# Radiation Risk: A Scientific Problem?

Just about every proposal for a new use of atomic energy has been greeted with some opposition, and efforts have been made to demonstrate that the radiation produced by the proposed project would be more harmful than claimed. Most of these efforts eventually consider the question of the adequacy of allowable radiation exposures, but they have been concerned primarily with specific projects, not with radiation standards per se. Now John Gofman and Arthur Tamplin of the Lawrence Radiation Laboratory have mounted what they call "a direct frontal attack" on existing standards.

The two scientists claim that, on the basis of existing data, it is possible to predict the number of cases of leukemia and cancer that would be produced if the general population received maximum permissible doses of radiation. An analysis of their work reveals that most of the assumptions they use in making predictions can be neither proved nor disproved, but the consensus of their peers is that at least some of the assumptions are wrong. The inability to readily disprove their work on scientific grounds dramatizes the tenuous role that science plays in the determination of radiation risk.

### Development of Radiation Standards

There are several organizations that conduct the studies from which radiation standards in the United States are derived. These include: the International Commission on Radiological Protection (ICRP), the National Committee on Radiation Protection and Measurements (NCRP), and the Federal Radiation Council (FRC). This last organization was formed in 1959 to provide "guidance for all federal agencies in the formulation of radiation standards." Thus, standards used by the Atomic Energy Commission come from the FRC. The United Nations Committee on the Effects of Atomic Radiation and (from 1954 through 1960) the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation have also made major contributions to radiation studies. All of these bodies utilize hundreds of the world's experts in the pertinent fields of radiation and health.

Within the numerous reports of these bodies are a variety of standards for specific purposes, but the one of interest here is the value of 0.17 rem* per year for the general population. In the mid-1950's, both the ICRP and the NCRP concluded that 5 rem per year should be the maximum permissible dose for occupational exposure, and that the general population receive no more than one-tenth this amount. The FRC divided this latter value by 3 in order to allow for variations of exposure to individuals within the population.

In 1956, geneticists on the NAS Committee recommended that the contribution of man-made radiation to the human body not exceed 10 rem per generation (30 years). At that time they estimated that exposure from medical uses of radiation already accounted for about one-half of this value. The remaining 5 rem, when divided by 30 years, again gave a figure of 0.17 rem per year.

Knowledge of human exposure to ionizing radiation is limited because it is based on studies of past tragedies. These include: (i) Japanese survivors of the Nagasaki and Hiroshima bombings and Marshall Islanders who were heavily exposed during tests in 1954, (ii) radiologists who suffered heavy exposures before the long-term effects of radiation were realized, (iii) children x-rayed *in utero*, (iv) persons treated for various diseases by radiation, (v) persons with body burdens of radium, (vi) uranium miners, and (vii) a variety of victims of radiation accidents. The value of the studies varies greatly depending on the size of the sample, the ability to estimate dose, and the availability of control groups.

There are hundreds of papers on these studies and more will be published as delayed effects appear. However, except for accident victims, most of the people were exposed many years ago. Indeed many scientists who follow the studies believe that the main results are already available and that no major new findings will be produced.

In the literature of all the organizations that recommend standards is a statement to the effect that the task requires a careful balancing of the benefits to be derived from the process that will produce radiation against the expected risks. Determination of benefit —for example, military preparedness, abundant electric power, and so forth—is entirely a social problem, but even the determination of risk is only partially scientific.

During interviews with many scientists working on the standards organizations, three guide lines used to estimate probable risk were repeatedly mentioned. (i) The lowest absorbed dosage at which medically significant damage to humans has been observed. This is somewhere between 50 and 100 rad, depending on how rigorous a statistical correlation between radiation intensity and effect one demands. (ii) The natural background radiation. This is produced by cosmic rays and radioactive materials in the earth and human body. It varies from location to location, with most of the world's population living in a background of from 0.05 to 0.20 rem per year. In some areas relatively large populations live in a background of about 1.5 rem per year. (iii) An attempt to estimate an upper limit of risk. The assumption is made that deleterious effects observed at high doses can be linearly extrapolated to predict the effects at low doses.

The first two considerations tend to give standards setters confidence that the 0.17 rem per year figure is acceptable, but the third keeps open the possibility that it is not. It is no surprise, therefore, that the "direct frontal attack" on the standards involves the last procedure.

### Worst of All Possible Worlds

Gofman and Tamplin have presented their case through a variety of channels including: a talk at a symposium on Nuclear Science sponsored by the Institute of Electrical and Electronics Engineers in San Francisco last October; testimony before the Senate Subcommittee on Air and Water Pollution last November and before the Joint Committee on Atomic Energy on January 28, in several privately circulated documents; and in Lawrence Radiation Laboratory reports. The most complete col-

* The rad is the measure of radiation corresponding to the absorption of 100 ergs per gram of tissue. The rem is a measure that includes an estimate of the biological effectiveness of different types of radiation. For the types of radiation considered here the two terms are roughly equivalent.

lection of their work is a set of ten documents, totaling 120 pages, that accompanied their testimony before the Joint Committee on Atomic Energy. In this material they consider several scientific problems, but the central issue—and the only one to be considered here—is the possibility of predicting the damage caused by low-level radiation on the basis of observations made at high levels.

For radiation intensities above about 100 rad, the incidence of several effects—leukemia and some other forms of cancer, for example—show a linear relation with respect to dose. The shape of the dose effect curve at low levels is not known, but a number of possibilities have been considered. If the effect increased at low levels it would have been observed in existing studies, so the most hazardous remaining possibility is that the relation remains linear and that there is no threshold below which radiation has no effect. There could be a threshold, or low levels of radiation could be less effective in producing damage. Finally, the effect of a given dose absorbed over a long time could be less than the same dose absorbed all at once because of the ability of biological material to regenerate or partially regenerate.

Gofman and Tamplin asssume that the relation is linear, that there is no threshold, and that there is no regenerative effect at low dose rates. They then proceed to use data reported in the literature on the increases in leukemia and several other forms of cancer. For thyroid, breast, and lung cancers, and leukemia they take the dose-effect relation that is observed at high doses and calculate the percentage increase in these forms of cancer per rad per year. They obtain values for three other types of cancer and two categories of combined cancers by an indirect method. After tabulating their results they note that there is "a very small range in the estimated increase in incidence rate per rad for these widely differing organ sites in which cancers arise." Among their conclusions they suggest (i) "All forms of cancer, in all probability, can be increased by ionizing radiation," and (ii) "All forms of cancer show . . . closely similar increases in incidence rate per Rad."

They select a 1 percent increase in incidence rate per year per rad as a suitable average value from their tabulated data. The natural incidence of cancer is about 280 cases per 100,000 people per year. If 100,000 are exposed to 0.17 rad per year for 30 years, they absorb a total dose of 5 rad. The increase in cancer incidence would be 280 cases times 1 percent times 5 rad or 14 additional cases of cancer. On the basis of these calculations, one would expect 14,000 additional cancer cases per year for the population over age 30 in the United States.

The natural incidence of cancer in people under 30 is low, but radiation effects on the very young are greater because of the increased rate of cell division. Gofman and Tamplin rather arbitrarily assume that there would be at least 2,000 cancer cases in this group and arrive at a total figure of 16,000 cancer cases per year. On the basis of these figures they argue that the FPC's allowable dose of 0.17 rad per year for the population at large be immediately reduced by a factor of 10.

They are careful to point out that we are not near a population exposure of 0.17 rad per year, and they have not attempted to counter AEC claims that, by the year 2000, the radioactive wastes from nuclear power plants will still be only 1/50 of the present maximum permissible dose. Their reasons for wanting to reduce the standards now are (i) that we must do away with the idea that there is a margin of safety built into the standards, and (ii) that the standards should be reduced before the radiation from nuclear power plants and other sources could only be reduced by stopping projects that are already started.

### Minority Opinion and the Consensus

Most scientists who have worked on setting standards believe that many of the assumptions made by Gofman and Tamplin are unjustifiable but find it difficult to disprove specific points. During interviews several people spoke of being "annoyed" by the arbitrary selection of data to support their arguments and "irritated" at their lack of professionalism. Several times scientists have mentioned that the internal Lawrence Radiation Laboratory reports, speeches at symposia, and congressional testimony are not subject to review by peers, as is work that appears in scientific literature.

At present the only formal counter to their work is a seven-page document prepared by the Division of Biology and Medicine of the AEC at the request of the Joint Committee on Atomic Energy. The FRC is studying the work, but Director Paul Tompkins told *Science* that, if a report is made, it will not be until after all of the material has been reviewed.

The strongest evidence for a non-threshold, linear relation between dose and effect is based on genetic studies. Several experiments have shown that when animals are mated soon after irradiation, mutations appear in the offspring, and that can be correlated with specific locations on the chromosomes. Dose rate did not alter mutation rate, so the effect was assumed to be linear. These results were interpreted to mean that after sperm and ova are formed the radiation damages a specific point on the chromosome. Since no further cell division occurs until fertilization occurs, there is no chance for regenerative effects to take place.

No specific mechanism for chromosome damage was or is now known (for example, a specific energy photon breaking a certain bond or removing particular atoms), but it was assumed that whatever the mechanism, it was likely to be effective at such low doses that it would be wise to assume that there is no threshold. Thus, in assessing genetic radiation damage, biologists assume a non-threshold, linear relation.

The question is: Does this genetic work have any bearing on the somatic effects discussed by Gofman and Tamplin? Recent animal studies have shown that, if mating is delayed after irradiation, the mutation rate drops. This has been interpreted to mean that the gonadal cells, which can continue to divide before producing sperm and ova, have some regenerative power. Many biologists believe that somatic damage is more closely related to the gonadal processes than to those involving sex cells. Gofman and Tamplin disagree because they believe that there is a chromosomal mechanism for cancer initiation.

Perhaps the best studies for determining the shape of the dose-effect curve are those on several hundred people who accumulated residual radium and daughter nuclei in the course of painting radium dials, working as chemists, or drinking radioactive mineral water for "health" reasons. In these cases the determination of cumulative doses, while far from perfect, is better than it is in most human studies because the source of radioactivity is still present in the body and can be measured with sensitive laboratory instruments.

Full treatment of the data from these studies requires rather elaborate statistical analysis, but it can be dealt with roughly by considering a graph on which dose is plotted against number of cancer cases. All the cancer cases appear above a certain value, so it is possible to draw a curve that breaks abruptly at the dose values for which no cancer has been seen. Robley Evans of Massachusetts Institute of Technology, the principal investigator of one of the two major series of radium studies, believes such a curve is the best fit of the data and that it is adequate proof of the presence of a threshold. However, the few points on the graph are close together, so it is also possible to draw a straight line through them and exend it to zero dose.

It can be argued that both explanations fit the data at low doses. For example, in one study there was no cancer among 36 people whose median radium burden was 0.0055 millicuries. This dose is below Evans' threshold, so he would not expect to see any cancer. However, with only 36 people one would expect only 0.012 cases of cancer on the basis of the linear relation, so there is a 99 percent chance that no cases would be observed.

The standards-setting organizations no longer use the idea of a threshold, so Gofman and Tamplin are not in disagreement with them on this point. There is, however, a question about the validity of using the linear relation in combination with the assumption that all forms of cancer are increased by radiation in proportion to their natural occurrence, and there also is a question of the validity of the assumption itself.

The increases in leukemia and thyroid cancer shown in the Atomic Bomb Casualty Commission (ABCC) studies are accepted by most workers in radiation studies. On the basis of ABCC studies it is also possible to make a case for increases in breast and lung cancer, but the evidence in these instances is marginal. For other forms of cancer it is possible to pick studies that show increases and those that do not. There are no studies that show increases in cancer at low (below 50 or 100 rad) doses, although there are a few that should have detected it if it had occurred. For example, 22,000 patients who received whole-body doses of 14 to 15 rad while being treated for hyperthyroidism with iodine-131 showed a slight increase in leukemia, but it was not greater than the increase in a control group of 12,000 patients who were treated surgically for the same disorder.

The reluctance of most scientists to accept the hypothesis that all forms of cancer are increased by radiation in proportion to their natural incidence is based on the feeling that if this were the case large increases in some common forms of cancer should already have been observed. For example, in Japan, where stomach cancer is about 7 times as common as in the United States and is the most prevalent form of cancer, the incidence of stomach cancer among survivors of the 1945 atomic bomb blasts should be much higher.

It is generally agreed that most forms of cancer have longer latency periods than leukemia (which reaches a peak incidence rate about 5 years after exposure), but the ABCC studies have data through 1966, so Gofman and Tamplin have to propose a latency period of more than 21 years for stomach cancer to explain the fact that no increase in this disease has been observed.

### What Can Science Prove?

If the critics of Gofman and Tamplin are right, then it appears to be impossible to determine the risk of low levels of radiation on the basis of existing human population studies. What are the prospects that this risk can be determined on the basis of other studies?

Animal studies will continue to be useful; but, to observe effects at low doses, very large numbers of animals are needed. The expense of maintaining and studying these animals raises the question as to whether or not the possible results justify the effort. For example, at Oak Ridge National Laboratory (where, in studies by William Russell's group, 5 million mice have already been used) a recent project for studying 82,000 mice was cut to a study of 15,000 mice.

Studies of cells and chromosomes show some promise of providing information about biological effects at low doses of radiation. Increases in chromosome aberrations (breaks, splitting, and others) have been observed down to about 5 rad. The aberrations seem to increase in proportion to their natural occurrence, and they have not been associated with any specific pathological effect.

Depression in white blood cell counts is a recognized symptom of radiation exposure, and a number of other blood cell abnormalities (such as binucleate lymphocytes) have been associated with low doses of ionizing radiation. These abnormalities may prove to be the most sensitive indicators of low-level radiation. In studies of Swedish radiation workers correlations have been found between abnormal cells and radiation as low as the background.

Finally there is the possibility of finding some correlation between damage and continuing, low-level radiation in people who live in high-background areas. Guarapary, a coastal town north of Rio de Janeiro, Brazil, and the Kerala area in India have background levels from 1.5 up to 5 rad, as the result of the high thorium content in the soil. Indian scientists have been talking about making a study of the Kerala population, but interested AEC officials are not sure that it has been initiated. The AEC has contracted several studies in Brazil, but the initial results are inconclusive. Results of a very limited population survey published in 1964 indicated a statistically significant increase in chromosome aberrations. A later report contradicted the first, but a recent private communication to an American scientist who had been associated with the project gives a hint that the increase in aberrations is still present. Obviously, it is necessary to see a complete analysis of a large population sample before drawing final conclusions, but the fact that the effect does not show clearly indicates that nothing disastrous, at least in terms of chromosome aberrations, happens as the result of this high-background radiation.

The present consensus seems to be that epidemiological studies probably cannot measure the effects of low radiation doses, and that the cellular and sub-cellular changes that recent studies have shown are produced by low doses of radiation are not deleterious. These studies do not completely rule out the possibility that harmful effects can be demonstrated in the future, but they indicate that such a demonstration is unlikely, and thus, illustrate the importance of setting standards that are in the same range as the natural background radiation. Even a study of the human population extended over a period of decades might fail to demonstrate a relation between low doses and harmful effects because the natural variations of diseases such as cancer are greater than the variations expected from changes in radiation. In short, the term "acceptable risk," as used in radiation standards, could mean a risk that is actually present but that cannot be demonstrated to exist by scientific studies.—Robert W. Holcomb