CHAPTER 1

A Solvable Problem

During the forty-year period from the 1940s into the 1980s, the disposal of radioactive waste evolved from a problem that experts regarded as challenging but solvable to a problem that many people viewed as bewildering and perhaps insurmountable. In 1959 Abel Wolman, a professor at Johns Hopkins University and a sanitary engineer of international renown, told a congressional committee, "There was a period, perhaps 10 years ago, when the problem of radioactive waste was considered to be nonexistent." Wolman's claim was overstated, but it captured the prevailing optimism among experts in government and industry at the time he made it. They recognized that finding suitable means of disposing of radioactive waste materials from the production of nuclear weapons and the generation of nuclear power was essential, and they expressed confidence that, in time, research on and experience with the problem would provide a solution. In 1956 the staff of the U.S. Atomic Energy Commission (AEC), the agency that Congress made responsible for building nuclear weapons, encouraging the growth of commercial nuclear power, and regulating the safety of nuclear technology, declared that "practical, safe ultimate disposal systems will be developed." Glenn T. Seaborg, chairman of the AEC, echoed that view when he commented in 1967 that "handling radioactive waste in a future large scale nuclear economy . . . was not a major problem."[1]

Other observers were considerably more troubled about the difficulties of protecting public health from the dangers of radioactive waste.

Articles in popular magazines during the 1950s and early 1960s cited the hazards of "deadly atomic garbage," "death-dealing debris," and "lethal liquid waste." In March 1960 the journalist Walter Schneir described radioactive waste as "clearly . . . the most hazardous and treacherous material man has ever tried to deal with." By that time, growing public apprehension about this "treacherous material" was obvious; indeed, as early as 1949 the AEC's director of public information had worried about "possible latent hysteria" over nuclear wastes. Thus, within a short time after the nuclear attacks on Hiroshima and Nagasaki introduced the "atomic age," the disposal of radioactive waste appeared to be both a complex technical issue and an imposing political problem. This pattern became even more pronounced as the use of nuclear technology generated growing controversy. In December 1978 *Business Week* reported in an article on opposition to nuclear power that "the most politically sensitive of all nuclear energy's problems is waste disposal." The challenge of resolving both the technical and the political questions surrounding radioactive waste periodically confronted and persistently confounded policy makers during the four decades following the dawn of the atomic age.[2]

Waste Disposal during the Manhattan Project and the Early Cold War

Radioactive waste in large quantities was first created as a by-product of the Manhattan Project, the herculean effort to build an atomic bomb during World War II. Amid the urgency with which they worked, responsible officials did not regard establishing a permanent repository for waste materials as a pressing matter. Instead they adopted temporary expedients with the assumption that improved approaches would be developed at a later time.

The principal sources of the most dangerous forms of highly radioactive waste were the reprocessing plants at the Hanford Engineer Works, located along the Columbia River in eastern Washington. Hanford produced the plutonium that fueled the first nuclear test explosion in New Mexico and the bomb dropped on Nagasaki in 1945. The complex process of making plutonium on an industrial scale was first carried out at Hanford during the later stages of the war. The initial step was construction of a reactor that, despite still-limited theoretical knowledge, a lack of practical experience, a time-dictated inability to conduct preoperational testing, and a series of false starts, succeeded in splitting atoms in its uranium fuel. The result of nuclear fission was the creation of a variety of radioactive "fission products" and "activation products," including plutonium-239, which can be used to trigger an atomic explosion. In order to recover the plutonium, the irradiated fuel slugs were transferred under heavy shielding to a reprocessing plant. There, after the fuel pellets were dissolved in acid, plutonium was separated by chemical extraction. Along with the plutonium, reprocessing yielded large quantities of gaseous, solid, and liquid radioactive wastes. The highly radioactive liquid wastes, which also contained a sinister brew of chemicals, were pumped into hastily fabricated, single-shell, steel-lined, underground storage tanks.

The liquid waste from reprocessing at Hanford was, in terms of volume and radioactive intensity, the most hazardous by-product of the Manhattan Project's far-flung operations. But other activities at sites around the country also created abundant lower-level radioactive waste. Huge volumes of water became irradiated when used for, among other things, cooling reactors, washing contaminated clothing, and cleaning laboratories. This liquid waste, which was far less radioactive than that from reprocessing, was often pumped into ditches or holding ponds and sometimes discharged directly into nearby streams or rivers. Solid wastes, which included contaminated equipment, pipes, valves, filters, clothing, instruments, and tools, were buried in trenches and covered with soil. Gaseous waste products were released into the atmosphere; those with the highest levels of radioactivity were first filtered or precipitated. The practices adopted during the Manhattan Project continued after World War II ended and the cold war began.[3]

RADIATION PROTECTION

Despite the limited knowledge about radioactive waste and the rudimentary treatment it received, the officials in charge of radiation safety in the Manhattan Project's facilities were convinced that the methods of disposal provided adequate protection to employees and the public, at least in the short term. Professionals in the field of radiation protection, who called themselves health physicists, carefully monitored workers' exposures and radiation releases into the environment. Their goal was to prevent health disorders that radiation could cause, including cancer, bone disease, sterility, and genetic defects. In assessing the hazards of exposure to low levels of radiation, health physicists drew on the knowledge and experience gained since the discovery of x-rays in 1895 and natural radioactivity the following year. At the same time, they were acutely mindful of the many uncertainties about the health effects of radiation. In 1934 scientific groups had for the first time announced a recommended "tolerance dose" for exposure to x-rays, which can penetrate deeply into bodily tissue. Seven years later they had taken another important step by recommending tolerance doses for the "internal emitters" radium and its decay product, the radioactive gas radon. Radium and radon present serious hazards if they become deposited inside the body after being swallowed or inhaled. Radiation experts did not claim that the tolerance doses were definitive, but they believed that the recommended limits offered an ample margin of safety for the relatively small number of persons exposed to external or internal radiation in their jobs.

Radiation protection became vastly more complex with the development of the atomic bomb and the prospect of widespread use of atomic energy for other purposes. One reason was that nuclear fission created many radioactive isotopes that did not exist in nature. Instead of dealing only with x-rays and radium, health physicists had to consider the potential hazards of new radioactive substances about which they knew little. Further, the number of people exposed to radiation from military and civilian applications of atomic energy was certain to grow greatly. Radiation protection broadened from a medical and industrial issue of limited scope to a public health question of potentially major dimensions. The possible genetic consequences of increased population exposure to radiation was a matter of particular concern. Even before World War II, genetic research had indicated that reproductive cells were especially vulnerable to small amounts of radiation and that mutant genes could be inherited from a parent with no obvious radiation-induced injuries.

Soon after the war ended, health physicists revised their approach to radiation protection in light of the new conditions. The professional organization in the United States that recommended exposure limits, which had been established in 1929 and named the National Committee on Radiation Protection (NCRP) in 1946, replaced the term "tolerance dose" with "maximum permissible dose." Its members believed that the new term better conveyed the idea that no quantity of radiation was certifiably safe. The NCRP defined its recommended permissible dose as that which, "in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime." It tightened its previous recommendations by reducing the permissible dose for whole-body exposure from external sources to 50 percent of the 1934 level. It measured the whole-body limit by exposure to the "most critical" tissue, in the lenses of the eyes, the gonads, and the blood-forming organs; higher limits applied for less sensitive areas of the body. The NCRP recommended a maximum permissible dose for occupational exposure of 0.3 roentgen per six-day workweek (or 15 roentgens per year). The roentgen was a unit that indicated the quantity of x-rays that would produce a specified degree of change in the atomic structure of cells in the human body under prescribed conditions. The NCRP made comparable revisions in its recommendations on exposure to internal emitters. An international organization of radiation experts, the International Commission on Radiological Protection (ICRP), followed the lead of the NCRP in the early postwar years by adopting the term and concept "maximum permissible dose" and by recommending that occupational exposure to external sources of radiation be limited to 0.3 roentgen per week.[4]

RADIATION SAFETY AND WASTE DISPOSAL

The AEC, headed by five commissioners appointed by the president and confirmed by the Senate, was created by the Atomic Energy Act of 1946. After the agency began operations in January 1947, it followed the NCRP's recommendations on radiation protection. Its goal in radioactive waste disposal, as in all its programs, was to guard against radiation exposures that exceeded the NCRP's guidelines. The NCRP and the ICRP made clear that the permissible levels they recommended did not constitute a threshold that offered absolute safety. Although they considered the risk small, they acknowledged that a person whose exposures stayed within the dose limits might still suffer injury. In practice, they believed that the recommended doses provided a serviceable and generally applicable measure of safety.[5]

In keeping with the approach of the professional organizations, officials in charge of radiation protection at nuclear weapons plants did not regard the complete avoidance of exposures to individuals or releases to the environment as either possible or necessary. Two leading authorities at Hanford articulated this view in an internal report they prepared in August 1945. Simeon T. Cantril, assistant superintendent of industrial medicine, and Herbert M. Parker, who had established and supervised the health physics program at the site, wrote, "Never before had so many people been engaged in an occupation wherein the hazard was one of radiation and radioactive substances on so large a scale. . . . It can be stated without reservation that to date no employee . . . has received an amount of radiation which would be injurious." Cantril and Parker were also confident that radioactive releases to the environment had not endangered the public. They declared that radioactive gases from Hanford's plants were "entirely innocuous" and that radioactive wastewater channeled to the Columbia River had never "been in excess of that which would cause an overtolerance radiation exposure to any living thing immersed in it." In January 1948 Karl Z. Morgan, director of the health physics department at Clinton Laboratories in Oak Ridge, Tennessee, where much of the Manhattan Project's work on the first atomic bombs had taken place, offered an equally favorable assessment. "There is considerable evidence that as long as present standards are maintained," he wrote in *Scientific American,* "the plutonium projects will remain among the safest industrial operations in the country."[6]

The conviction that radiation exposure at levels below the permissible dose was generally safe, even if not risk-free, guided waste disposal practices of the Manhattan Project during World War II and of the AEC during the early cold war. Those responsible for radiation protection adopted two approaches for dealing with radioactive waste. The method of treating the high-level liquid wastes produced by the reprocessing of reactor fuel was to concentrate them "in as small a volume . . . as possible" and store them "in a safe manner" to prevent the escape of radioactivity. The method of handling the much larger volume of lower-level wastes was to dilute their radioactivity to levels that posed "no danger to plants, animals, or humans" and often, in the cases of liquids and gases, to disperse them into the environment. The process of nuclear fission created a variety of radioactive isotopes, many of which had very short half-lives (the time it takes one-half of the atoms to decay to a different form). The isotopes that caused the most concern were those with half-lives long enough to remain intensely radioactive for an extended period. They included strontium-90, with a half-life of 29 years, and cesium-137, with a half-life of 30 years. This meant that it would take about 300 years, a span of ten half-lives, for those elements to lose most of their radioactivity. Isotopes with much longer half-lives, such as plutonium-239 (about 24,000 years) and technetium-99 (about 210,000 years), were regarded as a less critical problem because the intensity of radioactive materials is inversely proportional to their half-lives. Consequently, those long-lived elements were grouped in the broad category of low-level waste, which included everything except the high-level liquid waste from reprocessing.[7]

The operating principle that radiation exposures below permissible doses were acceptably safe enabled health physicists at Hanford to acquiesce in a large, intentional release of iodine-131 in 1949. From the time that Hanford began plutonium production, iodine-131 was among the radioactive gases routinely dispersed to the atmosphere. It is a radioactive isotope with a half-life of eight days that concentrates in the thyroid gland if ingested or inhaled. Although information about the effects of iodine-131 was sketchy, health physicists at Hanford worried about its presence on vegetation and in livestock near the site. Parker recommended a "tolerable concentration" of iodine-131 on edible plants as early as January 1946.[8]

Despite efforts to promote safety and protect the environment from hazardous levels of radiation at Hanford, Manhattan Project and AEC officials consistently subordinated those concerns to their assessment of national security demands. The discovery that the Soviet Union had exploded its first atomic bomb placed the AEC's priorities in especially sharp relief. In October 1949, a few weeks after atmospheric sampling revealed that the Soviets had conducted a nuclear test, the AEC, the General Electric Company (which ran Hanford under a government contract), and the U.S. Air Force made plans to release radioactive gases from the Hanford site as a means to gain insight into Soviet reprocessing procedures and estimating plutonium production. The operation came to be known as the "green run," because it used "green" spent fuel elements in which the cooling period was much shorter than usual. This meant that radioactive elements in the fuel had less time to decay to stable forms and that more iodine-131 than normally present in plant emissions was introduced directly into the environment. The quantities of iodine-131 were increased further when Hanford officials deliberately bypassed filters that trapped radioactive materials. As a result, the green run, conducted on December 2–3, 1949, released about 8,000 curies—a unit of measurement that indicates the decay rate (or level of activity) of radioactive substances—of iodine-131 to the area surrounding the site. Although this was a small percentage of the total amount of iodine-131 discharged from Hanford to that time, it was probably the largest release in a single day. The green run produced high offsite radiation readings; concentrations on vegetation and in animals temporarily intensified by dramatic proportions even miles away.[9]

The offsite radiation from the green run troubled Parker and other health physicists at Hanford. Parker, a leading figure among professionals in the field of radiation protection, had first built his reputation as a medical physicist. He was born in England and after earning bachelor's and master's degrees in physics, began his career at the Holt Radium Institute in Manchester in 1932. He and the director of the institute, James Ralston Kennedy Paterson, collaborated in developing uniform doses for treating cancer with radium. This achievement, as one expert commented many years later, "revolutionized radium therapy." In 1938 Parker accepted a position at the Swedish Hospital Tumor Institute in Seattle, Washington, where he worked under the radiologist Simeon Cantril. After the United States entered World War II, he joined Cantril at Clinton Laboratories in Tennessee, to establish programs to protect Manhattan Project employees from largely uncharted radiation hazards. In 1944 he moved to Hanford to perform the same services. Thus Parker was in the vanguard of the emerging field of "health physics," a term he disliked intensely. The term was adopted during the war to disguise the purpose of the Manhattan Project, and Parker thought it was not only vague but also easily confused with his original field of medical physics. He was known to his colleagues as an exceptionally able and sometimes intimidating professional who "was quick to decimate a half-baked idea or ill-prepared presentation with his pungent British prose."[10]

Parker generally took an optimistic view of the occupational and public health hazards created by Hanford operations. He was confident that "present disposal procedures may be continued . . . with the assurance of safety for a period of perhaps 50 years." In July 1948 he suggested that even if all the high-level waste stored in tanks leaked to the ground, it would not cause a "major disaster." He acknowledged, however, that a worst case accident could require "radical curtailment of the use of river water." New research findings convinced him to modify some of his earlier views about radiation hazards. In April 1949 he voiced concern that permissible dose levels recently drafted by the NCRP did not adequately account for the concentration of certain radioactive isotopes in river plankton and fish. Investigations at Hanford had shown, for example, that plankton in the Columbia River concentrated phosphorus-32 "by a factor of two hundred thousand," which raised the threat of contaminated food chains.[11]

For the same reasons, Parker was disturbed that the green run distributed iodine-131 far beyond plant boundaries. In a report he submitted in January 1950, he noted that the green run "resulted in greater contamination spread than had been anticipated." Although he concluded that it presented only a "negligible risk" to Hanford workers, he expressed misgivings about exposing the general population to more releases of similar magnitude. The green run, Parker wrote, "came close enough to significant levels, and its distribution differed enough from simple meteorological predictions," that he and his colleagues "would resist a proposed repetition of the test." The green run demonstrated the AEC's prevailing philosophy that radiation exposures within permissible levels were acceptable for operating purposes. Parker's reaction to the test also indicated that the AEC and its contractors regarded radiation safety as an important, if secondary, consideration and that they took permissible dose limits seriously. Nevertheless, in light of the many scientific uncertainties about radiation hazards, the extent to which permissible doses could be viewed as a reliable measure of safety stirred controversy among experts and raised questions about the AEC's handling of radioactive wastes.[12]

CRITICISM OF THE AEC'S WASTE PROGRAMS

Even before Parker cited his reservations about a repeat of the green run, other prominent health physicists and sanitary engineers had criticized the AEC's waste management practices at Hanford and other sites. In April 1948 members of the AEC's Safety and Industrial Health Advisory Board raised a series of questions about the adequacy of radiation protection measures in general and waste disposal in particular. Although they did not condemn the agency's approach, they expressed skepticism about the effectiveness of existing efforts to guard against excessive occupational and public exposure to radiation. The AEC had established the advisory board in September 1947 to survey fire, construction, electrical, chemical, and radiation hazards at the many installations it had inherited from the Manhattan Project. Among the experts appointed to the board was Abel Wolman, who had urged David E. Lilienthal, chairman of the AEC, to consider the sanitary engineering problems that might "arise in the continued development of nuclear fission studies and production programs." Wolman, in addition to serving on the faculty at Johns Hopkins University, was at that time chairman of the Committee on Sanitary Engineering of the National Academy of Sciences–National Research Council, a prestigious organization that prepared a wide variety of reports on scientific issues for the federal government.[13]

As his position on the National Academy of Sciences committee indicated, Wolman was a highly regarded authority in the field of sanitary engineering. After completing graduate work in engineering at Johns Hopkins, he began his career with the Maryland Department of Health in 1915. Within a short time he made his reputation by developing, in collaboration with a former classmate, the chemist Linn Enslow, a formula for eliminating bacteria in water through chlorination. He also had a major role in designing the water system for the city of Baltimore, and he later provided similar services as a consultant for many American cities, foreign countries, and international organizations. In 1922 he became the chief engineer for the Maryland Department of Health. He joined the faculty at Johns Hopkins on a full-time basis in 1937. Wolman "became a legend in his time," the *Baltimore Evening Sun* observed when he died in 1989, in large part because of his devotion to and concern about environmental and public health issues. His commitment to environmental protection was leavened with a keen sense of what was politically, economically, and technologically practical. He did not believe that attaining a risk-free society was either possible or desirable. "I can't conceive of being promised a world in which there are no problems," he once remarked. "I don't want my grandchildren to have the feeling that's what I'm trying to give them. That would be a bore."[14]

As a pioneer in the field of sanitary engineering, Wolman took a strong interest in the potential impact of atomic energy development on public health. He first became involved in the issue when the National Academy of Sciences Committee on Sanitary Engineering requested that he visit Lilienthal to convey its uncertainty that the AEC was giving "sufficient attention" to protecting workers or the public from radiation hazards. Wolman had a high opinion of the AEC chairman, whom he knew from serving as a consultant to the Tennessee Valley Authority, which Lilienthal had headed during the 1930s. When Wolman presented the committee's misgivings in July 1947, Lilienthal replied that he thought its "worry was unwarranted." Nevertheless, he asked that Wolman talk with James B. Fisk, director of the AEC's research division, and then report back to him. When Wolman met with Fisk, whom he regarded as a "superb scientist," he was not convinced by the assurances he received. After Wolman told Lilienthal about his doubts that "adequate protection was being provided," the AEC chairman invited him to join the agency's Safety and Industrial Health Advisory Board.[15]

Wolman carried out his new responsibilities with characteristic energy and dedication. Along with other members of the board, he made extended visits to the AEC's laboratories and production facilities to evaluate their safety programs. In November 1947 he collaborated with Arthur E. Gorman, a longtime friend and well-known sanitary engineer, in drafting a memorandum on "problems of environmental sanitation encountered in atomic energy operations" for inclusion in the Safety and Industrial Health Advisory Board's report to the AEC. Wolman valued Gorman's "expertise, which was superb," and "his dynamic pursuit of anything he touched, to the point—almost—of making himself obnoxious."[16]

In their memorandum on environmental protection in atomic energy installations, Wolman and Gorman expressed their views clearly and candidly. They observed that "in the haste to produce atomic bombs during the war certain risks may have been taken . . . with the understanding that subsequently more effective control measures would ameliorate those risks." They suggested many areas in which such measures were necessary. They were disturbed that "tolerance limits for radioactive and toxic materials" had been established without review by "public health officers normally concerned with and responsible for such problems in civilian life." In matters relating directly to their own field, sanitary engineering, Wolman and Gorman found much that was worrisome. They feared that water supplies at Clinton, Hanford, and elsewhere were contaminated. They commented that radioactive waste disposal practices had "been developed without full consideration of the hazards involved." And they concluded that the "control of the disposal of radioactive and toxic materials into the atmosphere . . . is subject to criticism in varying degrees. We cannot recall a single stack in any of the areas of such height or design which would meet modern requirements of industrial or laboratory operations."[17]

Wolman and Gorman's analysis appeared virtually unchanged in the final report of the Safety and Industrial Health Advisory Board, submitted to the AEC in April 1948. The panel, chaired by Sidney J. Williams, assistant to the president of the National Safety Council, concluded that safety and health hazards, including, in addition to radiation, fires, motor vehicle traffic, construction, exposure to chemicals, and industrial hygiene, demanded more attention from top managers of the AEC and its contractors. "The Atomic Energy Commission inherited from the Manhattan Project an excellent safety program and record," the board declared. "There are recent indications that these are deteriorating."

The report's criticisms of radiation protection and waste disposal programs drew not only on Wolman and Gorman's findings but also on the comments of Hymer L. Friedell, another leading authority. Friedell, director of the radiology department at the University Hospitals of Cleveland, had served as one of the chief medical officers in charge of the Manhattan Project's efforts to manage radiation hazards. He wrote in the Safety and Industrial Health Advisory Board report that the problems the AEC faced in providing adequate radiation protection for workers and the public were "arresting in their magnitude." He suggested that although the exposure "levels that have been used have been safe during wartime," they should be "reduced as low as is practicable" during peacetime. Friedell echoed Wolman and Gorman on the subject of radioactive waste. He lamented that "no concrete program exists at the present for waste disposal" and urged that "this problem . . . be tackled at the earliest opportunity." Hanford's Herbert Parker, who was also a member of the advisory board, placed the existing radiation protection programs of the AEC and its contractors in a more favorable light. He insisted that they had produced a record that was "better than that enjoyed by any other organization," and indeed, was "phenomenally good." But he agreed with his colleagues that waste disposal was "one of the Commission's most pressing safety problems." Among its many recommendations to the AEC, the Safety and Industrial Health Advisory Board called for the creation of a health unit with "top level policy responsibility" and the appointment of a "sanitary engineer of broad experience" to the agency's staff.[18]

Wolman was disappointed that the AEC did not view radioactive waste disposal with the same urgency as did members of the advisory board. He believed that "people at the highest level in the Commission . . . discounted" the perplexities of handling high-level waste. He was especially displeased with the attitude of J. Robert Oppenheimer, chairman of the AEC's General Advisory Committee, which exercised great influence on the agency's scientific and policy decisions. At a meeting of the committee in April 1948, Oppenheimer dismissed the waste problem as "unimportant"—a prevalent judgment among physicists and other scientists who held influential posts with the AEC. Some time later, after enjoying a pleasant dinner at Oppenheimer's home, Wolman bluntly voiced his opinion. He told Oppenheimer, "[I have] tremendous respect for your field of activity and your views," but added: "When you enter my field . . . your ideas as to how we shall manage this 'unimportant' problem are characterized almost completely by a total ignorance of the nature of disposal." Wolman, who had a way of disagreeing without making enemies or holding grudges, later recalled that he and Oppenheimer "parted friends."[19]

Despite Wolman's complaints about the AEC's attitude toward waste, he and his colleagues on the Safety and Industrial Health Advisory Board succeeded in convincing the agency to take initial steps to deal with the problem. Lilienthal agreed with the board's recommendation to add a

Figure 1. The AEC's Safety and Industrial Health Advisory Board. Seated at the far left is Arthur Gorman. Seated third from the left is Abel Wolman and fifth from the left, Herbert Parker. (Abel Wolman Papers, The Johns Hopkins University)

sanitary engineer to the staff of the AEC and told Wolman, "Since you push it . . . you find me the man." Wolman quickly concluded that his friend and professional colleague Arthur Gorman was the man for the job, and he then prevailed on Gorman to leave his post as the head of water operations in Chicago and join the AEC. In 1949 Gorman hired Joseph A. Lieberman, who had earned his Ph.D. in sanitary engineering at Johns Hopkins under the direction of Wolman. For many years, Gorman and Lieberman were the entire sanitary engineering staff of the AEC, and in that capacity they sought, in the face of both technological and political hurdles, satisfactory ways to deal with growing quantities of radioactive waste.[20]

THE AEC'S PUBLIC REPORT ON WASTE

In addition to creating a small sanitary engineering staff, the AEC, apparently in response to the findings of the Safety and Industrial Health

Advisory Board, prepared and eventually published a report on waste management practices at its installations. In July 1948 the commissioners requested that the staff submit a technical analysis of waste issues to provide the basis for a public report. When a draft paper, presumably written by Gorman, was presented to the commissioners three months later, Lilienthal reiterated "that this subject would be suitable for a special public report." He hoped that the AEC's review of the problem would both inform and reassure the public. A short time later, Morse Salisbury, director of the agency's public and technical information service, received a copy of the draft and found to his dismay that it was "far more pessimistic and alarming than previous statements we have seen." He suggested that it was inconsistent with the views of other experts. Salisbury was "only too well aware of the great public interest in waste disposal problems" and was concerned about the potential impact of the report.[21]

There was little evidence to support Salisbury's impression of "great public interest" in radioactive waste. He noted that the "volume of inquiries" on the subject that the AEC received, which was "stimulated every time a sanitary engineer or a medical man makes a public talk," was "growing." The problem of waste disposal had also been discussed in ominous terms in a few newspaper articles. In October 1947 an Associated Press story on disposal of "hot" atoms declared, "There has never been a problem like this. Any disposal previously known for wastes will leave these atoms to menace present and future generations." An article in the *New York Times* a few months later pointed out that scientists could not yet offer "sure protection" from the "malignant forces" of radioactive waste. Nevertheless, the issue of waste disposal was not a matter of prominent media attention or public anxiety. The AEC's concern about the public's apprehension over waste hazards was apparently rooted in a flurry of disquieting stories in the press about radiation effects in general. Roy B. Snapp, secretary to the Commission, made this connection when he urged that the agency's report on waste make clear the "universal and constant existence of radiation." He suggested that if "we can drive home the concept" that radioactivity was not something new, "tendencies toward hysteria might be alleviated."[22]

Snapp's comments reflected the AEC's dismay about increasing public fears of radiation from nuclear weapons. In the immediate aftermath of World War II, the death and destruction caused by the blasts and heat from the atomic bombs dropped on Hiroshima and Nagasaki commanded much more attention than the effects of radiation. This changed after the United States conducted highly publicized nuclear weapons tests at Bikini Atoll in the Pacific Ocean in July 1946. Following the tests, which were witnessed by 168 reporters, many articles appeared in popular publications about the dangers of radiation. *Life* magazine told its readers that "science learned at Bikini," among other things, "that radioactive elements generated by atomic bombs are . . . even more dangerous than large-scale destruction." The potential genetic consequences of radiation exposure seemed especially alarming. *Newsweek* revealed that Hermann J. Muller, who received a Nobel Prize in 1946 for his research on genetic effects of x-rays, feared that "mass exposure to high-energy radiation can doom the human race." The journalist Edward P. Morgan warned in *Collier's* that "the a-bomb's invisible offspring" could "dangerously alter human cell structure and ultimately produce freaks."[23]

A best-selling book, *No Place to Hide,* presented the message about radiation dangers to a popular audience in an especially striking manner. Its author, David Bradley, had served as a U.S. Army physician assigned to the "radiological safety section" during the Bikini tests. Published in 1948, his book offered an absorbing account of his experiences; he concluded that "if life as we know it is to continue, men must understand and deal with the menacing aspects of atomic energy." He warned that the use of nuclear weapons "may affect the land and its wealth—and therefore its people—for centuries through the persistence of radioactivity." *No Place to Hide* spent ten weeks on the *New York Times* best-seller list and sold about 250,000 copies within a few months.[24]

Bradley's book and the numerous magazine articles that appeared in the wake of the Bikini tests undoubtedly fueled public concern about radiation hazards. But attention was largely fixed on the effects of nuclear weapons, and there was little evidence of sustained or deep-seated public anxiety about the dangers of radiation from other sources. A public opinion poll taken on November 10, 1948, indicated that despite the news reports about radiation, support for, or at least optimism about, atomic energy remained strong. The survey asked, "Do you think that, in the long run, atomic energy will do more good than harm?" By a margin of 42 percent to 23 percent, the respondents believed that it would "do more good." Among college-educated participants, the favorable response was even higher; 61 percent thought that atomic energy would "do more good," and only 18 percent thought it would "do more harm." Two years later researchers who conducted a study for the AEC on public attitudes toward atomic energy were surprised to find "a general disinterest in the subject, a lack of fear or anxiety, and a thorough lack of concern about developments in the field."[25]

Nevertheless, the stories about the effects of radiation exposure caused considerable concern to professionals in the field and to ranking officials in the AEC. Without seeking to play down genuine radiation hazards, they worried that overstated popular accounts would provoke unwarranted public fear. Herbert Parker, in his contribution to the report of the AEC's Safety and Industrial Health Advisory Board, commented that the "insidious danger of radiation damage receives a spotlight in the popular and technical press . . . out of proportion to the hazard in comparison with injury risk in many other industries." In a review of Bradley's book, Austin M. Brues, a prominent health physicist and a staff member at both Argonne National Laboratory and the Institute of Radiobiology and Biophysics at the University of Chicago, agreed that there was "plenty of reason to worry" about radiation. But he disputed Bradley's suggestion that "in radioactivity we have something which is truly and completely intolerable." David Lilienthal urged his fellow citizens to recognize that "atomic energy and atomic bombs are not synonymous." He also encouraged them to "learn the essential facts about atomic energy" so that they could make informed judgments regarding the use of "this new force that may make the difference between calamity and progress."[26]

It was in this context that the AEC drafted its public report on radioactive waste disposal. Lilienthal and his colleagues wanted a document that would inform the public and at the same time reduce the potential for excessive alarm. Preparing a report that met those criteria without compromising classified data proved more difficult and time-consuming than they anticipated. While various AEC offices worked on the report, Lilienthal, Salisbury, and Carroll L. Wilson, the agency's staff director, complained about delays in its completion and deficiencies in its presentation. In the meantime, the AEC decided to hold a meeting with representatives of professional organizations and federal agencies involved in sanitary engineering and waste disposal. It hoped to collect information and to ease the "concern which technical and administrative representatives of public and private agencies have indicated in response to waste from atomic energy operations."[27]

The meeting took place on January 24–25, 1949. In opening remarks, Lilienthal expressed confidence that "we will conquer" the waste disposal problem, which he depicted as "a part of learning how to live with radiation." He made the same points during a press conference that followed the seminar. He described radioactive waste disposal as "an extremely important problem" and acknowledged that there was "no doubt" that it was "a tough one." But Lilienthal suggested that the experts at the meeting believed solutions would be found, and he hoped that radioactive waste would not become "a subject of emotion and hysteria and fear." In a front-page story, the *New York Times* reported that "the sum of the two-day study was that the hazard was being closely monitored in every way possible."[28]

The AEC finally published its report on radioactive waste in December 1949. The objective, Salisbury reminded the commissioners, was to "inform citizens generally on a subject about which public information is needed in order to dispel misconceptions and allay possible latent hysteria." The report gave a description, in lay terms, of the nature of radioactivity and the sources of radioactive wastes. It acknowledged that radioactive wastes were "potentially harmful" and explained how they posed a danger from exposure to internal radiation. Gaseous wastes, for example, could be inhaled directly or could settle on plants and, in turn, be consumed by animals or humans. Liquid wastes could be hazardous if they contaminated water supplies or if they deposited radioactive particles in algae that were eaten by fish. The report pointed out that the quantities of radioactive waste generated in the AEC's facilities were unprecedented. It noted that "an operating nuclear reactor generates radiation equivalent to several hundred tons of the naturally radioactive element, radium," while, "in contrast, only 3 pounds of pure radium have been made available in the whole world during the last 50 years." The report concluded that "the methods of safe handling used to date have successfully protected workers and the public" but also cited the need for improved methods to deal with waste and for a "more complete understanding of the permissible doses (tolerance levels) which men, animals, and plants can absorb without affecting their health, growth, and length of life."[29]

The AEC provided a comprehensible guide to the nature of radioactive waste that was a useful introduction to the subject. In keeping with the dual and in some ways conflicting goals of the report, however, it was not entirely candid. One objective was to inform the public; the other was to reduce the potential for public alarm. As a result, the report gave few details about the great uncertainties surrounding safe disposal of high-level wastes and only passing attention to the most hazardous liquids stored in tanks at Hanford. Although it briefly discussed the discharge of low-level waste products, it did not disclose the efforts to conceal releases of iodine-131 at Hanford. The green run occurred just days before publication of the report, so there was, of course, no mention of it. But neither was there any mention of other iodine-131 releases from the plant. Indeed, the commitment to secrecy sometimes reached ludicrous levels. On at least one occasion in 1946, a Hanford scientist posed as an animal husbandry expert to clandestinely check for iodine-131 levels in the thyroids of cattle without arousing the suspicion of local farmers. Such ploys were probably effective in reducing public anxiety about radiation in the short run. But the AEC's oft-repeated concern about "hysteria" was far out of proportion to existing public attitudes, and its abridged candor undermined public confidence over the long run. The AEC recognized that waste disposal was a long-term problem but used short-term palliatives to reduce the potential for a public outcry. It assumed that over time solutions would be found that would win public acceptance because it was aware that "if the [atomic] industry is to expand, better means of isolating, concentrating, immobilizing, and controlling wastes will ultimately be required."[30]

RADIOACTIVE WASTE AND COMMERCIAL NUCLEAR POWER

In the first few years of its existence, the AEC centered its consideration of waste disposal on its own facilities. The bulk of the AEC's waste was created in the production of materials for nuclear weapons. This pattern changed significantly in 1954, when Congress passed a new Atomic Energy Act that eased restrictions on access to technical information and made possible the widespread use of nuclear energy for civilian purposes. The legislation gave the AEC statutory responsibility for both encouraging the development and regulating the safety of the peaceful applications of nuclear power. Once a commercial nuclear industry was established, it would increase, perhaps drastically, the volumes of radioactive waste that required safe handling, storage, and disposal. In its approach to civilian nuclear waste, the AEC drew on the assumptions it had adopted and the experience it had acquired in dealing with the problem at its own installations.

The treatment of radioactive waste from commercial reactors and other civilian sources was not qualitatively different from that at the AEC's own plants. Experts believed that highly radioactive spent fuel rods in power reactors would be chemically reprocessed, just as they were at Hanford and other AEC sites. This would enable the recovery of uranium-235 that was not consumed and that could be used in the fabrication of new fuel rods. It would also reduce the volume of high-level wastes that had to be stored and eventually disposed of in a suitable depository. The most serious problem in dealing with waste from nuclear power plants, as in weapons plants, would be the toxic liquids that were the by-product of reprocessing. As Arthur Gorman and Joseph Lieberman, the AEC's sanitary engineers, put it in 1956, "High-level liquid wastes presently associated with chemical reprocessing are . . . the core of the waste disposal problem." Although this problem would be qualitatively the same for both government and commercial facilities, it was likely to differ quantitatively. If the AEC carried out the mandate of the 1954 Atomic Energy Act to promote nuclear industry development, the volume of waste that commercial reactors produced would far exceed the output of its own plants.[31]

Nuclear experts believed that finding satisfactory methods of radioactive waste disposal had to be accomplished if the nuclear industry was to reach its full potential. In 1955 Glenn Seaborg, a Nobel Prize recipient for his pioneering work in identifying and isolating the element plutonium and later chairman of the AEC, declared, "Probably the most difficult problem, which may well be the limiting factor in determining the extent to which nuclear energy will be used for industrial power, is that of disposal of the tremendous quantity of radioactive waste material." He added: "These problems will be solved, however, and a nuclear energy industry will probably be developed in the future because of the advantages of this form of energy." The following year, a highly publicized report by the National Academy of Sciences on the biological effects of radiation reached a similar conclusion about future quantities of waste materials. The committee that investigated the issue, which was chaired by Abel Wolman and included Gorman and Lieberman along with other leading authorities, described radioactive waste as "an unparalleled problem." It estimated that by the year 2000 the volume of high-level liquid waste, mostly from commercial reactors, could total a staggering 2.4 billion gallons. Although the committee found that research to date "indicated that a number of systems for ultimate disposal of wastes may be feasible," it cautioned that "considerably more work is required . . . before any of them is at the point of economic operating reality."[32]

In light of the new conditions created by the 1954 act and the prospective growth of nuclear power, the AEC carefully reexamined the uncertainties surrounding radioactive waste and their potential impact on commercial applications. One source of concern was the cost of handling and disposing of waste materials. By the end of 1956 the AEC had invested about $100 million in waste facilities and was spending between $3 million and $5 million annually for treatment and disposal in its own plants. Tank construction and storage alone cost from thirty cents to two dollars per gallon, depending on the nature of the wastes being contained. Those amounts appeared to be an important obstacle to commercial nuclear power development because they were significantly higher than waste disposal expenses in other industries. Nuclear experts anticipated that the price of waste management would decline proportionately as the industry grew, and they hoped that the extraction of potentially valuable isotopes would reduce costs further. Scientists were exploring the possibility of using cesium-137 in industrial radiography, strontium-90 in storage batteries, and other radioisotopes found in nuclear waste for a variety of medical, industrial, and agricultural purposes. If recovery of some portions of radioactive wastes for constructive applications proved feasible, it could help overcome the economic burdens they imposed. *Business Week,* while reporting that safety and cost problems could make it difficult to "reap the full benefits that can come from nuclear energy," also suggested that "today's waste may be tomorrow's bonanza."[33]

The AEC's primary concern about radioactive wastes was not their cost but their threat to public health. In March 1956 the AEC staff, drawing heavily on the views of Gorman and Lieberman, reviewed the existing status of and future prospects for waste disposal in a paper prepared for the commissioners. The paper stated that "disposal of radioactive wastes is under control at all AEC installations" and that the "serious problem" of gaseous emissions at Hanford and other sites had been largely resolved by the addition of high-efficiency filters and "iodine and rare gas removal units." It also pointed out the many outstanding questions that required consideration. It maintained that neither solid nor low-level liquid wastes presented major technical difficulties but cautioned that as the commercial nuclear industry grew, finding suitable locations for dispersing liquids and burying wastes would be essential.

The disposal of highly radioactive liquids from reprocessing remained by far the most formidable waste problem facing the AEC. The staff report cited several possible approaches to ultimate disposal of high-level wastes that were being investigated and that appeared promising. One was fixation of waste products in a solid, stable medium, such as clay, synthetic feldspar, or ceramic materials, to contain their radioactivity. The solid blocks might then be buried or stored in a way that would not endanger the environment. A second approach was to discharge high-level liquid wastes directly into geologic formations that would keep their radioactivity from reaching water supplies or other natural resources. Among the kinds of sites being considered were salt beds and domes, deep basins of 5,000 to 15,000 feet that were geologically isolated, and selected shale formations. A third proposal was to remove the long-lived isotopes, strontium-90 and cesium-137, from the high-level wastes. This would ease the difficulty of controlling the remaining isotopes but would not solve the problem of what to do with the strontium-90 and cesium-137. Finally, high-level wastes might conceivably be dumped in ocean waters, but this idea seemed less attractive than the others because of "lack of knowledge of pertinent oceanographic factors and complex technical problems and costs involved."

The AEC staff expressed confidence that suitable means and sites for radioactive waste disposal would eventually be found, but it offered no imminent solutions. Research on satisfactory methods to deal with high-level waste was still in preliminary stages. The AEC was sponsoring projects at its own laboratories and at several universities and also was working with the National Academy of Sciences, the U.S. Geological Survey, and other government agencies to gather and evaluate information. The agency staff reminded the commissioners that resolving technical issues was only a part of the problem; public relations was "an especially important consideration." As the atomic industry expanded and moved into populated areas, public concern about nuclear safety generally and waste disposal specifically seemed likely to increase. Therefore, it was essential to cooperate closely with state and local government officials to explain technical matters and to secure their assistance in planning, siting, and promoting the safety of waste operations.[34]

In 1955 the AEC took an initial step to determine the best method to dispose of high-level wastes by requesting that the National Academy of Sciences establish a committee on waste disposal within its Division of Earth Sciences. In a series of seminars, representatives of the AEC and the U.S. Geological Survey, industry officials, and prominent individual scientists shared knowledge and exchanged opinions. The committee's final report, published in April 1957, declared that "radioactive waste can be disposed of in a variety of ways and at a large number of sites in the United States." It cautioned, however, that much research remained to be done "before any final conclusion is reached on any type of waste disposal" and added that "the hazard related to radio-waste is so great that no element of doubt should be allowed to exist regarding safety."

In the judgment of the Committee on Waste Disposal, the most promising approach for permanent disposal of high-level liquid wastes was to place them in salt formations. The greatest advantage of this method was that large salt deposits occur in dry geologic surroundings, and the absence of water would prevent liquid wastes from migrating to other locations. Further, fissures in salt formations, unlike those in clay, shale, or granite quarries, would be "self-sealing," thus avoiding leakage. The two principal areas in the United States with large salt deposits, the north-central states and the southern states along the Gulf Coast, had low seismic activity and were level enough to facilitate underground access. The committee made clear, however, that important technical uncertainties about using salt formations for high-level wastes had to be resolved. It was concerned about the possibility that salt cavities might collapse and urged that research be done to determine the "size and shape of openings which can be relied upon to be structurally stable." Another potentially serious problem was that the large amount of heat produced by radioactive wastes as they decay would weaken the walls of salt formations. Finally, transportation of high-level wastes from the sites of their creation to a disposal facility raised challenging cost and safety issues.

The committee cited fixation of high-level wastes in stable solids as the second most promising approach to final disposal. It suggested that if means for "forming a relatively insoluble product" could be developed, the blocks could then be stored on land, in mines, or in salt cavities. Although optimistic that solutions to high-level waste disposal would be found, the committee emphasized that many complex problems first had to be addressed. It suggested that "several years of research and pilot testing" might be necessary "before the first such disposal system can be put into operation."[35]

FUROR OVER OCEAN DUMPING

While the AEC staff and scientific experts in a number of disciplines were weighing options for dealing with radioactive waste, an unexpected public furor arose over the dumping of low-level wastes in ocean waters. The uproar was largely a result of growing public fears of radiation that were not directly related to the problem of waste disposal. The source of public anxieties that became prominent during the mid- and late 1950s was radioactive fallout from atmospheric testing of nuclear weapons by the United States, the Soviet Union, and Great Britain. Scientists disagreed sharply about the severity of the risks that fallout imposed on the population. The AEC, which was responsible for conducting the U.S. 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. Critics were not convinced; they contended that the AEC underestimated the hazards of radioactive fallout. They suggested that even low levels of continuous fallout could pollute food supplies and cause increased rates of birth defects, cancer, and other afflictions.

The fallout debate became a prominent subject in news reports, magazine stories, political campaigns, and congressional hearings. For the first time, the dangers of exposure to low levels of radiation became a bitterly contested political question and a subject of sustained public concern. A decade earlier, the AEC's worries about "latent hysteria" over radiation were overblown, or at least premature. But in the late 1950s, public fears about the effects of low-level radiation from any source became widespread and acute. A poll taken in May 1957 showed that 52 percent of those questioned believed that fallout was a "real danger," compared to 28 percent who did not think so and 20 percent who did not know. Physicians complained that their patients were so alarmed about radiation that they resisted legitimate x-ray treatment. The fallout debate also seriously damaged the AEC's standing as a guardian of public health. The agency was so deeply concerned that growing apprehension about radiation would impair its nuclear weapons testing programs that it consistently played down the potential threat to public health that fallout conceivably represented. As a result, it forfeited much of its credibility. In 1951 investigators attributed a lack of public fear of or interest in atomic energy to trust in scientific experts and the government. By the end of the decade, however, faith in the AEC's commitment to protection of the public from radiation hazards had clearly eroded.[36]

The diminished confidence in the AEC's performance on public health issues was apparent in the protests against ocean disposal of radioactive wastes. Dumping of low-level wastes into the sea had begun as early as 1946, and for more than a decade the U.S. Navy had carried drums of waste materials from AEC facilities to selected sites in the Atlantic and Pacific Oceans. In addition, as of October 1958, the AEC had licensed six private firms to dispose of low-level wastes from hospitals, laboratories, and industrial operations at sea. Although one licensee, the Crossroads Marine Disposal Corporation, had discarded wastes in relatively shallow waters near Boston under a permit granted in 1952, the AEC, in accordance with the recommendations made by the National Committee on Radiation Protection in 1954, began to require that disposal take place at sites with a depth of at least one thousand fathoms (6,000 feet). The agency was satisfied that its procedures created no public health hazard, principally because the amount of radiation that could reach the ocean environment from dumping was minuscule compared to the billions of curies of natural radiation present in the sea.[37]

For several years, the ocean dumping of radioactive wastes attracted little public attention. But once the fallout controversy made radiation hazards a hotly disputed and highly visible subject, applications for AEC licenses to dispose of waste materials in the Gulf of Mexico and in the Atlantic Ocean stirred a storm of opposition. Citizens in several locations turned out to protest at meetings or hearings. Senator Clair Engle of California complained, "Questions have been raised regarding the prevalence of . . . radioactive material in the atmosphere. Apparently now we are going to get it in the ocean as well." The well-known writer E. B. White declared, "The sea doesn't belong to the Atomic Energy Commission, it belongs to me. I am not ready to authorize dumping radioactive waste into it, and I suspect that a lot of other people to whom the sea belongs are not ready to authorize it, either." The *Nation* accused the AEC of clandestinely carrying on "reckless dumping" for years. Other observers urged that responsibility for assuring the safety of radioactive wastes be removed from the AEC and entrusted to the U.S. Public Health Service. In a story on ocean dumping in January 1962, *Time* reported that "public uneasiness continues to increase," even though "many of the arguments against waste storage and disposal are ridiculous."[38]

AEC officials were dismayed by the outcry over ocean dumping. Although they regarded the concerns as greatly exaggerated, they took the signs of public anxiety seriously. The AEC sponsored studies of three areas in which wastes had been dumped. The investigations, carried out by the U.S. Coast and Geodetic Survey and the Public Health Service, showed no "radioactivity attributable to disposal operations." Nevertheless, the AEC decided, at least for the time being, not to issue any new licenses for ocean disposal of radioactive wastes. Chairman John A. McCone suggested that "there would be little justification at the present time to press for ocean disposal sites in the face of strong public objection—despite the fact that such objections might be founded on emotional fears and not on technical facts."[39]

In response to the "strong public objection," the AEC turned to land burial of solid low-level wastes generated by its licensees, which was both less controversial and considerably cheaper than ocean disposal. By 1963 it had issued licenses for commercial operation of three low-level sites on state-owned land in Nevada, Kentucky, and New York. At that time, about 95 percent of solid low-level waste was buried on land,

and the AEC staff concluded that ocean disposal was "no longer . . . an important service."[40]

From the late 1940s to the early 1960s, the AEC regarded management of radioactive waste as an issue that required attention. It reached this conclusion after Abel Wolman and his colleagues on the Safety and Industrial Health Advisory Board convinced Lilienthal and other leading officials to recognize the significance of waste programs both for protecting public health and for promoting the peaceful applications of atomic energy. In 1962, in a report to President John F. Kennedy on the civilian nuclear power program, the AEC declared that aside from the development of safe and commercially viable power reactors, "no other phase of the entire program is more important than that of waste disposal." But this did not mean that the agency considered waste disposal an urgent problem. It was confident that radioactive waste was under control at its own installations, even as it sought a permanent method for disposal of high-level materials. It did not view low-level waste as a major threat to public health, though it acknowledged that finding satisfactory ways to deal with large quantities of commercially generated materials was essential. The nuclear power industry was still small, so determining the best method to dispose of high-level wastes from reactors was not yet a pressing matter.

The AEC sponsored research projects on a wide variety of waste questions, and it felt no pressure to rush to settle on a solution to the many outstanding issues that those projects were investigating. It preferred to explore the advantages and disadvantages of different alternatives rather than to increase the chances for errors by moving too rapidly. But it insisted that a suitable means for ultimate disposal of the most dangerous wastes would be found in the foreseeable future. "There is no reason," an AEC report to Congress declared in January 1960, "to believe that proliferation of wastes will become a limiting factor on future development of atomic energy for peaceful purposes."[41]

Within a short time, however, the AEC's position was undermined by strong criticism of its approach to waste issues. The prevailing view within the agency and the scientific community that waste disposal was a problem that could be solved reasonably soon was challenged by a series of controversies that cast doubts on the comfortable assumptions of the previous decade. And the strong expressions of public anxieties about radioactive waste, so evident in the outcry over ocean dumping, made the siting of waste facilities, even if the scientific issues were settled, even more problematic.