Conservation of the Water Resource: The Responsibility of the Scientist
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Source: *Journal (Water Pollution Control Federation)*, Vol. 37, No. 1 (Jan., 1965), pp. 60-70
Published by: Wiley
Stable URL: https://www.jstor.org/stable/25035213
Accessed: 12-02-2022 02:40 UTC

CONSERVATION OF THE WATER RESOURCE: THE RESPONSIBILITY OF THE SCIENTIST

Barry Commoner

Nuclear Fallout

The greatest single cause of environmental contamination of this planet is radioactivity from test explosions of nuclear weapons in the atmosphere. The international treaty that banned such explosions, which recently celebrated its first anniversary (it was signed by President Kennedy on October 7, 1963), is the most important social action ever taken to conserve the quality of water, air, and the soil.

The massive effect of nuclear testing on the environment is evident from a single datum: Carbon 14 produced by nuclear explosions between 1952 and 1962 will approximately double the natural concentration of this radioisotope in the earth's atmosphere. In contrast, between 1900 and 1935 carbon dioxide, which is the major product of the most intensive non-radioactive man-made process—combustion—increased in concentration less than 10 percent.

Radioactivity from nuclear tests completed through 1962 contaminates every part of the earth's surface and all of its inhabitants. Strontium 90, previously absent from the earth, is being built into the bones of every living person and will be carried in the bodies of several future generations. During active testing radioactive iodine concentrates in the thyroids of animals and man. In certain regions of the U. S. the resultant exposure of children suggests the possibility of detectable medical harm which is now being sought for by a public health survey. Cesium 137 has become concentrated in the bodies of Arctic peoples, such as Eskimos, who live on the food chain peculiar to these regions. It has reached levels which according to present standards require corrective action. The increase in Carbon 14 will be reflected in an elevated incidence of hereditary defects in hundreds of generations to come. If nuclear testing had not been halted by the treaty matters would now be significantly worse.

If we are to survive the coming years of this new age of science, scientists and citizens alike need to learn why this massive contamination has come about. More important, they need to learn how the objectivity of scientific investigation and the judgments of public opinion, properly interrelated, have now brought this contamination to a halt at its source.

It is appropriate to consider what these lessons are and how they can be applied to the control of other contaminants which, like the radioactive debris of nuclear tests, are also the unwanted result of the union between modern scientific knowledge and intense social demand for its use.

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The paper was presented at the 37th Annual Conference of the Water Pollution Control Federation in Bal Harbour, Fla., Sept. 27–Oct. 1, 1964.

Fallout History

Contamination of the earth's surface with fallout originates in the scientific revolution set off 50 years ago by far-reaching discoveries in atomic physics. By 1940 it was apparent that the new knowledge of atomic structure could lead to technological processes of enormous power and scope. That these potentialities were realized so rapidly reflects the force of social demands. Faced with the grim dangers of war with Nazi Germany the U. S. and British governments undertook the monumental task of translating what was until then an esoteric laboratory experiment—nuclear fission—into the awesome reality of the nuclear bomb. The bomb was created by the magnificent new insights of nuclear physics, driven to success by the nation's determination to apply the full force of modern science to victory in the war.

With later scientific successes, weapons of increasing explosive power became possible in the decade following World War II. Given the existing political rivalries, these possibilities were fully exploited by those nations capable of making the necessary economic and technological effort. As a result, in 1948 there began a constantly accelerating series of nuclear explosions designed to develop weapons of increasing destructiveness and versatility. The total explosive power released by nuclear explosions between 1948 and 1962, which is equivalent to about 500 mil tons of TNT, is 170 times the total power of all the bombs dropped on Germany in World War II. The amount of only one constituent of fallout—Strontium 90—released by nuclear tests has introduced into the environment radioactivity equivalent to about one billion grams of Radium. The significance of this sudden intrusion of radioactivity can be visualized by comparing it with the world supply of Radium before World War II—a few grams. Our lack of preparedness to cope with nuclear debris is apparent from the fact that until the advent of nuclear fission these few grams of Radium represented the total human experience with radioactive substances.

Of course the nuclear test program must be regarded as an enormous success in the solution of exceedingly difficult problems in physics and engineering. However, it is equally evident that this claim does not apply to mastery of the resultant world-wide contamination from fallout. Massive nuclear testing which began with the development of the hydrogen bomb in 1953 was well underway before most of its biological consequences were appreciated. The unanticipated tendency of world-wide fallout to deposit preferentially in the north temperate zone was unknown until 1956; the hazard from radioactive iodine and from Carbon 14 was not brought to light until 1957; the special ecological factors which amplify the fallout hazard in the Arctic were elucidated for the first time in 1960; experiments which suggest that Strontium 90 may cause hereditary damage by becoming concentrated in the chromosomes were first reported in 1963.

Scientists Seek Data

Thus, the first lesson to be learned from experience with fallout is that, given the enormous power and scope of modern physical science and intense social pressure for its application, massive technological processes are likely to be put into operation before the eventual biological consequences are understood.

One reason for this difficulty is the disparity between the present state of the physical and biological sciences. Physical theory and practice is quite capable of producing intensive sources of radioactivity but neither the theory nor practice of biology has yet mastered the chief hazard of such radioactivity—cancer.

Another reason for the early gap between nuclear capability and understanding of its biological consequences is that the full strength of the scientific community was not, at first, mobilized to deal with the problem. Until 1954 basic data regarding the results of nuclear testing were under complete secrecy restrictions which, even then, were only partially lifted. Before 1954 all evaluations of the fallout contamination problem were made by small groups of scientific advisors to the responsible government agencies. It was inevitable that such considerations, while valuable approaches to the problem, should be inadequate to elucidate it fully. Science gets at the truth by a continuous process of self-correction which remedies the errors and corrects the omissions that are always present to some degree in any single analysis. Nuclear contamination involves a wide range of complex areas of science, not only the physics of nuclear reactions, but also the physics of the stratosphere, meteorology of world air masses, ecology, nutrition, radiation biology, genetics, and pathology. It is impossible for any small group of scientists, however carefully selected, to reflect the full knowledge of the total community of scientists on such a range of subjects.

Thus, the government's scientific advisors who met, under secrecy restrictions, in 1953 to evaluate the potential biological hazard from Strontium 90, apparently were not aware of an unusual property of the grass plant—its capability of absorbing fallout from rainwater held in a special part of the leaf—that seriously affected their calculations (1). Nor were they aware of the peculiar habit of lichens to absorb their mineral nutrition and fallout directly from the air. This was later to be revealed as the source of the intense fallout problem in the Arctic.

Once the curtain of secrecy was lifted, it was possible to expose the fallout problem to the full attention of the entire scientific community. As an immediate result a number of scientists outside the circle of those professionally concerned with fallout made important contributions to the problem.

A partial list of such contributions is impressive. The importance of Iodine 131 as a biological hazard was first put forward by a geneticist, E. B. Lewis, of the California Institute of Technology. Evidence of high local concentrations of fallout in regions near the Nevada test site was first developed by a zoologist, E. W. Pfeiffer, of the University of Montana. The enormous value of large-scale analyses of deciduous teeth as an index of Strontium 90 absorption by children was first suggested by a biochemist, Herman Kalckar of Harvard, and the first actual project to collect such teeth, The Baby Tooth Survey, was initiated by the St. Louis Committee for Nuclear Information. The Canadian botanist, Gorham, first reported the extraordinary capacity of lichens to absorb fallout and indicated the importance of this effect in amplifying the fallout hazard in the Arctic. It is this scientific observation which explains the fact, first made evident by direct measurements reported recently, that Eskimos in Alaska (who eat the meat of caribou that feed on lichens) have exceeded the allowable limits of Cesium 137 radioactivity.

Here then is another lesson to be learned: A problem as intricate, subtle, and pervasive as world-wide contamination from fallout cannot be solved by committees nor can it be fully elucidated by an entire corps of specialized experts. Such a problem touches on so vast a range of basic scientific questions as to require the full knowledge of the total community of scientists. Many scientists whose direct professional interests are only remotely connected with the problem of environmental contamination are ready to devote themselves to it once the need becomes known.

Controversy Existed

During the first few years that followed the lifting of secrecy restrictions scientific discussion of fallout was marked by considerable controversy. When the importance of Iodine 131 and of Carbon 14 in the fallout hazard was first put forward the matter was disputed intensively. However, controversy is nothing new to science; it is common when the available data are insufficient to decide between conflicting points of view. The remedy is more data and the controversies were useful because they revealed the need for more information about the distribution and effects of fallout radioactivity.

It is to the credit of the U. S. Public Health Service that it responded magnificently to this situation. Until 1957 monitoring of the environment for radioisotopes from fallout was largely in the hands of the agency engaged in nuclear operations, the Atomic Energy Commission. The AEC gathered much useful data, but these were necessarily closely connected with the test program itself. Sampling was intense in the test regions but rather spotty elsewhere in the U. S. and in the world. Beginning in 1957 the USPHS established a growing system of monitoring and now produces a detailed and widespread series of measurements of radioactivity in the atmosphere, in surface waters, in the soil, and in foods. The monthly bulletin which the USPHS now issues on these measurements and those provided by other U. S. and international agencies is the most detailed information now available about any aspect of environmental contamination.

These new data-gathering systems have already led to a striking improvement in understanding the fallout problem, and previous controversies have begun to give way to fact. Thus, the initial controversy over the possible hazard from Iodine 131 was due largely to the infrequency of the necessary measurements. Because of its short half-life (only 8 days) Iodine 131 can be detected only if measurements are frequent and detailed. When the USPHS monitoring system went into operation it became apparent at once that each nuclear test in the atmosphere was accompanied by a brief but intense introduction of Iodine 131 radioactivity into the food chain. Direct measurements of radioiodine in milk enabled fairly precise calculations of the resultant exposure, especially to children. It then became evident for the first time that in continental U. S. Iodine 131 is responsible for the most intense tissue exposure to radioactivity from fallout. More important, it became possible to warn milk producers of the hazard and to devise relatively simple countermeasures, such as temporary diversion of milk supplies from the market, to bring this hazard under control.

The successful interpretation of such monitoring data was possible only because the source of the contamination was established clearly. Every nuclear test in the atmosphere, by the U. S. and other nations, is recorded as to size, time, and place. The same is true of other possible sources of radioactive contamination, such as nuclear reactors, for the atomic energy law requires close reporting of such activities. The scientist is, therefore, thoroughly informed as to where any significant amount of radioactive isotope is produced and where and when it is disseminated. This detailed registry of sources combined with intensive and widespread monitoring gives an admirable insight into the mechanisms which spread radioactivity into the biosphere and information of great practical importance in the development of control procedures.

The lessons of this experience are self-evident. Massive and pervasive contamination such as that due to fallout can indeed be understood and controversies as to its effects resolved, if its sources are known and reports of the dissemination of the contaminants are made by a system of detailed monitoring.

Nevertheless, even with these improvements, certain important controversies about fallout persisted. These were centered about the establishment of standards of acceptable exposure which are necessary guides to any system of control. When the fallout issue first arose the only existing radiation standards were designed for industrial protection and were not immediately applicable to situations in which whole continents and entire populations were exposed. For this reason, and because the levels of radioactivity due to fallout were very much lower than those of concern in industrial practice, standards became a matter of controversy.

A particularly important lack was the absence of a clear-cut evaluation of the mechanisms of radiation damage. One theory of radiation damage suggested that biological repair processes might occur so that very low levels of radiation might have no effect at all on tissue damage. This approach leads to the concept of a threshold dose which must be exceeded if any biological damage is to ensue. In this case a standard of exposure is easily devised simply by setting it below the threshold dose. In contrast, another theory of radiation damage held that there was no threshold and that any increment in radiation exposure would increase proportionally the risk of biological damage. In this case, there is no absolute way to establish a standard of tolerable exposure. Since any exposure must then be regarded as harmful to some degree, the level to be tolerated can be established only by balancing the medical risks against the benefits expected from the related use of radiation.

Here again, the scientific community has played a decisive role in resolving the conflict. Largely in response to the fallout problem geneticists carried out elaborate experiments to study the mutation rate at the low-radiation levels which approximate those encountered in fallout. Radiation pathologists also pressed their experiments to lower radiation limits and studied the effect of dose-rate on exposure. A number of scientists devoted considerable effort to painstaking analysis of the theory of radiation damage and produced valuable background reports such as those of the National Academy of Sciences' radiation committees and of the U.N. Scientific Committee on the Effects of Atomic Energy.

As a result there is now a rather common agreement among scientists that the linear theory of radiation damage is the most reasonable guide to radiation standards. The standards adopted by the responsible U. S. agency, the Federal Radiation Council, reflect this conclusion.

The Scientist and Public Affairs

With the adoption of this approach a vital link was established between the scientific data on radiation damage, and the public interest. According to the linear theory of radiation effects, a standard of acceptability is to be established by a balance between medical risks and social benefit. In this case the standard necessarily reflects both objective scientific fact, and the value judgments of public opinion. The risk of radiation exposure can be estimated by scientific means. However, many of the benefits, for example the value of nuclear testing to the nation, are not subject to scientific evaluation and are, instead, matters of moral and political judgment; nor can any scientific rule determine the proper balance between risk and benefit. There is no conceivable principle of science which can tell how many cases of leukemia or of congenital defects are to be tolerated in order to develop a new nuclear weapon. This is a matter of public morality and is the proper province of religion and politics rather than of science. Thus, the establishment of a radiation standard inevitably introduces public opinion into the entire matter of control. Here a new problem arose. If radiation standards require a public judgment then the public must know the risks and evaluate them against the benefits. The citizen ordinarily is not equipped to understand the complex scientific aspects of a problem such as fallout. He is prepared poorly to understand nuclear physics, the relation between calcium and strontium chemistry, the laws of genetics, or the crucial difference between a food chain based on grass, and one based on lichens. Yet such knowledge is essential if the citizen is to make an informed and intelligent judgment of the risks and the benefits of nuclear testing.

Once again, the scientific community has tried to meet the challenge. For the last six years a growing number of scientists have devoted themselves to the enormous task of informing their fellow citizens about the basic facts of nuclear war, fallout, and the radiation hazard.

The connection between science and public affairs is not new, but now science has created problems of an intensity and a scale that were once confined to the imagination. Today's scientists have the distinction of being the first generation of scientists to live with the knowledge that their work, ideas, and daily activities impinge with a frightening immediacy on national politics, on international conflicts, and on the planet's fate as a human habitation.

Scientists have tried to live with these responsibilities in a number of ways. Sometimes, in moments of impending crisis, we are aware only that the main outcome of science is that the planet has become a kind of colossal, lightly-triggered time bomb. Then all we can think of doing is to issue an anguished cry of warning. In calmer times we try to grapple with the seemingly endless problem of unraveling the medley of nuclear physics, seismology, electronics, radiation biology, ecology, sociology, normal and pathological psychology, which, added to the cross-currents of local, national, and international politics, has become the frightful chaos that goes under the disarming euphemism ''public affairs.''

Many scientists have studied the technology of public affairs and have mastered the new vocabulary: megatonnage, micromicrocuries, MPC, RPG, and all the rest. Nuclear physicists have struggled to learn the structure of the chromosome and how cows give milk. Biologists have returned to long-discarded textbooks of freshman physics.

Many have become aware that the public is having even greater difficulty in understanding the new problems. We have had to assure neighbors that the white spots on their lawn grass were mold, not fallout; that there was no conceivable way to save the world by extending the half-life of radioactive atoms. Sometimes we have had to tell them that despite authoritative statements announcing that fallout levels were below the danger point, it was, nevertheless, true that any increase in radioactivity intensifies the risk of medical harm.

Scientists have found, too, that every attempt to share knowledge with fellow citizens leads to demands for more. Many have become heavily engaged in the community's lecture circuit: P.T.A.'s, Lions, Rotarians, forums, and television interviews. Religious denominations and parts of our city that we never before knew existed have been discovered. We have learned that, like ourselves, many other citizens, less favored by their educational background, are grappling with the new names, the new ideas, and the large but distant hazards.

The scientific community has begun to develop new means for accomplishing this educational task. In St. Louis there is the increasingly effective Committee for Nuclear Information which, since 1958, has worked hard to provide citizens in the community and throughout the nation with the best available scientific facts about nuclear and other forms of environmental contamination. There are now more than 20 such groups throughout the U. S., and a year ago the Scientists' Institute for Public Information was organized to facilitate and intensify this growing educational movement.

The collaboration between scientist and citizen is not a one-way street. Citizens have contributed significantly to what scientists now know about fallout. When Herman Kalckar showed that the collection of deciduous teeth and their analysis for Strontium 90 would provide an irreplaceable source of data on absorption of radioactive elements from fallout by children, it was the children of St. Louis and their parents who made this remarkable scientific project possible. Through the St. Louis Baby Tooth Survey, the children of that city have contributed, as of now, some 150,000 teeth to the cause of scientific knowledge about fallout. The children have themselves created the scientific basis for establishing in St. Louis the most detailed evidence available anywhere regarding the Strontium 90 content of their own bodies. By such means and through hard work and financial support many citizens have become partners in the scientific effort to elucidate the fallout problem and to provide the people of this country, and of the world, with the sober facts which they must know if they are to make the judgments which alone can determine how the hazard is controlled.

Such public knowledge of the scientific facts about fallout has played an important role in achieving the great national decision to end the hazard by approving the test ban treaty. The statesmen here and throughout the world who patiently negotiated the treaty and the senators whose votes brought it into reality were moved by an appreciation that people everywhere had begun to understand the biological cost of the nuclear arms race. Statesmen, legislators, and citizens were determined that this cost should not increase beyond the price that we were already destined to pay.

Conclusion

This then is the nuclear test story. A number of new responsibilities have been thrust upon both science and society. Many agencies and numerous individuals have played decisive roles. While the problem remained in the realm of purely military activity devoted specialists attached to government agencies grappled with the enormous and growing complexities of worldwide radioactive contamination. Later the USPHS, the FDA, and other government agencies played increasingly important roles. Once acquainted with the issue the general community of scientists, without regard to their own professional specialization, turned their collective skills to the difficult and broad-ranging scientific problems and learned how to meet a new responsibility toward the education of their fellow citizens. For their part statesmen have had to study the intricate details of nuclear contamination and evaluate its cost against the benefits which they believed to come from nuclear testing.

The children who have foregone the traditional visit of the "tooth fairy" to contribute their baby teeth to science and the parents who have had to live with the gnawing uncertainties about the ultimate harm of fallout to their children are the final source of the great social decision to stop fallout contamination by establishing the test ban treaty.

Organic Pollutants

It is hardly necessary to prove the close parallel between the fallout problem and the still unsolved problems of water pollution in general. Those who face the direct responsibility for maintaining the purity of our water resource know that the issues which are revealed so clearly in the fallout problem also encumber the growing problem of water contamination from new synthetic organic pollutants.

What does the experience with fallout tell us about the most troublesome of recent cases of possible contamination from synthetic organic pollutants—the controversy over the cause of massive fish kills in the Mississippi River? Despite deep-seated disagreement between the disputing parties, two facts are clear and acknowledged: many fish have died and the Mississippi River contains detectable quantities of several chlorinated hydrocarbon insecticides and related organic compounds. The issue is whether the insecticides are the cause of the fish kills and are a hazard to human health, and if so, what should be done about it.

Several general facts about the insecticide controversy become evident, if we use the insight gained from the review of the fallout problem. First, it is clear that the synthetic organic contaminants are new products of recent scientific progress. Synthetic organic pollutants of water were unknown 25 years ago. Just as the revolution in physics has given the power to produce massive nuclear explosions, so a parallel revolution in chemistry has given the ability to synthesize an enormous number of valuable new organic compounds.

Social Demand for Organic Compounds

As in the case of nuclear power, there has been an intensive social demand for the exploitation of this new chemical capability. As a result many of these materials—pesticides, herbicides, detergents, and industrial byproducts—have been introduced into our economy and into the environment in massive amounts. Again, just as in the case of nuclear debris, the ability to manufacture and use the new materials has far outstripped understanding of the biological consequences. Most of the evidence that the new synthetic insecticides, for example, were a practical hazard to fish, birds, and wildlife was not discovered during the laboratory work that preceded their introduction into agriculture. Instead the public learned about these secondary effects much later because, as happened in the Orient for example, widespread agricultural use of insecticides caused massive fish kills in nearby hatcheries.

Knowledge of synthetic chemistry is much more advanced than present understanding of the ecological fate and biological hazards of the new materials now produced by chemical synthesis. Thus, the present insecticide controversy and the fallout problem have the same root source in the serious imbalance between the levels of advancement of the several relevant sciences—at a time when there is a powerful social demand for immediate application of what we do know.

Social Demands Answered

In the Mississippi River problem, an important argument centers around the possible harm to humans of the very small amounts of pesticide residues present in edible fish and in drinking water. One side points to the fact that laboratory animals exhibit no toxic effects unless exposed to pesticide concentrations many times greater than those due to river pollution. On the other side is the fact that we have no adequate data regarding the effects of small concentrations of pesticides on laboratory animals exposed for long periods of time, nor is there any information regarding the possible effects of chronic, long-time exposure of humans to low concentrations of pesticides because, in a sense, the necessary experiment has only just begun.

This is the same issue that troubled the fallout problem 10 years ago, and the same solution is indicated. Estimates of the hazard must be based on the assumption that any increase in exposure results in a proportional risk to the total living population of the biosphere. This approach is recommended by the following considerations. Like radiation, many of the new synthetic substances act on basic biochemical processes that occur in some form in all living things. Hence, some effect on all forms of life must be anticipated. Since some of these substances appear to increase the rate of mutation and of cancer incidence it is entirely possible that, like radiation, they may act on the genetic structure of the cell. Changes in the genetic complement of a cell often persist in its daughter cells and may similarly be perpetuated in a population. Hence, any increase in the probability of a chemical effect on the genetic structure of the cell results in an additive risk of eventual biological harm. Moreover, whenever the biological system exposed to a possibly toxic agent is very large and subject to complex interactions, the probability that any increment in contamination will lead to a new point of attack somewhere in this intricate system cannot be ignored. Finally, because the toxic effects of many organic pollutants, like those of radiation, may appear only after a delay of many years, extreme caution ought to be the rule in the early stages of use. For these reasons, it is prudent to regard any addition of a potentially toxic substance to the biosphere as capable of producing a total biological effect which is roughly proportional to its concentration in the biosphere.

In this view, the very presence in the Mississippi River of substances known to be toxic to fish at low concentrations and to mammals at higher concentrations must be regarded as a finite risk to any biological population exposed to it. Hence, the only feasible way to judge the significance of this type of contamination is to evaluate the risks, compare them with the benefits associated with the use of such substances, and strike a balance acceptable to the public between risk and benefit.

This requires, to begin with, a determination of whether the observed fish kills, which already appear to have impaired seriously certain economic operations, are in fact due to the insecticides present in the river. Furthermore, if the hazard must be evaluated by a balance between benefits and the risk to fish and possibly to man, these risks must be compared with whatever beneficial operations have resulted in the unquestioned presence of insecticides in the river water. This means that we must know the sources of the contaminants and determine, for example, whether the relevant beneficial operation is the spraying of corn and cotton crops in the river valley, or the activity of riverside plants which manufacture pesticides.

While these are, of course, difficult questions to answer, some useful approaches to them are suggested by experience with the fallout problem. For example, a survey of recent increases in the rate of congenital malformations in the province of Alberta (2) has suggested to the author of that report that such increases may be due to fallout from nuclear testing. To resolve this problem it will be necessary, at the least, to show by further analyses that subsequent changes in the incidence of these defects correlate quantitatively with changes in environmental radioactivity in the region, and that the latter are in turn correlated with the incidence of nuclear tests. These correlations will eventually be made, for the reason that the necessary records of nuclear testing and of fallout are available.

Thus, if the risks and benefits involved in the Mississippi River pollution problem are to be balanced, experience with fallout tells how this can be done: by frequent and detailed monitoring of the pollutant, and by registry of the events which disseminate the pollutant into the biosphere. Until adequate monitoring of insecticides in the river is achieved, it will not be possible to determine how these changes are correlated on the one hand with the fish kills, and on the other hand with the beneficial operations such as manufacture and agricultural spraying which are possible sources of the river pollution. Unless there is a registry of the amount of insecticides released into the river by agricultural and industrial operations, the benefits cannot be balanced against the risks. Until known risks can be balanced against specific benefits, no meaningful decision as to the action required by the pollutants is possible. Even in the absence of such a decision, the rule of prudence, which is demanded by the unknown long-term hazards, requires that extreme caution be exercised in continued use of these agents. Most important, we must understand that present difficulties are due to the large scale dissemination of substances that have not yet been subjected to adequate biological analyses on the scale in which they are used. Such an understanding ought to be reflected in a resolve to require that newly synthesized compounds be tested in the biosphere on a full-scale model before they are committed to large-scale economic investment and use.

Theoretical Considerations

Another important parallel between fallout and organic water pollution which is worth close attention is that in both cases the practical problem raises questions of profound theoretical importance. The eventual elucidation of the effects of low-level radiation will require a basic understanding of the mechanism of radiation damage in living things and of the mechanisms of mutation and chemical carcinogenesis. Because some organic water pollutants are closely related to known mutagens and carcinogens, the latter problem also is closely associated to water contamination. In the case of water pollution, the enormous importance of water in the basic chemistry of the cell must be remembered. Water is a substance which has an intricate intermolecular structure, and scientists are just beginning to appreciate how intimately this structure is associated with the chemical organization of the cell. Water structure is maintained by certain subtle intermolecular bonds, such as the hydrogen bond. These bonds and, therefore, the structure of water, may be profoundly affected by various types of organic compounds. A fundamental appreciation of the still poorly understood role of water structure in biology and of the influence of organic compounds on this structure will be essential to a proper understanding of the hazards of organic pollution. Knowledge of these basic problems is still so rudimentary that great prudence ought to be the guide in the introduction of any new organic substance into the water supply.

Conclusion

The problem of organic water pollution, like the fallout problem, will require the close attention and full participation of the entire community of scientists for its solution, if only to improve awareness of the serious theoretical questions which remain unsolved. It should be evident, too, that unless all scientists begin to educate the public about the risks and benefits involved in the growing dissemination of new organic compounds into water supplies, citizens and their legislators will be poorly prepared to undertake the necessary measures of control.

There are formidable difficulties that stand in the way of a proposal to establish a system of detailed monitoring of organic pollutants and a registry of their major sources of dissemination by industry and agriculture. Technical methods of analysis are still inadequate; many new laboratories will need to be built and their personnel recruited; large sums of money will be needed.

However, these difficulties are more than matched by the urgency. If measurement of levels of organic substances in surface waters are not started now, irreplaceable base-line data that will be essential to interpret later results will be lost. If these sources are not registered, controversies and uncertainty regarding the cause of the biological hazards will continue and grow worse. If we fail in these tasks we shall be unable to make full and beneficial use of the growing power of modern science.

There are those who will react with alarm to the proposal that surveillance of the manufacture and use of new synthetic organic compounds be increased strongly. Some will complain that this proposal reveals a lack of faith in scientific progress and a timidity which ill-befits this adventurous age of science. Critics will assert that increasing human exposure to new substances is an inevitable accompaniment of the heedless march of science and technology.

In reply, look again to the lesson of fallout. Only a few years ago nuclear contamination was regarded as the necessary price of scientific progress. Few could believe that the vast military and political commitment to nuclear testing could be turned aside.

In a few short years the people of this and many other nations have learned that the vast new powers of science carry with them equally vast and equally new responsibilities. With the knowledge gained through the devotion of the scientist and the wisdom of an informed people, the hazard of fallout was confronted and solved.

If scientists, citizens, and government administrators have together achieved this great accomplishment, they can surely find the means to preserve the water, the air, and the soil against any other threat, and to conserve the resources of this planet for their proper service to the welfare of man.

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