautionary notes are in order. First, legislative inertia can make it extremely difficult to change these limits in either direction at a later date in the light of later findings. Second, results of air pollution analyses are seldom absolute. For example, the measurement for quantity of settled dust per unit area is highly dependent upon the shape of the container used for collection, and on its location.

From the scientific standpoint, it seems most desirable to set standards of cleanliness of the community air, to compare the present degree of cleanliness with these standards, and to infer from these data the reduction of pollution necessary to bring the ambient air within safe limits. This approach has been taken in Russia and Czechoslovakia, is being adopted in West Germany, and is used in California, Colorado, and some other states. These standards must be based on demonstrable ill effects on persons, property, plants, or animals, or on demonstrable disregard of esthetic values.

Public Policy Considerations

After reviewing the facts, the Air Conservation Commission identified a number of basic assumptions that it deemed central to a rational consideration of the problem: Air is in the public domain; although pollution is an inevitable concomitant of modern life, a conflict does exist between man's economic and his biologic concerns; this conflict can be resolved or mitigated by the application of scientific knowledge during the formulation of public policy; methods proposed for reducing air pollution levels must not result in increased pollution of other important sectors of man's environment.

Employing these assumptions, and taking into account the factual information at its disposal about the nature of air pollution and the problems of its control, the commission developed several basic recommendations: that scientists in all disciplines become familiar with the available information about air pollution, and that they play active roles in informing both the public and public policy bodies of the facts and their significance; that the decisions as to what to do about the facts—the weighing of risks versus benefits—be considered a responsibility of the entire community, including scientists; that air pollution be viewed as a problem that transcends political and national boundaries; and that communities, metropolitan areas, states, and appropriate federal agencies give special consideration not only to the elimination or reduction of air pollution but to air conservation planning.

Because the number of alternative policies available to public bodies is enormous, the commission attempted to define them only in the broadest of terms.

Some communities have no obvious air pollution problem other than the problem they share with the entire world. Such communities are usually small, are not near a large metropolitan center, and have few or no industries producing toxic airborne wastes in large quantities. But the proportion of our population living in such communities is dwindling rapidly as the population grows and more and more Americans move into burgeoning metropolitan areas. Furthermore, even if a community has no problem today, it may be able to avoid future problems by the early adoption of a sound air conservation program.

The local-government agencies in the areas where most Americans live face a fundamental policy alternative: to recognize air conservation as an important need, or to ignore it. To ignore it is to invite a host of consequences, suggested earlier in this article. If a community chooses not to ignore the question—if it chooses action as its alternative—it faces consequences of a different kind, for then it must formulate an effective and equitable program that will accurately reflect the community's standards of air purity. The point should be made at the outset that a partial solution of an air pollution problem is very much better than no solution at all.

Air pollution in metropolitan areas may be ascribed to four major sources: (i) motor vehicles, (ii) thermoelectric power stations, (iii) assorted industries, and (iv) householders, through household heating and through burning of rubbish. Individual citizens, by their use of cars, their demands for electric power, and their household-heating and trash-disposal measures, are the principal contributors to community-wide air pollution in most modern cities. The detailed policies needed for an air conservation program depend substantially on the situation in the community in question.

Air-pollution-control programs, and air conservation efforts, should take into account the volume and mobility of the air mass overlying the area where emissions occur; the interaction of pollutants and the self-cleansing attributes of the atmosphere; the topography of the region and any effects it may have on dispersion of pollutants; variables of meteorology; the existing pattern of industrial practices, of transportation, of land use, of energy production, and all matters that pertain to the further development of these; and the range of sensitivity of the humans, plants, and animals in the region.

Underlying the complex variety of technical procedures suitable for control and prevention of air pollution are a smaller number of social and administrative principles. These include, first, voluntary restraints, based on views of acceptability, of good neighborliness, and of what might be called "common decency." Such voluntary restraints are often reinforced by the courts in applying and interpreting the legal doctrine of nuisance.

A second basic principle is the development and application of regulations based upon the police powers of government. These may be used to prohibit certain types of activity; to prohibit specified types of emission at certain times; to require the use of certain control devices; and, finally, to permit certain types of pollutant-emission under specified conditions in certain areas, as in the case of zoning regulations.

A third general type of restraint, one so far not much used in air pollution control and air conservation, is what might be called flexible social controls. The major example is the use of market economics. Air zoning—that is, allowing, under specified conditions, the emission of specified types and amounts of pollution into a given body of air—as opposed to land zoning, might also be considered one of the more flexible, social restraints.

Many communities may wish to use multiple methods. However, those with acute air pollution problems probably will need to make more extensive use of police powers, while those only threatened with problems may want to rely on flexible social restraints.

To the extent that radioactive materials are involved in the production of public power and in other nonmilitary applications, the policy issues involved in their control closely resemble those encountered in the control of other highly toxic industrial effluents. However, fallout from testing of nuclear weapons involves issues that arise in connection with only the most persistent of the chemical- and biological-warfare agents.

Certain radioactive pollutants are highly persistent and, when forced into the stratosphere during a nuclear weapons test, may fall out slowly. They cannot be made harmless by any means now known to man. Some of the pollutants can cause damage to various parts of the body, and can produce changes in genetic material, changes that are irreversible.

To assess the possible effects of radioactive pollution on man is extremely difficult. The effects may be masked. Under such circumstances, any assessment of effects must depend heavily on statistical data. It may be several generations before the scientist will have the evidence necessary to say that pollution probably does or does not produce certain effects. If the evidence should show that there has indeed been an effect, and that the effect is undesirable, the knowledge would by that time be of limited use. The damage would be done, it would be irreversible, and the persistent, steady fallout of radioactive contaminants might continue to inflict damage.

At the same time, nuclear devices are the major weapons in the arsenals of the major world powers. Any nation with pretensions to such status feels compelled to develop its own arsenal and to test nuclear weapons. Furthermore, not only does the existing limited-test-ban agreement not cover new members of the "nuclear club" but its effectiveness among the signatory nations depends upon the willingness of those nations to honor it. Resumption of testing by one nation would tempt others to resume testing, because additional tests presumably advance the sophistication of a nation's weaponry.

Even if, by some flash of wisdom beyond any that has yet illuminated man's political horizons, the threat of war and the desire for testing should vanish, the problem of radiactive pollution would not. For nuclear energy offers too many possible peacetime applications to be ignored.

The Tasks Ahead

The quality of the air succeeding generations will breathe will depend to a large extent on what we do or fail to do during the next several years. The tasks ahead are numerous and complex. If they seem too imposing, we may derive some small comfort from the knowledge that the sooner we start the more easily we may accomplish them.

The commission report urges the scientific community to undertake three broad tasks: (i) to do more extensive research on the nature of air pollutants, how they interact, what their effects are, how they may be controlled more effectively and economically, how they are carried from one place to another, and how such transmission can be predicted; (ii) to become familiar, or more familiar, with the facts about air conservation and air pollution, even if these matters are outside the area of the individual's immediate professional concern; (iii) to participate in the process of informing public officials and the general public about the nature of air pollution and the possibilities for air conservation.

The commission is, in effect, calling upon the scientist to recognize that the products of the scientific community's efforts have imposed upon him new obligations and offered him new opportunities. The citizen-scientist must appraise realistically the geographical extent of the pollution problem he is considering, then work for air conservation measures covering that area. And, having made up his own mind, having persuaded others to be of like mind, he should also cast his vote.

The commission report urges agencies of government at the appropriate level (federal, state, or local) to undertake five tasks: (i) to recognize and state the need for air conservation efforts, and to gather information necessary for developing needed programs; (ii) to support appropriate research; (iii) to establish monitoring systems; (iv) to develop programs of air conservation and air pollution control, using whatever enforcement procedures are necessary; and (v) to support, and participate in, educational programs that are aimed at giving the public the broadest possible understanding of air pollution problems and air conservation needs.

Some of these functions can be performed most effectively at the local level, others at the state or federal level. Thus, gathering of basic data and sponsoring of basic research can be done best by the federal government, but some states and several metropolitan areas may be able to make significant contributions. Federal and state governments and international agencies probably could handle monitoring most effectively. Development of programs of air conservation and pollution control have, until now, been viewed as tasks of local governments, and this is proper. But federal and state governments may properly have an interest in cooperating with the local authorities.

The best program in the world can fail in the face of opposition or apathy on the part of the public. The commission report calls upon the public to undertake three tasks: (i) to become familiar with information about air conservation and air pollution, calling upon the scientific community and the government for assistance; (ii) to consider the problems of all segments of the community: industries, utilities, and private citizens; (iii) to urge, permit, and require the appropriate governments (federal, state, and local) to take actions necessary to ensure that the air of the areas within their respective jurisdictions is of the quality desired by the people of those areas, and that the quality is maintained.

A Challenge and an Opportunity

Man has been wasteful of the resources of the world in which he lives. He has ravaged its forests and soils and has plundered its mineral wealth; he has squandered and soiled its waters; he has contaminated its air. No reasonable person would suggest that man not use his environment, or that he revert to his primitive past. But no reasonable person can condone his wasteful excesses.

The problem of air pollution very probably will never be "solved." But if man is willing to recognize it as a problem, if he is prepared to bring to the problem his political wisdom, his scientific knowledge, and his technological skills, if he is willing to work with nature instead of against it, then he can leave to his children and his children's children something more valuable and more necessary to human life than any of the manufactured products of his civilization. He can bequeath to them the blessing of clean air.

Learning to Read

Experimental psychologists examine the process by which a fundamental intellectual skill is acquired.

Eleanor J. Gibson

Educators and the public have exhibited a keen interest in the teaching of reading ever since free public education became a fact (*1*). Either because of or despite their interest, this most important subject has been remarkably susceptible to the influence of fads and fashions and curiously unaffected by disciplined experimental and theoretical psychology. The psychologists have traditionally pursued the study of verbal learning by means of experiments with nonsense syllables and the like—that is, materials carefully divested of useful information. And the educators, who found little in this work that seemed relevant to the classroom, have stayed with the classroom; when they performed experiments, the method was apt to be a gross comparison of classes privileged and unprivileged with respect to the latest fad. The result has been two cultures: the pure scientists in the laboratory, and the practical teachers ignorant of the progress that has been made in the theory of human learning and in methods of studying it.

That this split was unfortunate is clear enough. True, most children do learn to read. But some learn to read badly, so that school systems must provide remedial clinics; and a small proportion (but still a large number of future citizens) remain functional illiterates. The fashions which have led to classroom experiments, such as the "whole word" method, emphasis on context and pictures for "meaning," the "flash" method, "speed reading," revised alphabets, the "return" to "phonics," and so on, have done little to change the situation.

Yet a systematic approach to the understanding of reading skill is possible. The psychologist has only to treat reading as a learning problem, to apply ingenuity in theory construction and experimental design to this fundamental activity on which the rest of man's education depends. A beginning has recently been made in this direction, and it can be expected that a number of theoretical and experimental studies of reading will be forthcoming (*2*).

Analysis of the Reading Process

A prerequisite to good research on reading is a psychological analysis of the reading process. What is it that a skilled reader has learned? Knowing this (or having a pretty good idea of it), one may consider how the skill is learned, and next how it could best be taught. Hypotheses designed to answer all three of these questions can then be tested by experiment.

There are several ways of characterizing the behavior we call reading. It is receiving communication; it is making discriminative responses to graphic symbols; it is decoding graphic symbols to speech; and it is getting meaning from the printed page. A child in the early stages of acquiring reading skill may not be doing all these things, however. Some aspects of reading must be mastered before others and have an essential function in a sequence of development of the final skill. The average child, when he begins learning to read, has already mastered to a marvelous extent the art of communication. He can speak and understand his own language in a fairly complex way, employing units of language organized in a hierarchy and with a grammatical structure. Since a writing system must correspond to the spoken one, and since speech is prior to writing, the frame-

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