Communication

The Controversy Over Radiation Safety

A Historical Overview

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The hazards of ionizing radiation have aroused concern since a short time after the discovery of x-rays and natural radioactivity in the 1890s. Misuse of x-rays and radium prompted efforts to encourage radiation safety and to set limits on exposure, culminating in the first recommended "tolerance doses" in 1934. After World War II, the problems of radiation protection became more complex because of the growing number of people subjected to radiation injury and the creation of radioactive elements that had never existed before the achievement of atomic fission. Judging the hazards of radiation became a matter of spirited controversy. Major public debates over the dangers of radioactive fallout from atmospheric bomb testing in the 1950s and early 1960s and the risks of nuclear power generation in later periods focused attention on the uncertainties about the consequences of exposure to low-level radiation and the difficulties of resolving them.

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NEARLY a century after the discovery of x-rays and natural radioactivity, the health hazards of ionizing radiation continue to provoke controversy. During the past few months, for example, scientists have offered sharply conflicting opinions about the dangers of radioactivity from nuclear accidents at Three Mile Island and Chernobyl and from radon levels in millions of American homes. In addition, public fears about the risks of radiation exposure have been fueled by recent revelations about radiation released into the environment from nuclear weapons plants.

The debates center on evaluations of the hazards of low-level exposure and judgments about whether the risks of using radiation sources outweigh their benefits. How, for example, should the environmental costs of nuclear weapons production be balanced against their role in national defense? Are the advantages of nuclear power plants a fair price for the radiation they release? Are the dangers of radon severe enough to justify enormous expenditures in safeguards? There are no incontestable answers to those questions, partly because the scientific evidence about radiation effects remains inconclusive but mostly because they are not strictly scientific matters. They involve a bewildering array of national defense, energy, environmental, and public health policies and priorities that inevitably arouse differing views

Radiation hazards have been a matter of dispute for such a long time that it is easy to lose sight of the origins of the disagreements. An examination of the historical record can help to clarify the reasons why radiation safety remains such a contentious subject. This article focuses on the period from the 1890s to the early 1970s, tracing the evolution of radiation from a source of intoxicating hopes and flagrant misuse to a source of widespread public, medical, and regulatory concern.

EARLY RESPONSES TO RADIATION HAZARDS

When Wilhelm Konrad Roentgen discovered x-rays in 1895 and Pierre and Marie Curie isolated the element radium 3 years later, they inspired a wave of public excitement. Physicians quickly recognized the diagnostic and therapeutic value of x-rays, but the hazards were less apparent. THE JOURNAL reported in 1896 that "the surgeons of Vienna and Berlin believe that the Roentgen photograph is destined to render inestimable services to surgery," and it added casually: "Half an hour is the shortest exposure possible, and most [cases] require an hour."[1] E. P. Davis, editor of the *American Journal of Medical Sciences*, told the College of Physicians the same year that x-rays "might prove useful in the diagnosis of pregnancy."[2] Some physicians applied x-rays for frivolous purposes, such as removing patients' unwanted body hair.[3]

The same problem occurred in the use of radium. Although it provided an important medical advance in the treatment of cancer, it was abused even more indiscriminately than x-rays. Physicians prescribed radium solutions or injected radium intravenously to combat disorders that ranged in severity from acne to heart disease, and hucksters sold radium water or salts as all-purpose health tonics.[3,4]

It soon became apparent to scientists and physicians, however, that x-rays and radioactivity could cause serious illness. Researchers who worked with x-

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rays reported skin irritations and in some cases severe burns. Within two decades after the discovery of x-rays, some scientists and physicians had concluded that exposure to them could produce even more harmful consequences, including sterility, bone disease, and cancer.[3] The potential hazards of x-rays were further highlighted by the findings of H. J. Muller, whose research with *Drosophila* during the mid-1920s indicated that radiation was particularly effective in causing genetic mutation.[5] Although the precise nature and mechanism of the dangers of x-rays remained uncertain, it became increasingly obvious that they posed a threat to the health of those exposed to their penetrating power from an external source.

The hazards of radium were more insidious and took longer to identify. They first became a matter of concern in the late 1920s after Harrison S. Martland, the medical examiner of Essex County, New Jersey, and several coworkers called attention to the harmful effects of ingesting radium. Martland based his conclusions on autopsies and clinical examinations of young women who had painted radium dials on watches and frequently licked their brushes to a point to facilitate the task. He reported that once radioactive elements entered the body, there was "no known way of eliminating, changing or neutralizing them." They would continuously irradiate the tissue in which they lodged, and during an extended period of time the "late effects" of radioactivity could cause death from leukopenic anemia or other diseases.[6-9] Martland's warnings about the dangers of ingesting radioactive materials were substantiated by some highly publicized cases in which people died from consuming large quantities of radium tonics, and the perils of long-term exposure to radium were underscored by the death of Marie Curie in 1934 from the consequences of her research with the element.[3,10]

Public interest in radiation hazards remained sporadic and superficial, but the attention the problem occasionally received helped spur efforts by professionals to guard against needless or excessive exposure. In 1929, the American Medical Association passed a resolution that condemned the use of x-rays to remove body hair, and 3 years later it withdrew radium from its list of remedies approved for internal administration (*New Yorker*. May 2, 1959: 64).[3,11] Meanwhile, other organizations were taking action to encourage better safeguards for workers exposed to radiation. In 1928, the Second International Congress of Radiology established the International X-Ray and Radium Protection Committee, and the following year several professional societies and x-ray equipment manufacturers formed an American counterpart, the Advisory Committee on X-Ray and Radium Protection. Both groups were made up of scientists and physicians who met periodically to discuss recent findings and offer guidance regarding radiation protection. They had no official standing or statutory authority, and they could only make recommendations that they hoped would increase awareness of the hazards of radiation and improve practices in dealing with it. Their advice was directed to physicians, x-ray technicians, and others frequently exposed to radiation sources in their work; it did not apply to patients who received radiation for therapeutic purposes.[12,13]

In 1934, both the international and the American radiation protection groups took an unprecedented step by recommending a quantitative "tolerance dose" of radiation. The US committee agreed on a level of 0.1 R (2.58×10^{-5} C/kg) per day for whole-body exposure to external sources of radiation, while the international group set a limit of 0.2 R (5.16×10^{-5} C/kg) per day. The discrepancy arose not because of any fundamental disagreement between the two organizations but from differences in rounding off similar figures derived from available data. They drew their recommendations largely from observations of the dose required to cause erythema. Because of this limited empirical evidence on which to base their proposals, neither group claimed that its suggested tolerance dose was definitive. However, each believed that exposure below the recommended limit would be unlikely to cause permanent damage to an individual in normal health.[12,13]

Seven years later, the American committee also published advice regarding protection against radium and its decay product, radon gas. Radium was employed primarily for medical purposes, but it also was useful in a variety of industrial applications, including not only the infamous watch dials but also aircraft instruments, roulette wheels, and rayon fabric.[4] Recognizing that the major peril of radium came from ingesting it, the committee sought to prevent harmful concentrations from being swallowed or inhaled. It suggested that any worker who had a "body burden" of more than 0.1 μg of radium should change employment immediately, and it recommended a maximum concentration of 10 pCi/L of air (37×10^{-2} Bq/L of air) of radon gas in workplaces. Although tolerance doses for external radiation and the levels established for the "internal emitters," radium and radon, were based on imperfect knowledge, they were important advances in the theory and practice of radiation protection. On the eve of World War II, then, physicians, other health professionals, and scientists had responded to the misuse of radiation sources by providing information and establishing standards, admittedly imprecise, designed to protect a relatively small number of people from occupational exposure to both external and internal radiation.[10-14]

A NEW ERA FOR RADIATION SAFETY

Then came Hiroshima. The dawn of the atomic age made radiation safety a vastly more complex task for two reasons. First, nuclear fission created many radioactive elements and isotopes that did not exist in nature. This meant that instead of considering only x-rays and radium, professionals in the field of radiation protection had to evaluate the hazards of new radioactive substances about which even less was known. Furthermore, although they did not deal with the massive exposures that would occur if nuclear weapons were ever again used in warfare, they realized that the number of people exposed to low levels of radioactivity from the development of new applications of nuclear energy was certain to expand dramatically. The problem of radiation safety extended to significantly larger segments of the population who might be exposed in the production of nuclear weapons and materials, industrial and medical applications of radioactive isotopes, and the anticipated growth of nuclear power. Radiation protection had broadened from a medical issue of limited proportions to a public health question of, potentially at least, major dimensions.

Under these radically altered circumstances, both the American and the international radiation-protection organizations lowered their suggested exposure limits for external radiation. The American body, renamed the National Committee on Radiation Protection (NCRP) in 1946, reduced its recommended levels by a factor of 2. It was mindful of what was known about the genetic effects of radiation and of what was not known about other effects. Since a larger number of people were subject to radiation injury and major questions remained about the impact of radioactivity on different individuals, the NCRP reasoned, with little dissent, that the best course was to recommend lower levels of exposure.[13] It advised a whole-body limit of 0.3 R (7.74×10^{-5} C/kg) per 6-day workweek, measured by exposure of the "most critical" tissue in the blood-forming organs, head and trunk, and gonads. Higher limits applied to less sensitive areas of the body The NCRP also adopted new terminology, replacing tolerance dose with "maximum permissible dose." It hoped that the new term would better convey its position that no amount of radiation was certifiably harmless. The committee emphasized that the permissible limits sought to make "the *probability* of the occurrence of [radiation] injuries . . . so low that the risk would be readily acceptable to the average individual."[15]

The NCRP took another important step shortly after World War II by preparing recommendations for body burdens and concentrations in air and water of a long list of internal emitters that were by-products of atomic fission. As with the earlier limits for radium and radon, the objective was to keep hazardous amounts of radioactivity from being swallowed or inhaled. The NCRP did not regard its permissible levels for either external or internal sources as final or definitive.[16] It had more data than previously on which to draw, including knowledge of x-ray and radium injuries, experiments with animals, and limited clinical experience with humans, but many uncertainties about the health effects of radiation remained. The NCRP sought to set limits that offered reasonable assurance that workers exposed to radiation would not suffer injury without discouraging the use of radiation for constructive purposes. Although progress toward nuclear-generated electricity was slow, radioactive isotopes were soon employed for a wide range of medical, industrial, and agricultural purposes, such as diagnosing diseases, measuring the thickness and wear qualities of manufactured products, and controlling weeds and insects.[13]

The international counterpart of the NCRP, renamed the International Commission on Radiological Protection, followed the example of the US organization in the early postwar period. It adopted the same terminology and permissible limits for external and internal radiation. In its only major departure from the NCRP, the International Commission on Radiological Protection suggested a maximum permissible dose of one tenth of the occupational levels for large population groups. This was an arbitrary and tentative limit, but it represented the first formal effort to establish protection guidelines for the general population.[12,17]

THE FALLOUT CONTROVERSY

By the time the NCRP and the International Commission on Radiological Protection published their new recommendations during the mid-1950s, a spirited public controversy over the effects of low-level radiation had begun. It arose because atmospheric testing of hydrogen bombs by the United States, the Soviet Union, and Great Britain produced radioactive fallout that spread to populated areas far from the sites of the explosions. Although radiation hazards had commanded public attention on occasion in the past, the fallout debate made it a bitterly contested political issue for the first time. As a subject of sustained public concern, radiation moved from the rarified realms of scientific and medical discourse to the front page. It became a prominent subject in news reports, magazine stories, political campaigns, and congressional hearings.[13]

Scientists disagreed sharply about how serious a risk fallout posed for the population. The Atomic Energy Commission (AEC), which was responsible for conducting the US tests, insisted that the levels of radioactivity were too low to significantly threaten public health and that the risks were far less dangerous than falling behind the Soviets in the arms race. "The degree of risk must be balanced," an AEC report declared in 1955, "against the great importance of the test programs to the security of the nation."[13]

Critics were not convinced, they contended that the AEC underestimated the hazards of fallout Ralph E. Lapp, a well-known physicist and free-lance writer, accused the agency of making "reckless or unsubstantiated statements" about the magnitude of the risks. The AEC published a great deal of scientific data regarding fallout, but undermined its own credibility by consistently placing the most benign interpretation on it. Opponents of testing used the same information to arrive at different conclusions. In response to the AEC's statements that an individual's chances of being harmed by fallout were statistically small, for example, the opponents argued that the absolute number of people exposed to fallout, even if a small percentage of the population, represented an appreciable health hazard. They further suggested that even low levels of continuous fallout could pollute food supplies and cause increased rates of birth defects, cancer, and other diseases.[18,19]

The central issue in the debate was whether the national security benefits of nuclear bomb testing justified the hazards of radioactive fallout. Some scientists and physicians approached the issue by seeking new sources of information. The most famous example was a widely reported effort by the Greater St Louis Committee for Nuclear Information to increase understanding of strontium 90, a bone-seeking radioisotope, by collecting tens of thousands of baby teeth. However, scientific data alone could not answer the questions raised by the fallout controversy; they required subjective assessments and political judgments. This was clearly illustrated in 1962 when the Federal Radiation Council, created 3 years earlier to assume the lead among federal agencies concerned with radiation safety, estimated that fallout up to that time would cause 40 deaths per year in the United States from cancer and that during a period of 30 years it would cause 110 cases of serious birth defects. *Newsweek* asked the critical question that the report left unresolved: "How much do 40 adults or 110 children weigh on the scales of policy?" (June 11, 1962:62).[15,16]

The fallout controversy not only highlighted the political judgments involved in radiation protection but also made clear that scientists did not know the answers to many important questions about the effects of radiation. The issue that attracted the most attention was whether or not there was a threshold for somatic radiation injury. Although leading authorities had agreed even before World War II that there was no threshold for genetic consequences, some scientists maintained that since no short-term somatic effects of exposure to doses of less than 50 to 100 rem (<0.5 to 1.0 Sv) had been observed, there was a somatic threshold at some as yet undefined level. Experts on radiation were also uncertain about the ability of both somatic and genetic cells to repair damage from radiation and about the impact of dose rate (the length of time during which a dose is absorbed) on cell structure.[15-21]

The concern over radiation that the fallout issue triggered also called attention to medical practices. Several commentators submitted that there was still much room for improvement. Mitchell R. Zavon,[22] writing in *JAMA* in 1956, criticized fellow physicians for needless administration of radiation in treating nonmalignant diseases and for careless use of x-rays. "Why is it," he wondered, "that the physician remains in awe of the atomic bomb and radioactive fall-out, but thinks nothing of his x-ray equipment or the radium in his desk drawer?" The National Academy of Sciences, in a widely publicized report on the biological effects of radiation the same year, issued a similar warning.[23]

The National Academy's report concluded that "even very low levels of radiation can have serious biological effects." It stressed the need to reduce radiation exposure as much as possible, especially because the use of atomic energy was likely to expand in the future. In response to that advice and the growing public concern about radiation, both the NCRP and the International Commission on Radiological Protection again lowered their recommended permissible limits. They cut the total maximum permissible dose (MPD) for occupational whole-body exposure to external radiation to an average of 5 rem/y (0.05 Sv/y) after 18 years of age, using the formula $MPD = 5(N-18)$, where N indicated a person's age. They reduced the limits for internal emitters by corresponding proportions. They continued to suggest that the limit for individual members of the public be 10% of the occupational level, 0.5 rem (0.005 Sv), and they added a new stipulation that for genetic reasons, the average level for large population groups be one thirtieth of the occupational level, 0.17 rem/y (0.0017 Sv/y).[23,24]

The reductions in the recommended permissible doses by both the NCRP and the International Commission on Radiological Protection stirred some speculation that previous levels had been dangerously high. Both groups denied such assertions; they pointed out that there was no indication that workers exposed to radiation had suffered harm under the older standards. Some critics charged that the NCRP worked in concert with the AEC, but there is no evidence that the government exercised undue influence in the committee's deliberations over its recommended exposure limits.[25] The NCRP had grown over the years from an intimate group of experts to a much larger and more structured organization. It included but was not dominated by representatives of government agencies. Its members, even when they disagreed on specific issues, favored the use of radiation for constructive purposes and believed that this could be done in a responsible manner. Confident that their recommendations provided a wide margin of safety, NCRP members sought to keep exposure to levels that seemed generally safe without being impractical. As Lauriston S. Taylor, chairman of the NCRP, declared in 1956: "Any radiation exposure received by man must be regarded as harmful. Therefore, the objective should be to keep man's exposure as low as possible and yet, at the same time, not discontinue the use of radiation altogether."[26]

THE DEBATE OVER NUCLEAR POWER AND RADIATION

The fallout controversy of the 1950s and early 1960s largely faded from public view after the Limited Test Ban Treaty of 1963 prohibited atmospheric testing of nuclear weapons. Many questions about the consequences of fallout remained unresolved, and the debate left a legacy of ongoing scientific inquiry and latent public anxiety about the health effects of low-level radiation. Those fears, and acrimonious scientific dissension, were rekindled in the late 1960s and early 1970s. This time the major issue was the hazards of radioactive effluents released from nuclear power plants.

Nuclear power experienced rapid growth during the late 1960s. Although only 11 plants were operating in 1968, dozens more were on order or under construction. Utilities, striving to meet ever-growing demand for electricity and seeking to reduce the air pollution caused by coal-fired plants, increasingly exercised the nuclear option. In 1954, Congress had assigned the AEC the dual responsibilities of encouraging the use of nuclear power and at the same time regulating its safety. In imposing requirements for radiation protection on the facilities it licensed, the agency adopted the recommendations of the NCRP. To establish the limit for public exposure to routine releases of radiation outside a nuclear plant, the AEC assumed that a person stood outdoors at the boundary for 24 hours per day, 365 days per year. Licensees generally met those conditions easily. In 1968, for example, releases from most plants measured less than 3% of the permissible levels for liquid effluents and less than 1% for gaseous effluents.[27]

The conservative assumptions of the AEC and the performance of operating reactors did not prevent criticism of the AEC's radiation standards. As concern about industrial pollution took on increasing urgency as a public policy issue in the 1960s, the environmental impact of nuclear power received more public scrutiny than ever before. A number of observers suggested that, in light of the uncertainties about radiation effects, the AEC's regulations were insufficiently rigorous and should be substantially revised. This first emerged as a major controversy when the state of Minnesota, responding to questions raised by environmentalists, stipulated in May 1969 that a plant then under construction must restrict its radioactive effluents to a level of about 3% of that allowed by the AEC.[28,29]

The adequacy of the AEC's radiation standards became even more contentious in the fall of 1969, when two prominent scientists, John W. Gofman and Arthur R. Tamplin, suggested that if everyone in the United States received the permissible population dose of radiation, it would cause 17 000 (later revised to 32 000) additional cases of cancer annually. Gofman and Tamplin worked at the Lawrence Livermore National Laboratory, which was funded by the AEC, and their positions as insiders gave their claims special credibility. They initially proposed that the AEC lower its limits by a factor of 10 and later urged that it require zero releases of radioactivity.[30,31]

The Livermore scientists not only argued that the existing standards of the AEC and other radiation-protection organizations were inadequate, but challenged the prevailing consensus that the benefits of nuclear power were worth the risks. Tamplin[32] declared that it was "not obvious that the benefits of more electrical power outweigh the risks." Gofman was more outspoken in his dissent; he insisted that in its radiation standards, "the AEC is stating that there is a risk and their hope that the benefits outweigh the number of deaths." He added: "This is legalized murder, the only question is how many murders" (*Baltimore Sun*. December 8, 1970;sect C:20).

The AEC denied Gofman's and Tamplin's assertions on the grounds that they extrapolated from high doses to estimate the hazards of low-level exposure, and that, furthermore, it was impossible for the entire nation to receive the levels of radiation that applied at plant boundaries.[30] Most professionals in the field of radiation protection agreed with the AEC that the risks of effluents from nuclear power were far smaller than Gofman and Tamplin maintained.[33] The disagreement deteriorated into a bitter dispute. When the NCRP's Taylor, for example, commented that Gofman and Tamplin had "presented no new data, new ideas, or new information" that "highly experienced" experts had not already considered, the Livermore scientists responded: "Incompetence in the extreme is our only possible evaluation of Lauriston Taylor and his cohorts."[34] The controversy refocused public attention on the effects of low-level radiation, but it did little to clarify a complex and ambiguous issue.

The debate over nuclear plant effluents also again called attention to x-ray hazards. Perhaps nothing illustrated so clearly the intractability of the problems of radiation protection, even on an issue on which expert opinion was undivided. An editorial in *JAMA* in 1971, written by Leonard A. Sagan,[35] pointed out that 90% of the public's radiation exposure came not from nuclear power or fallout but from medical applications. He complained that physicians ordered x-rays with excessive and unnecessary frequency, and he warned that if the medical community did not police itself, the growing public anxiety about radiation could lead to legislative action. "It seems likely that public attention, now focused on very small exposures from reactors," he asserted, "will not for very long ignore the much larger doses from medical sources." Although Sagan's specific arguments applied to the time in which he wrote, the general points he made echoed a refrain that had become familiar during the previous half century.

Concern about the use and uncertainty about the effects of radiation continued to generate debate during the 1970s and 1980s. Medical and scientific researchers continued to seek answers to questions about the consequences and risks of exposure to low-level radiation Although these researchers provided new information, they could not offer definitive conclusions. New reports by the National Academy of Sciences, reexaminations of the evidence from the bombing of Hiroshima, epidemiologic studies of groups exposed to radiation in their work or to radioactive fallout, and surveys of health trends in the areas around Three Mile Island and Chernobyl considered the issues but did not resolve them.

The history of radiation protection suggests that this pattern is likely to continue One reason is the scientific uncertainty that has prevailed since the earliest efforts to set safety guidelines. Although authorities in the field of radiation protection have recommended exposure limits in accordance with the best information available at the time, the data have chronically been insufficient, inconclusive, or contradictory. More important, issues that involve the use of radiation sources have not been strictly scientific matters; they necessarily required policy assessments and priority judgments. Just as divergent views emerged in the past regarding whether atmospheric testing provided benefits that compensated for the hazards of fallout or whether the risks of nuclear power outweighed its advantages, different individuals and groups are likely to take different positions in the future regarding the seemingly timeless question of what constitutes an acceptable level of exposure to radiation.

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