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The Fallout Problem

It is an example of the interaction between the advances of science and the conditions of society.

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Not so long ago the impact of science on society was a process to be demonstrated by scholarly research. In the last two decades, however, the effects of rapidly advancing scientific knowledge on public policies have had the lively attention of those responsible for the advances, and since last October 4, this subject has won many new enthusiasts. Ten minutes of research with the morning newspaper will now convince anyone that at least two scientific subjects—investigation of nearby space and nuclear physics—have become the source of major political developments.

Recent events not only demonstrate the intimate interaction between science and social problems; they also show that this relationship is far from harmonious. It is regrettable but true that the very areas of public affairs most closely linked to scientific matters have been marked by misunderstanding, disagreement, and controversy. What has happened in recent months authenticates the warning voiced just a year ago in the report of the AAAS Interim Committee on the Social Aspects of Science: "There is an impending crisis in the relationship between science and American Society. This crisis is being generated by a basic disparity. At a time when decisive economic, political and social processes have become profoundly dependent upon science, the discipline has failed to attain its proper place in the management of public affairs" (*1*).

My purpose here (*2*) is to examine this situation as it is illustrated by one of the more troublesome issues: the long-range effects of world-wide fallout from tests of nuclear weapons.

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Fallout

The fallout problem results from the decision on the part of three governments to carry out a particular type of military activity: test explosions of nuclear weapons. It is reasonable to expect these governments to determine that nuclear tests shall not cause inadmissible hazards to human life. This responsibility requires: (i) determination of the need for, and the advantages to be derived from, the nuclear operations; (ii) estimation of the extent and character of the hazards; and (iii) a judgment of the relative weights of the advantages and hazards.

In an orderly state of affairs we expect scientists to produce an evaluation of possible dangers sufficiently clear and sufficiently close to being unanimous to provide a workable basis for decision. We expect the makers of policy to reach a conclusion which represents a balanced evaluation of needs and hazards. We expect the public to be sufficiently informed about the needs and possibly harmful consequences to understand and support this judgment.

This is the ideal. What is the reality?

That governments find advantage in conducting test nuclear explosions may as well be taken here as a fact of political life. It is not our purpose at this time to debate the validity of this need.

As to the scientific aspects of the possible health hazards of fallout, we are fortunate in having the extensive report of the hearings that the Joint Congressional Committee on Atomic Energy held in June 1957, which is now available in two printed volumes of some 2000 pages each (*3*). This report contains the best available summary of the facts, estimates of the variability of the pertinent data, and discussions of the theoretical considerations which bear on the question. The chief facts may be summarized as follows:

Radioactive isotopes contained in the fallout produced by past nuclear tests are being spread throughout the world and increase the radioactivity received by every person on the earth. Since the isotope of chief concern, strontium-90, is relatively long-lived, fallout radioactivity will be perceptible for a few generations even if no further tests occur. Fallout adds to the burden of radioactivity from natural sources, and from medical treatment, to which persons are exposed. Where the relatively low levels of natural radioactivity appear to be agents of disease (as in the case of genetic defects and, probably, leukemia and bone tumors), we may expect the incidence of disease to increase as a result of fallout. The average increased incidence of disease due to fallout from tests conducted thus far will be small (of the order of 0.2 to 2.0 percent) compared with the natural incidence. However, since fallout affects the entire population of the world, the absolute numbers of persons who may become diseased because of its radioactivity are not small. Thus, estimates reported at the Congressional hearings indicate that fallout from past tests may account for the birth of from 2500 to 13,000 genetically defective children and for 25,000 to 100,000 cases of leukemia and bone tumor (considered together) during the next generation. The damage expected from fallout will in most cases not occur until a minimum of about 10 to 30 years has elapsed, and often it will be much later. When the damage does occur it will ordinarily be impossible to distinguish between an effect of fallout and effects of natural radiation or other factors. Moreover, any numerical estimate of the average increase in disease incidence expected from fallout must be accompanied by a very large probable error and is subject to considerable regional variation. Finally, the factual and theoretical basis for such prediction is sparse, contains important gaps, and is subject to divergent interpretations.

These are the facts relative to biological hazard that the policy-maker must use to determine whether the testing of nuclear weapons shall continue unabated, shall be diminished, or shall be stopped entirely. How useful to this purpose are these facts?

The recent hearings of the Joint Committee give us a means of testing this question. This committee heard evidence about fallout hazards from some fifty scientists who represented a broad cross-section of the scientific community, both within and outside of the Government. The committee is a group of legislators experienced in the matter of developing policy from facts provided to them by expert testimony. It appears that the evidence presented at the committee's hearing was not sufficient, in their eyes, to dictate policy. This uncertainty is summed up, in the analysis prepared by the Joint Committee after the hearings were concluded, as follows: "There were differences of opinion [i.e., among witnesses] on how to forecast the consequences of further testing" (*4*). The analysis also states: "It is apparent, however, that the people of the world and their governments lack information on the operational problems—meaning information that can be acted upon in a given situation—associated with fallout" (*4*).

Although the Congressional hearings did not consider how the advantages of nuclear testing might be weighed against the estimated hazards, the evidence heard gives us a picture of the size of the problem. Anyone who attempts to determine whether or not the biological hazards of world-wide fallout can be justified by necessity must somehow weigh a number of human lives against deliberate action to achieve a desired military or political advantage. Such decisions have been made before—for example, by military commanders—but never in the history of humanity has such a judgment involved literally every individual now living and expected for some generations to live on the earth.

It is not clear who is expected to make this decision and thereby assume, in an unprecedented degree, the grave moral burden carried by those who must judge the social worth of human life. Should this judgment be made by experts with special competence? If so, where should their expertness lie? In nuclear physics, radiochemistry, biology, medicine, sociology, military strategy? On the other hand, should a responsibility of this weight be reserved to elected officials, in order to ensure that the decisions will reflect the ethical views of our society? At the moment, we seem to have no stated policy in this matter.

Finally, the present situation is also unsatisfactory with regard to the state of public knowledge on the fallout problem. This conclusion could be documented in many ways, but perhaps the most objective and significant view is that contained in the Joint Committee's summary-analysis: "Information on fallout has evidently not reached the public in adequate or understandable ways" (*4*).

Besides being poorly informed, the public has been confused by disagreements among scientists regarding the biological danger of present and anticipated radiation levels from fallout. The public is accustomed to associating science with truth and is dismayed that scientists appear to find the truth about fallout so elusive.

There is, it would appear, some need for improvement in the management of public affairs relative to the problem of fallout. In what follows, I shall discuss some of the reasons that may account for our present difficulties and suggest some possible remedies.

Why Do Scientists Disagree?

Why do scientists disagree in their estimates of the biological hazard of world-wide fallout?

The scientific problem is extraordinarily difficult and complex. Its solution requires an understanding of vast interactions among masses of air, water, and soil and innumerable varieties of plants, animals, and men. Compared with our knowledge of other agencies that affect life, such as light and heat, our knowledge of ionizing radiation is recent. In the scant 60 years since the discovery of radiation, there has not been time enough for biologists satisfactorily to explore its effect on life. Strontium-90, the chief source of fallout radiation, is an element only recently made by man; there has been little time to study it in the laboratory or to analyze the consequences of its intrusion into nature. Finally, the major hazards of radiation—cancer and genetic mutation—are perhaps the most difficult unsolved problems of modern biology. Until the basic causes of these processes become more clear, the effects of radiation will be but poorly understood.

In this situation the available facts are often not sufficient to support or contradict conclusively a given explanatory idea; therefore, opposing theories will for the time flourish together. This accounts for some of the disagreement among scientists' estimates of the probable biological hazard of fallout radiation.

In part, our present troubles derive from the unequal pace of the development of physics and biology. We understand nuclear energy well enough to explode great quantities of radioactive materials into the atmosphere. But our present knowledge of biology and its attendant sciences is not adequate for contending with the difficulties that follow when the radioactive dust settles back to earth.

The remedy is apparent if not easy: more research. Witnesses at the Congressional hearings as well as the earlier report of the National Academy of Sciences radiation committee have emphasized the urgent need for more information. The required research will be costly, and much of it needs to be started at once, before continuing fallout permanently obscures the needed data. Following the recent hearings, the Atomic Energy Commission decided to expand its studies of fallout. But our total effort does not yet either approach the scale demanded by the whole problem or reflect sufficient participation on the part of the university laboratories concerned with basic biological research.

Another source of difficulty is that what *is* known about fallout hazards has not been fully communicated to the scientific community. Originally this problem arose from the association of fallout data with military operations that were closely regulated by security measures. In recent years considerable data on world-wide fallout appear to have been declassified and are now open to free communication among scientists (*5*). Nevertheless, the scientific community has not fully appreciated this change and still takes a gingerly approach to these areas of fact.

All scientists are aware that the spread of man-made radioactive isotopes, especially from fallout, is causing progressive changes in the radioactivity levels of air, water, soil, milk, and plant and animal tissues. Apart from the matter of possible medical hazards, this process has significant effects on various scientific endeavors, such as dating methods and isotope geology and ecology, and creates many opportunities for new insight into a broad range of terrestrial events. For these reasons, one would think that the spread of radioactivity would be followed closely by the scientific community and that data would be collated systematically with respect to location, origin, and time and published in a form easily accessible to all scientists. This has not yet been done. Of course, the Atomic Energy Commission makes numerous measurements relative to its own activities and supports projects for studying world-wide radioactivity levels in various materials. Some of the results appear in separately published reports, and in occasional papers in scientific journals. But the available information is nowhere brought together in an integrated, graphic form that reaches scientists generally—and especially those with no immediate interest in the information. Without such unified publication, gaps in the present data-gathering activities may go unnoticed and fail to attract the attention of investigators who might otherwise enter into the work.

Such gaps appear to exist. The first intensive survey of the U.S. Public Health Service has been determining radioactive pollution of air at 40 stations throughout the United States for several years. However, the Public Health Service pilot program for a nation-wide survey of radioactivity in milk was begun only in April 1957. The data from this program's monthly analyses of milk from six locations in the United States have not yet been published. Comparably detailed studies of plant and animal tissues do not yet seem to be in the process of being made. Apart from intensive work by the Japanese, we seem to receive relatively little information about radioactivity levels elsewhere in the world. The Atomic Energy Commission reported receipt of the first fallout data from Soviet investigators in December 1957 (*6*).

The inadequacies which decision makers now find in basic and operational information about fallout hazards are, then, in part due to the lack of detailed, integrated, continuing data published in a form capable of enlisting the interest of the entire scientific community in this pervasive problem. We need to recall that the development of a scientific truth is a direct outcome of the degree of communication which normally exists in science. As individuals, scientists are no less fallible than any other reasonably cautious people. What we call a scientific truth emerges from investigators' insistence on free publication of their own observations. This permits the rest of the scientific community to check the data and evaluate the interpretations, so that eventually a commonly held body of facts and ideas comes into being. Any failure to communicate information to the entire scientific community hampers the attainment of a common understanding.

In sum, the fallout question has not yet become an integral part of the freely flowing stream of information which is the vehicle of scientific progress. The remedy is apparent and, for scientists, traditional: more and better publication in readily available journals. Can we not establish a systematic method of continuously reporting integrated information on world-wide levels of fallout radioactivity?

Source of Public Confusion

What is the source of public confusion on the fallout problem? In the past few years, and especially during the last presidential campaign, the public has become aware of a political cleavage on the wisdom of continued testing of nuclear weapons. Political controversy is a natural, expected, and welcome part of public affairs in this country. What appears to trouble the public is not that political opponents have disagreed on the nuclear test issue but that the opinions of scientists have been marshalled on *both* sides of the debate. This appears to violate science's traditional devotion to objectively ascertainable truth.

This division is in part due to the factual uncertainties that have already been discussed, and the public concern may reflect an unawareness of these uncertainties. However, this difficulty results as well from some confusion concerning the scientists' two roles in these matters. As a student and interpreter of nature, the scientist can explain to the public what consequences may result from a given policy that affects nature. As an informed citizen, the scientist has the right and the obligation shared by all citizens to form and express an ethical judgment on the wisdom of enduring that policy. Estimation of the probable damage to health that might result from the continuation of nuclear weapons tests is a scientific question. But there is, I believe, no scientific way to balance the possibility that a thousand people will die from leukemia against the political advantages of developing more efficient retaliatory weapons. This requires a moral judgment in which the scientist cannot claim a special competence which exceeds that of any other informed citizen.

The key word is "informed." Scientists as a group were the first citizens to express opinions on the wisdom of continued testing because they were naturally the first to acquire the facts about the possible hazards of fallout. It is only the lag in the spread of the necessary information to the rest of our citizens that has given the scientists their apparent monopoly on these opinions.

These observations lead to two conclusions. In the first place, scientists must take pains to disclaim any special moral wisdom on this matter. I do not mean to suggest that scientists stop expressing their opinions on this question. On the contrary, so long as the scientists remain the only group well informed about the hazards of fallout, it is essential that they form their judgments, express them, and keep the moral debate before the public. But we must not allow this issue, by default, to rest in the hands of the scientists alone. A question of this gravity cannot be handed over for decision to any group less inclusive than our entire citizenry.

The second conclusion is now self-evident: the public must be given enough information about the need for testing and the hazards of fallout to permit every citizen to decide for himself whether nuclear tests should go on or be stopped. It is the natural task of the scientists and their professional organizations to bring the necessary facts and the means for understanding them to the public. For some years the American Association for the Advancement of Science has recognized this kind of public responsibility, and scientists seem generally ready to assume it.

The National Academy of Sciences report is a good example of what can be done to inform the public about radiation generally. However, that report was only partly concerned with the fallout problem and in this respect is now outdated by the recent Congressional hearings.

What we need now is to marshall the full assemblage of facts about fallout, their meaning and uncertainties, and report them to the widest possible audience. This is not an easy task. It is much simpler to publicize conclusions alone, and have them accepted not because their factual origin is fully understood but because they carry the authority associated with science.

It seems to me that we dare not take this easy way out. Unless the public has sufficient information to provide a reasonable basis for independent judgment, the moral burden for the future effects of nuclear testing will rest on some smaller group. And no such group alone has the wisdom to make the correct choice or the strength to sustain it. Unless the public is made aware of the gaps and the uncertainties in our present knowledge about fallout, we cannot expect it to support the expensive research needed to minimize them. Without public understanding and support, no government policy can long endure.

Here then is our challenge. Can we, as scientists, with the help of our professional organizations, find a way to inform the public about these great issues? The raw material for such an educational campaign is available in the voluminous report of the Congressional hearings. We can distill from this material the essential facts and ideas and bring them to the people through the media of public communication: radio and television, newspaper articles, and widely distributed pamphlets.

In sum, here are the tasks which the fallout problem imposes upon us. Research into the hazards of fallout radiation needs to be more fully and widely published so that the scientific community will be constantly aware of the changes which world-wide radiation is making in the life of the planet and its inhabitants. This knowledge must be at the ready command of every scientist, so that we can all participate in the broad educational campaign that must be put into effect to bring this knowledge to the public. If we succeed in this we will have met our major duty, for a public informed on this issue is the only true source of the moral wisdom that must determine our nation's policy on the testing—and the belligerent use—of nuclear weapons.

There is a full circle of relationships which connects science and society. The advance of science has thrust grave social issues upon us. And, in turn, social morality will determine whether the enormous natural forces that we now control will be used for destruction—or reserved for the creative purposes that alone give meaning to the pursuit of knowledge.

References and Notes

1. "Social Aspects of Science," Preliminary report of the AAAS Interim Committee, *Science* 125, 143 (1957).
2. In connection with the preparation of this article, I thank my colleagues of the AAAS Committee on the Social Aspects of Science. I have relied considerably on ideas developed in the course of several committee meetings on the fallout problem.
3. "The Nature of Radioactive Fallout and Its Effects on Man," Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States (Government Printing Office, Washington, D.C., 1957), pts. 1 and 2.
4. "Joint Committee on Atomic Energy, Summary-Analysis of Hearings, May 27–29 and June 3–7, 1957 on the Nature of Radioactive Fallout and its Effects on Man" (Government Printing Office, Washington, D.C., August 1957).
5. It is not clear precisely how much of the existing fallout data is now unclassified. The statement of E. A. Martell at the Joint Committee hearings indicates that cumulative fallout data up to 1 Dec. 1955 obtained by the University of Chicago "Project Sunshine" (under contract to the Atomic Energy Commission) are reported in *Bulletin No. 11*, which is classified as "Secret." Data for the period 1 Dec. 1955 to August 1956 are reported in *Bulletin No. 12*, which is unclassified (see *3*, pt. 1, pp. 617, 618).
6. The work of the United Nations Radiation Committee, which is in session at this writing, may be expected to lead to a considerable increase in the amount of world-wide information currently available.

Assimilatory Power in Photosynthesis

Photosynthetic phosphorylation by isolated chloroplasts is coupled with TPN reduction.

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The concept is firmly established in cellular physiology that adenosine triphosphate (ATP) is a universal "energy currency" acting as a link between energy-yielding and energy-consuming metabolic reactions (*1*). It was natural, therefore, that its possible role in photosynthesis, an energy transformation process par excellence, should receive early scrutiny. The participation of ATP in the over-all process of photosynthesis became clear as soon as the enzymatic mechanisms of carbohydrate metabolism were elucidated, when it was recognized that carbohydrates, the main products of photosynthesis, are formed by a series of reactions in which phosphorylation steps with ATP are essential.

The recognition that ATP was needed shed no light on its mode of formation in photosynthesis. That a portion of light energy captured during photosynthesis is transformed into ATP without being first stored in some products of CO_2 assimilation has indeed been envisaged for some time (see review, *2*). What remained obscure was the cellular site at which this special phosphorylation occurred and the mechanism by which it was accomplished. From the standpoint of cellular physiology, the important questions were whether ATP used in photosynthesis was formed by some special light-driven assimilation of inorganic phosphate catalyzed by enzymes closely bound to the chlorophyll system or, in mitochondria, by the mechanism of oxidative phosphorylation.

Direct answers to these questions became possible with the discovery of light-induced ATP synthesis (photosynthetic phosphorylation) first in isolated chloroplasts (*3*) and soon thereafter, by Frenkel, in cell-free preparations of pho-

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