CHAPTER ONE

The Discovery of Radiation and Its Hazards

During a period of several decades after the German physicist Wilhelm Konrad Roentgen discovered x-rays in 1895, radiation evolved from a source of public fascination and scientific acclaim to a source of widespread public fear and scientific controversy. Roentgen's discovery, highlighted by an image of the bones of his wife's left hand and her wedding ring, created a wave of excitement. Newspapers and magazines gave it headline treatment, dozens of books and hundreds of technical articles rapidly appeared, and department stores provided demonstrations to attract customers. The *Journal of the American Medical Association* reported in 1896 that "the surgeons of Vienna and Berlin believe that the Roentgen photograph is destined to render inestimable services to surgery."[1] By the latter part of the twentieth century, attitudes toward radiation had changed dramatically. In 1973 the economist and technology critic E. F. Schumacher, in his influential book, *Small Is Beautiful,* described radiation as "the most serious agent of pollution of the environment and the greatest threat to man's survival on earth." The sociologist Kai T. Erikson spoke for many informed observers when he

1. Bettyann Holtzmann Kevles, *Naked to the Bone: Medical Imaging in the Twentieth Century* (New Brunswick: Rutgers University Press, 1997), pp. 16–27; Joel D. Howell, *Technology in the Hospital: Transforming Patient Care in the Early Twentieth Century* (Baltimore: Johns Hopkins University Press, 1995), pp. 136–37; Catherine Caufield, *Multiple Exposures: Chronicles of the Radiation Age* (New York: Harper and Row, 1989), pp. 3–8; "Roentgen Photograph," *JAMA: The Journal of the American Medical Association* 26 (March 7, 1896): 491.

commented in 1991 that radiation "clearly has a special place in the human sense of terror."[2]

The transformation of public attitudes and scientific views over a period of a century reflected the gradual recognition and then growing fear of the hazards of radiation and the protracted scientific debate over the risks of low-level exposure. The debate centered on often conflicting assessments of whether the risks of using radiation sources outweighed the benefits they provided. There were no incontestable answers to the questions that were raised, partly because the scientific evidence remained inconclusive and partly because they were not strictly scientific matters. The result was the emergence of a sharp and sometimes bitter controversy that pitted scientists, public health professionals, and regulatory officials against one another and generated confusion, uncertainty, and fear among members of the public who had no reliable way to evaluate the competing positions.

Radiation Hazards and the Tolerance Dose

Despite the unreliability of the gas tubes used to produce x-rays and doubts among physicians about the medical value of the images they provided, x-rays were employed for a variety of purposes within a short time after their discovery. Some applications were beneficial, such as diagnosing injuries, locating bullet and shrapnel wounds, and solving crimes. Others were frivolous, such as removing unwanted body hair or observing parts of one's skeleton. At first there was little awareness, even among scientists and physicians, of the hazards of x-rays. E. P. Davis, editor of the *American Journal of Medical Sciences,* told the College of Physicians in 1896 that he had used x-rays "in obtaining a shadow picture of the fetal head" and suggested that they "might prove useful in the diagnosis of pregnancy."[3]

2. E. F. Schumacher, *Small Is Beautiful: Economics as if People Mattered* (New York: HarperCollins, [1973] 1989), p. 143; Kai T. Erikson, "Radiation's Lingering Dread," *Bulletin of the Atomic Scientists* 47 (March 1991): 34–39.

3. "The Roentgen Rays in Surgery," *JAMA* 26 (March 14, 1896): 548; John K. Sutherland, "The Discovery of Radiation," *Nuclear News* 40 (April 1997): 34–37; Robert G. Arns, "The High-Vacuum X-Ray Tube: Technological Change in Social Context," *Technology and Culture* 38 (October 1997): 852–90; Rebecca Herzig, "Removing Roots: 'North American Hiroshima Maidens' and the X Ray," *Technology and Culture* 40 (October 1999): 723–45; Kevles, *Naked to the Bone,* pp. 24–53; Howell, *Technology in the Hospital,* pp. 103–9.

It soon became apparent, however, that exposure to x-rays could cause serious bodily injury. Some physicians noticed inexplicable burns on the bodies of patients after lengthy exposure to x-rays. An Austrian doctor who treated a five-year-old girl for a mole on her back with heavy doses of x-rays in 1896, for example, reported that although the process helped with the mole, it also caused severe burns. Thomas A. Edison, the celebrated inventor and an early x-ray enthusiast, conducted a series of experiments that left him with sore eyes and skin rashes. He became thoroughly disillusioned with the technology when a scientist who worked in his laboratory, Clarence Dally, became seriously ill and in 1904 died a painful death from his acute exposure to x-rays. Others suffered similar fates; injuries, disease, and sometimes death were especially prevalent among technicians and physicians who received occupational x-ray exposure. Within two decades after Roentgen's discovery, scientists and physicians had concluded that exposure to x-rays could cause sterility, bone disease, cancer, and other harmful consequences. The hazards of x-rays were further underscored by the findings of the pioneering geneticist H. J. Muller, whose research with fruit flies during the 1920s indicated that reproductive cells were highly susceptible to damage from even small amounts of radiation.[4]

A similar pattern followed the discovery of the element radium; after an initial outpouring of public excitement and promiscuous misuse, the hazards of exposure gradually became apparent. Experiments with x-rays led to the discovery of natural radioactivity in 1896. The French physicist Henri Becquerel expanded on Roentgen's findings by conducting research on luminescent materials and found to his surprise that uranium salts produced weak penetrating rays. Although he misinterpreted aspects of the phenomenon he detected, he correctly concluded that the element uranium spontaneously gave off radiation. Becquerel's work was extended and refined by Marie and Pierre Curie, who in 1898 identified what were later confirmed to be the new elements polonium and radium. The Curies demonstrated that polonium and radium produced radiation of much greater intensity than that of uranium. They came up with a new word, "radioactive," to describe the spontaneous emissions that they observed. Largely on her own, Marie Curie undertook heroic efforts to iso-

4. Caufield, *Multiple Exposures*, pp. 8–9; Kevles, *Naked to the Bone*, pp. 33–48; Jack Schubert and Ralph E. Lapp, *Radiation: What It Is and How It Affects You* (New York: Viking, 1957), pp. 181–201; Isaac Asimov and Theodore Dobzhansky, *The Genetic Effects of Radiation* (Washington, D.C.: U.S. Atomic Energy Commission, 1966).

late tiny amounts of radium from tons of residue of uranium ore (called pitchblende).[5]

The announcement of the discovery of radium in late 1898, like the discovery of x-rays, commanded the attention of scientists and fascinated the public. Newspaper and magazine articles, books, and public lectures suggested that radium could be useful for purposes that included bicycle lights, fertilizer, and cures for blindness. Physicians quickly recognized that the element offered an important advance in treating cancer, though they were less certain about the best way to apply their new weapon. The legitimate medical benefits of radium were often overshadowed by many indiscriminate and ill-informed applications that exceeded even the abundant abuse of x-rays. Physicians prescribed radium solutions or injected radium intravenously to combat disorders ranging in severity from acne to heart disease, and hucksters sold radium water or salts as all-purpose health tonics. In perhaps the most notorious case of misuse, a wealthy socialite named Eben M. Byers died of radium poisoning in 1932 after drinking huge quantities of a popular elixir called Radithor, which he consumed over a period of several years for relief from minor afflictions.[6]

Even before Byers's highly publicized death from ingestion of radium, scientists and physicians had begun to recognize the hazards of the element. The dangers of exposure to radium were more insidious than those of x-rays and took longer to identify. Unlike x-rays, which posed a threat to the health of those exposed to their penetrating power from an external source, radium caused its greatest harm if it were taken into the body. Whereas at least some of the immediate consequences of exposure to heavy doses of x-rays were visible, the damaging effects of radium did not show up for an extended period of time. Some researchers sounded notes of caution about the possible health risks of radium soon after its discovery, but the hazards did not become an issue of major concern and investigation until the 1920s. This occurred as a result of growing evidence that young women who had worked in factories where they painted radium dials on watches and clocks had become gravely ill from

5. Lawrence Badash, *Radioactivity in America: Growth and Decay of a Science* (Baltimore: Johns Hopkins University Press, 1979), pp. 10–12; Susan Quinn, *Marie Curie: A Life* (Reading, Mass.: Addison-Wesley, 1995), pp. 145–55; Edward R. Landa, "The First Nuclear Industry," *Scientific American* 247 (November 1982): 180–93; Caufield, *Multiple Exposures,* 22–23.

6. Badash, *Radioactivity in America,* pp. 19–32; Caufield, *Multiple Exposures,* pp. 24–28; Schubert and Lapp, *Radiation,* pp. 108–16; Landa, "First Nuclear Industry," p. 189; Roger M. Macklis, "The Great Radium Scandal," *Scientific American* 269 (August 1993): 94–99.

their exposure. Prodded by officials of the New Jersey Consumers' League and the National Consumers' League who took up the cause of the "radium girls," researchers established a connection between occupational exposure to radium and the serious afflictions that some of the dial painters suffered.[7]

The investigator who was instrumental in providing evidence that the ingestion of radium could lead to serious illness and death was Harrison S. Martland, the medical examiner of Essex County, New Jersey. Martland conducted autopsies and clinical examinations of several young women who had painted radium dials; they had ingested large cumulative doses by licking their brushes to a point to facilitate the task. In 1925 Martland and two colleagues reported in the *Journal of the American Medical Association* that once radium or other "long lived radioactive substances" entered the body, they spontaneously and continuously irradiated the "blood-forming centers," in which over time they could cause severe anemia and other disorders. Further, the authors concluded that there was "no known way of eliminating, changing or neutralizing" internally deposited radiation. In this article and others he published later, Martland demonstrated the dangers of the "deadly . . . rays" that were introduced into the body. As a result of the clear evidence of the hazards of radium, the risks of accumulating radioactive elements inside the body joined the effects of x-rays from external sources as a strong incentive for protective measures against radiation hazards.[8]

By the time Martland published his articles, scientists had determined that the harmful consequences of radiation were produced by its ionizing effect on human cell structure. Researchers conducted many experiments that revealed important information about ionization in the first two decades of the twentieth century, but the pathological implications of their findings, at least in attempting to set an acceptable level of radiation exposure, were uncertain. Radiation causes ionization because of its high levels of energy, whether in the form of x-rays from machines or

7. Claudia Clark, *Radium Girls: Women and Industrial Health Reform, 1910–1935* (Chapel Hill: University of North Carolina Press, 1997), pp. 57–58, 88–111; William D. Sharpe, "The New Jersey Radium Dial Painters: A Classic in Occupational Carcinogenesis," *Bulletin of the History of Medicine* 52 (Winter 1978): 560–70; F. G. Gosling, "Dial Painters Project," *Labor's Heritage* 4 (Summer 1992): 64–77.

8. Harrison S. Martland, Philip Conlon, and Joseph P. Knef, "Some Unrecognized Dangers in the Use and Handling of Radioactive Substances," *JAMA* 85 (December 5, 1925): 1769–76; Harrison S. Martland, "Occupational Poisoning in Manufacture of Luminous Watch Dials," ibid., 92 (February 9, 1929, and February 16, 1929): 466–73, 552–59; Clark, *Radium Girls,* pp. 103–4; Sharpe, "New Jersey Radium Dial Painters," pp. 565–66, 569–70.

in the form of alpha particles, beta particles, or gamma rays, which are emitted as the atomic nuclei of radioactive elements undergo spontaneous disintegration. The products of this radioactive decay differ from one another in mass, electrical charge, and power of penetration. Gamma rays from natural radioactive decay and x-rays from machines—both energetic forms of light—can penetrate far inside the body from external sources. The more massive beta particles and the much heavier alpha particles, by contrast, do not penetrate deeply from outside. But if an element that emits alpha or beta particles is breathed or swallowed and lodges in internal organs, as occurred with the radium dial painters, it poses a serious biological risk.

When radiation passes through matter, it deposits energy and can alter the structure of atoms by stripping electrons from them. If this occurs, the total negative electrical charge of the electrons no longer balances the total positive charge of the protons in the atom's nucleus, and the atom is left with an electrical charge. Such charged atomic fragments are called ions. Those changes in the composition of the atom's nucleus can lead to mutations and ultimately to serious biological injury. Scientists recognized within a short time after the discovery of x-rays and radium that the damage caused by ionizing radiation depended on the dose received, and researchers later identified other variables that could affect the severity of injury, including the sensitivity of different body organs and the form of radiation absorbed.[9]

The growing evidence about the dangers of radiation in the early years of the twentieth century led to efforts to guard against needless or excessive exposure. As early as 1904, William H. Rollins, a Harvard-trained physician and a practicing dentist, reported that the hazards of x-rays could be reduced by using shielding methods to protect patients, physicians, and equipment manufacturers. He advised against the common practice of holding x-ray tubes against a patient's body and urged instead that the tubes be kept as far away as possible from those receiving treatment. Although the immediate impact of Rollins's recommendations was slight, professional groups gradually took steps to discourage improper or unwarranted use of radiation sources. In 1929 the American Medical Association passed a resolution condemning the use of x-rays to remove body

9. Merril Eisenbud, *Environmental Radioactivity* (New York: McGraw-Hill, 1963), pp. 11–29; Schubert and Lapp, *Radiation*, pp. 65–87, 98–136; Badash, *Radioactivity in America*, pp. 13, 43, 96–97, 217–23, 231–43; Martland, "Occupational Poisoning in Manufacture of Luminous Watch Dials," p. 552.

hair, and three years later it withdrew radium from its list of remedies approved for internal administration.[10]

Meanwhile, other organizations were attempting to encourage better safety practices for radiation workers. In 1913 the German Roentgen Society developed guidelines to shield x-ray operators from excessive exposure, and two years later the British Roentgen Society took similar action. In response to the significant increase in the use—and misuse—of x-rays during World War I, a group of British radiologists and physicians formed a radiation protection committee in 1921 and issued a series of more detailed recommendations for safeguarding workers from the harmful effects of x-rays and radium. During the 1920s growing recognition of the serious problems caused by overexposure to radium prompted professionals to devote even more attention to devising protective measures against 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 on 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 receiving radiation for therapeutic purposes.[11]

The primary difficulty that faced radiation protection organizations was the lack of a standard for defining a level of exposure that did not cause observable injury. During the 1920s scientists who sought a solution to this problem worked on a standard drawn from the most immediate and visible effect of exposure to radiation from an external source, an inflam-

10. Barton C. Hacker, *The Dragon's Tail: Radiation Safety in the Manhattan Project, 1942–1946* (Berkeley and Los Angeles: University of California Press, 1987), p. 23; Schubert and Lapp, *Radiation,* p. 103; Kevles, *Naked to the Bone,* pp. 51–52; Caufield, *Multiple Exposures,* pp. 13–14.

11. Lauriston S. Taylor, *Organization for Radiation Protection: The Operations of the ICRP and NCRP, 1928–1974* (Springfield, Va.: National Technical Information Service, 1979), pp. 1-001 to 4-001; Lauriston S. Taylor, *Radiation Protection Standards* (Cleveland: CRC Press, 1971), pp. 9–20; Daniel Paul Serwer, "The Rise of Radiation Protection: Science, Medicine, and Technology in Society, 1896–1935" (Ph.D. diss., Princeton University, 1977), pp. viii–ix, 38–44, 68–70, 174–81; Schubert and Lapp, *Radiation,* p. 18.

mation of the skin known as an erythema. They realized that this was an imprecise method for measuring exposure and judging the level of hazard, but it was the best approach available. In 1934 both the American and the international radiation protection committees concluded that they had sufficient information to take the unprecedented step of recommending a quantitative "tolerance dose" of external radiation. The levels they proposed were based on experience with and research on calculating the amount of radiation it took to cause an erythema. Levels were measured by a unit that had recently gained wide acceptance among professionals, the roentgen, which indicated the quantity of x-rays that would produce a specified degree of ionization under prescribed conditions. The American committee agreed on a tolerance dose of 0.1 roentgen per day of exposure to the whole body and 5 roentgens per day for fingers. The international committee set a whole-body limit of 0.2 roentgen per day.[12]

Although the international committee's tolerance dose for x-rays was twice as permissive as that of the U.S. committee, the discrepancy resulted not from any fundamental disagreement but from differences in rounding off similar figures calculated from available data. Both groups based their recommendations on evidence that they acknowledged was incomplete, and neither claimed that its tolerance dose was definitive. They believed that available information made their proposals reasonable and provided adequate safety for persons in normal health working in average conditions. The radiation experts did not regard the exposure levels as inviolable rules; a person who absorbed more than the recommended limits would not necessarily suffer harm. Both committees recognized that exposure to radiation in any amount might be detrimental, but they considered levels below the tolerance dose to be generally safe and unlikely to cause permanent damage to the "average individual." Their recommendations represented a tentative effort to establish practical guidelines that would reduce injuries to radiation workers. Although the tolerance doses were based on imperfect knowledge and unproven assumptions, they were an important advance in the theory and practice of radiation protection.[13]

In May 1941 the American committee took another important step

12. Taylor, *Organization for Radiation Protection,* pp. 4-012 to 4-025; Taylor, *Radiation Protection Standards,* pp. 13–19; Robert S. Stone, "The Concept of a Maximum Permissible Exposure," *Radiology* 58 (May 1952): 639–58; Caufield, *Multiple Exposures,* pp. 16–21; Kevles, *Naked to the Bone,* pp. 88–91.

13. Taylor, *Organization for Radiation Protection,* pp. 4-012 to 4-021; Stone, "Concept of a Maximum Permissible Exposure," p. 642; Lauriston S. Taylor, "The Development of Radiation Protection Standards (1925–1940)," *Health Physics* 41 (August 1981): 227–32.

when it recommended tolerance doses for the principal sources of hazard from internally deposited radiation, radium and its decay product, the radioactive gas radon. The death of Eben Byers and the afflictions of the radium dial painters triggered scientific research on how to calculate the exposure from "internal emitters" that enter the body, which was considerably more difficult than measuring external radiation. Those tragedies also spurred efforts to determine an acceptable level of exposure. Radium was employed primarily for medical purposes, but it was also used in a variety of industrial applications, including not only the infamous watch dials but also aircraft instruments, roulette wheels, and rayon fabric. Although empirical evidence was sparse, a team of researchers, prodded by the U.S. Navy's desire for safety standards for producing instruments with radium dials, agreed on a "body burden" for radium and a maximum concentration of airborne radon in workplaces. While acknowledging that the standards for both external radiation and internal emitters were far from definitive, radiation experts believed that the recommended dose limits offered an ample margin of safety for the relatively small number of persons exposed to occupational radiation.[14]

The findings and recommendations of the U.S. Advisory Committee on X-Ray and Radium Protection provided the basis for the radiological health programs of the Manhattan Project during World War II. The effort to build an atomic bomb presented formidable challenges to the scientists who sought to ensure radiation safety for those employed on the project. They adopted the recommendations of the Advisory Committee on X-Ray and Radium Protection for those working with radioactive materials, but they encouraged the practice of preventing any exposure at all. The objective could not always be achieved; despite an impressive safety record, cases of overexposure inevitably occurred. The most serious took place after the war, when two separate accidents each claimed the life of a researcher who received acute exposure to radiation.[15]

14. Robley D. Evans, "Inception of Standards for Internal Emitters, Radon and Radium," *Health Physics* 41 (September 1981): 437–48; Taylor, *Radiation Protection Standards,* pp. 19–20.

15. Hacker, *Dragon's Tail,* pp. 10–83. Peter Bacon Hales argues that Manhattan Project officials were so indifferent to radiation hazards that they caused an "epidemic" of radiation injuries and disease. But he offers little epidemiological (or even anecdotal) evidence to support such a conclusion. Hales criticizes Manhattan Project scientists and physicians for failing to distinguish between "radiation emitters" and "radiation itself." He does not make clear what he means by those terms or what distinction he thinks could have been made. See Hales, *Atomic Spaces: Living on the Manhattan Project* (Urbana: University of Illinois Press, 1997), pp. 273–98.

A New Era for Radiation Safety

The opening of the atomic age in the aftermath of the bombings of Hiroshima and Nagasaki made radiation safety a vastly more complex task. 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, as professionals in the field of radiation protection called themselves, had to consider the potential hazards of new radioactive substances about which even less was known. Further, the number of people exposed to radiation from the development of military and civilian uses of atomic energy was certain to grow dramatically. Radiation protection broadened from a medical and industrial issue of limited proportions to a public health question of, potentially at least, major dimensions.

In light of the radically different circumstances, both the American and the international radiation protection committees made organizational changes, modified their philosophy of radiological safety, and lowered their suggested exposure limits. Because its activities would inevitably extend beyond x-rays and radium, in 1946 the U.S. body adopted a new name, the National Committee on Radiation Protection (NCRP). It designated as its chairman Lauriston S. Taylor, who had served in that capacity since the establishment of the Advisory Committee on X-Ray and Radium Protection in 1929. Taylor, a Cornell-trained physicist who had conducted research on x-rays, was also the American representative on the International X-Ray and Radium Protection Committee. He remained a key figure in and prominent spokesman on radiation protection for more than sixty years. The NCRP also enlarged its membership and created several new subcommittees to study specific problems.[16]

Shortly after its reorganization in 1946, the NCRP reassessed its position on radiation exposure levels. Largely but not solely because of genetic considerations, it abandoned the concept "tolerance dose," which had suggested that exposure to radiation below the specified limits was generally harmless. The findings of H. J. Muller and other geneticists had indicated that reproductive cells were especially vulnerable to even small amounts of radiation and that mutant genes could be inherited from a parent with no obvious radiation-induced injuries. At least for genetic

16. Taylor, *Organization for Radiation Protection,* pp. 7-001 to 7-007; Taylor, *Radiation Protection Standards,* pp. 23–24.

effects, by the time World War II began most scientists had rejected the earlier consensus that exposure to radiation was biologically innocuous below a certain threshold.

The NCRP took action that reflected the newer view by replacing the term "tolerance dose" with "maximum permissible dose," which it thought better conveyed the idea that no quantity of radiation was certifiably safe. It defined the 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 explicitly acknowledged the possibility of suffering harmful consequences from radiation in amounts below the permissible limits. But the NCRP emphasized that the permissible dose was based on the belief that "the probability of the occurrence of such injuries must be so low that the risk would be readily acceptable to the average individual."[17]

In response to the anticipated growth of atomic energy programs and a substantial increase in the number of individuals who would be subject to injuries from radiation, the NCRP revised its recommendations on radiation protection. It reduced the permissible dose for whole-body exposure from external sources to 50 percent of the 1934 level. It measured the new whole-body limit of 0.3 roentgen per six-day workweek by exposure of the "most critical" tissue in blood-forming organs, gonads, and lenses of the eyes; higher limits applied for less sensitive areas of the body. Although the committee did not formally publish its recommendations on permissible limits from external sources until 1954, it had agreed on its main conclusions by 1948.[18]

The NCRP also devoted careful attention to internal emitters. In the postwar world the major peril of internal emitters resulted not so much from misuse of radium as from the growing numbers of and expanded work with radioactive isotopes. Nearly every element has three or more isotopes, which have identical chemical properties but differ slightly in their nuclear composition. Only a few isotopes are naturally radioactive. Most radioactive isotopes are produced artificially in particle-accelerating machines or in nuclear reactions. After a four-year study by one of its subcommittees, in 1953 the NCRP published a handbook that cited max-

17. Stone, "Concept of a Maximum Permissible Exposure," pp. 642–44; Schubert and Lapp, *Radiation,* chap. 9; Taylor, *Radiation Protection Standards,* pp. 22, 35; National Committee on Radiation Protection, *Permissible Dose from External Sources of Ionizing Radiation,* Handbook 59 (Washington, D.C.: National Bureau of Standards, 1954), pp. 1–2, 17–19, 26–27.

18. Taylor, *Radiation Protection Standards,* pp. 24–25; NCRP, *Permissible Dose from External Sources,* pp. 61–73.

imum permissible "body burdens" and concentrations in air and water of a long list of radioactive isotopes. The committee based its recommendations on existing knowledge of x-ray, gamma ray, and radium injuries, comparison with the effects of naturally occurring radioactive isotopes, experiments with animals, and clinical experience with humans. To provide an adequate margin of safety, it proposed permissible levels as low as one-tenth of the numerical values derived from the sketchy data then available.[19]

The activities of the international committee, which was renamed the International Commission on Radiological Protection (ICRP), followed the example of the NCRP in the early postwar years. It too enlarged its membership, formed several subcommittees to examine specific problems, and abandoned the use of "tolerance dose" in favor of "maximum permissible dose." The ICRP also conformed with the NCRP in its recommendations for internal emitters and in lowering its suggested occupational whole-body exposure limits from external sources to 0.3 roentgen per week.

In its only major departure from the NCRP, the ICRP proposed a maximum permissible dose of one-tenth the occupational levels in case of exposure by persons other than radiation workers. In view of the genetic effects of radiation and the possibility that the general population, or at least a sizable segment of it, might be exposed in accidental or emergency situations, the ICRP agreed in 1953 on reducing the occupational level by a factor of ten. Although the NCRP had established the same limit for minors under the age of eighteen, it refused to do so for the entire population. It wished to avoid the appearance of a double standard of protection, one for radiation workers and one for the general public. Although the ICRP's recommendations on the issue were arbitrary and tentative, they represented the first formal effort to establish radiation protection guidelines for population groups outside the "controlled areas" where the permissible doses for radiation workers applied.[20]

While the NCRP and the ICRP were reorganizing and revising their recommendations on radiation protection, a new federal agency, the

19. Taylor, *Radiation Protection Standards,* pp. 28–30; Taylor, *Organization for Radiation Protection,* pp. 7-001, 7-123; Schubert and Lapp, *Radiation,* pp. 120–22; National Committee of Radiation Protection, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water,* Handbook 52 (Washington, D.C.: National Bureau of Standards, 1953).

20. Taylor, *Organization for Radiation Protection,* pp. 7-087, 7-235; Taylor, *Radiation Protection Standards,* pp. 37–40; NCRP, *Permissible Dose from External Sources,* pp. 55–57.

United States Atomic Energy Commission (AEC) was established by the Atomic Energy Act of 1946 to manage the nation's atomic energy programs. Congress had agreed on atomic energy legislation only after a great deal of controversy over the role of the military in directing the activities of the AEC. The agency was headed by five commissioners appointed by the president for five-year terms and confirmed by the Senate. The 1946 law, passed as postwar disputes with the Soviet Union were intensifying into the cold war, emphasized the military applications of atomic energy. The principal functions that it assigned the AEC were the production of the "fissionable materials" that fueled nuclear bombs and the development and testing of new weapons. The 1946 act encouraged the AEC to investigate the civilian uses of nuclear technology, but this clearly was a secondary goal. The preoccupation with the military applications of the atom and the tight government monopoly of the technology ensured that progress in exploring the potential of peaceful nuclear energy would be, at best, sluggish.[21]

The exception to the bleak short-term prospects for civilian applications of atomic energy, and the example of the potential benefits of the technology that the AEC proudly proclaimed in its early years, was the widespread distribution of reactor-produced radioactive isotopes. Even before the AEC began operations in January 1947, the use of radioactive materials for civilian applications had received a great deal of attention. Under the auspices of the Manhattan Project, the first transfer of a "radioisotope" from a reactor occurred at Clinton Laboratories in Oak Ridge, Tennessee, on August 2, 1946, with considerable fanfare. E. V. Cowdrey, a physician from the Barnard Free Skin and Cancer Hospital of St. Louis, purchased a small amount of carbon 14 for use in cancer research as a crowd of one hundred fifty people watched and movie cameras rolled. The transaction was a front-page story in newspapers; the *Washington Post* reported that radioisotopes might lead to a cure for cancer within ten years. The isotopes program at Oak Ridge, one of the installations that the AEC inherited from the Manhattan Project, proved to be extremely popular. In August 1948 the AEC, hailing the program as "the first great contribution of the development of atomic energy to peacetime welfare," announced that isotopes from Oak Ridge were being used in more than one thousand projects in medicine, industry, agri-

21. Richard G. Hewlett and Oscar E. Anderson, Jr., *The New World, 1939/1946: Volume I of A History of the United States Atomic Energy Commission* (University Park: Pennsylvania State University Press, 1962), pp. 409–530.

Figure 1. E. V. Cowdrey (in light suit at right) speaks to reporters and other observers after the purchase of a reactor-produced radioisotope (in metal container) for medical research, August 2, 1946. (National Archives 434–OR–58–1870–5)

culture, and scientific research. The applications included measuring the thickness of materials, studying the wear qualities of engines, gears, and tires, and controlling weeds and insects. In the period from August 2, 1946, to May 31, 1954, the AEC shipped more than forty-seven thousand radioisotopes.[22]

The 1946 Atomic Energy Act assigned the AEC responsibility for protecting public health and safety from the hazards of radiation produced by nuclear fission. Its regulatory authority did not extend to radium, other naturally occurring sources of radiation, accelerator-produced isotopes, or x-rays. In its conduct of the isotopes program, the AEC was acutely

22. *Knoxville Journal,* August 3, 1946; *Washington Post,* August 3, 1946; United States Atomic Energy Commission, *Fourth Semiannual Report* (1948), pp. 5, 16; AEC, *Major Activities in the Atomic Energy Programs,* July 1954, p. 97; Henry N. Wagner, Jr., and Linda E. Ketchum, *Living with Radiation: The Risk, the Promise* (Baltimore: Johns Hopkins University Press, 1989), pp. 73–76.

mindful of the misuse of x-rays and radium that had led to tragedy for dial painters and others exposed to high doses. Drawing on the lessons of the not-too-distant past, it sought to enforce safe practices by imposing regulatory requirements for isotopes produced by reactors. It established licensing procedures for applicants to promote safe handling and use of radioactive materials under its jurisdiction.[23]

In its efforts to encourage radiation safety, the AEC drew on the recommendations of the NCRP. The AEC took a keen interest in the committee's activities because the NCRP's judgments affected its programs. The NCRP included among its membership officials from the AEC and other government agencies involved in radiation protection, but it was committed to maintaining the independence of its deliberations and conclusions. The relationship between the NCRP and the AEC was informal and generally cooperative, but at times it was uneasy. When the AEC learned that the NCRP was considering lowering permissible doses for radiation workers it pressed for information in advance of formal publication. Despite the reluctance of some members, the NCRP agreed to give the AEC preliminary guidance on what its new exposure levels were likely to be. The committee was less accommodating on another AEC request. In February 1947 the AEC asked to review an updated edition of an NCRP handbook on x-ray protection before its publication on the grounds that it might contain classified information. The request caused the NCRP "considerable concern." It replied that it would submit potentially sensitive material that the AEC was legally obliged to protect but found it unnecessary and undesirable to do so with publications on subjects outside the AEC's jurisdiction, such as the x-ray handbook. The AEC accepted this argument while reiterating its insistence that the NCRP guard against the inadvertent disclosure of classified information.[24]

While the AEC was promoting radiation safety in its programs, it was also seeking to gain more knowledge about the biological effects of radiation exposure. In June 1947 an AEC advisory panel, the Medical Board of Review, reported that the need for sponsoring research on radiation was "both urgent and extensive." This was especially true of the element plutonium, which fueled the atomic bomb that destroyed Nagasaki and the weapons that the AEC built after the war. It was apparent that the

23. Paul C. Aebersold, "Philosophy and Policies of the AEC Control of Radioisotopes Distribution," in *Radioisotopes in Medicine (ORO–125)*, ed. Gould A. Andrews, Marshall Brucer, and Elizabeth B. Anderson (Washington, D.C.: Government Printing Office, 1955), p. 1.

24. Taylor, *Organization for Radiation Protection*, pp. 7-008 to 7-010, 7-016, 7-032.