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High-Level Radioactive Waste Management: The Nuclear Dilemma

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HIGH-LEVEL RADIOACTIVE WASTE MANAGEMENT: THE NUCLEAR DILEMMA

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INTRODUCTION

Twenty-five years ago the proponents of nuclear power predicted that nuclear power would eventually provide an unlimited supply of clean, safe and inexpensive electrical energy.[1] Unfortunately, their optimism proved to be unfounded. Today, nuclear power may be competitive with coal and oil as an energy source, but it is certainly not cheap.[2] In addition, serious questions have been raised about the safety of nuclear plants, despite government assurances to the contrary.[3] Moreover, nuclear power is

1. Lewis Strauss, Chairman of the Atomic Energy Commission (AEC), predicted in 1954 that "our children will enjoy in their homes electrical power too cheap to meter. . . ." *quoted in* STEINHART, *The Impact of Technical Advice on the Choice for Nuclear Power, in* PERSPECTIVES ON ENERGY 239, 244 (L. Ruedisili & M. Firebaugh eds. 1978).

2. *See* Bupp, Derian, Donsimoni & Trietel, *The Economics of Nuclear Power,* 77 TECH. REV. 5 (1975); McCaull, *The Cost of Nuclear Power,* 18 ENVIRONMENT 11 (1976). *But see* Rossin & Rieck, *Economics of Nuclear Power,* 201 SCI. 582 (1972).

3. AEC, REACTOR SAFETY STUDY: AN ASSESSMENT OF ACCIDENT RISKS IN U.S. COMMERCIAL NUCLEAR POWER PLANTS, WASH 1400 (1975). In this AEC document, known as the Rasmussen Report, the aggregate risk for a fatality from nuclear accident was estimated to be $5x10^{-11}$ per reactor year. Although the safety record of nuclear plants has been relatively good, there have been numerous "incidents" and several serious accidents. In 1966, the Fermi plant near Detroit suffered a partial meltdown of the reactor core. Scott, *Fuel-Melting Incident at the Fermi Reactor on Oct. 5, 1966,* 12 NUCL. SAFETY 123 (1971); *see also* J. FULLER, WE ALMOST LOST DETROIT (1975). More recently, a fire caused the loss

anything but clean. Instead, virtually every stage in the nuclear fuel cycle produces radioactive waste. All of this "radwaste" is dangerous and much of it is also extremely long-lived. Furthermore, unlike conventional forms of waste, its toxicity cannot be reduced by chemical treatment. The only available "treatment" is either dilution and release into the environment or containment and storage under conditions designed to prevent exposure to human beings.

Public awareness of the serious problems associated with nuclear power has grown, and consequently, many people are now deeply concerned about the dangers of nuclear power. Public interest groups have challenged nuclear power programs in the courts on various environmental and safety grounds[4] and some anti-nuclear groups have underscored their protests by acts of civil disobedience.[5] Public concern is also reflected by state legislative attempts to limit or prohibit the future construction of nuclear power plants.[6]

These problems and the public responses to these problems have cast a shadow over the continued viability of nuclear power as an energy source in the United States.[7] Nevertheless, because of increasing energy use coupled with declining supplies of fossil fuels, the United States will probably be forced to rely on nuclear reactors to provide electric power at least until the end of the twentieth century. At the present 80 quadrillion BTUs of energy are used annually.[8] This figure will rise to 185 quadrillion BTUs

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of several emergency cooling systems at the TVA's Brown's Ferry plant. Rippon, *Brown's Ferry Fire*, 20 NUCL. ENGINEERING INT'L 461 (1975). The most serious nuclear accident occurred at Metropolitan Edison's Three Mile Island plant near Harrisburg, Pennsylvania in March, 1979. *A Nuclear Nightmare*, TIME, April 9, 1979, at 8.

4. *See, e.g.*, Nader v. NRC, 513 F.2d 1045 (D.C. Cir. 1975); Union of Concerned Scientists v. AEC, 499 F.2d 1069 (D.C. Cir. 1973); Scientists Inst. for Pub. Information v. AEC, 481 F.2d 1079 (D.C. Cir. 1973). Opposition to nuclear power is also increasing outside the United States. Sweet, *The Opposition to Nuclear Power in Europe*, 33 BULL. OF THE ATOM. SCIENTISTS 40 (Dec. 1977).

5. The Clamshell Alliance organized a large-scale occupation of a nuclear plant construction site at Seabrook, New Hampshire in April, 1977. More than 1400 of the protestors were arrested and jailed. 19 ENVIRONMENT 28, 28 (June/July 1977). The following year, in June, 1978, ten to twenty thousand individuals participated in a peaceful protest at Seabrook. 21 NUCL. NEWS 31 (Aug. 1978).

6. Some of these laws and proposals are discussed in Murphy & La Pierre, *Nuclear "Moratorium" Legislation in the States and the Supremacy Clause: A Case of Express Pre-emption*, 76 COLUM. L. REV. 392, 420-33 (1976).

7. In 1976 the Energy Research and Development Administration (ERDA) reduced its estimates of U.S. nuclear capacity in the year 2000 from 1,250,000 megawatts to 380,000-620,000 megawatts. Shea, *New Nuclear Policy Under the National Energy Plan*, 29 BAYLOR L. REV. 689, 710 (1977).

8. *Report of the Special Committee on Energy Law*, 10 NAT. RES. LAW. 655, 67· (1978).

by the end of the century if the historical growth rate of energy consumption continues.[9] The growth rate of electric power use is even greater. It has doubled every 10 years for the past 50 years.[10]

This rising energy demand is particularly critical in light of the fact that domestic production of fossil fuels has not kept pace with demand. Domestic oil production apparently peaked around 1970 and since then the United States has become increasingly dependent on oil from foreign sources.[11] The Trans-Alaskan Pipeline may ease this situation somewhat, but it will not significantly reduce the need for foreign oil. Natural gas production is also declining, although perhaps President Carter's proposed deregulation policy will reverse this trend.[12] Coal is the only fossil fuel that is still plentiful.[13] However, coal production has only risen at a modest rate since 1960, while the relative importance of coal as an energy source has declined steadily over the past 75 years.[14] Oil shale, solar, geothermal, tidal and fusion power may eventually satisfy America's energy needs, but none of them is sufficiently developed to have much impact in the immediate future.

President Carter's Energy Plan of 1977 attempts to deal with this situation by both reducing energy use and increasing available energy sources. However, neither of these strategies is likely to be completely effective. While conservation, or using energy more efficiently, may slow down the energy growth rate, it cannot reverse the historical trend completely.[15] To increase supplies, the President's plan relies heavily on increased coal production. Unfortunately, this increased usage of coal will cause severe environmental problems[16] and will require huge investments of capital.[17]

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9. FORD FOUNDATION ENERGY POLICY PROJECT, A TIME TO CHOOSE 14-15 (1974).

10. In the past 50 years electric power production in the United States has increased at an average rate of seven percent. ERDA, FINAL ENVIRONMENTAL STATEMENT, LIQUID METAL FAST BREEDER PROGRAM III F-32, ERDA 1535 (1975).

11. EXEC. OFFICE OF THE PRESIDENT, THE NATIONAL ENERGY PLAN 14 (1977).

12. Hayes, *Energy Resources Available to the United States, 1985 to 2000*, 203 SCI. 233, 234 (1979).

13. Harris, *Alternative Energy Resources: An International Approach*, 16 COLUM. J. TRANSNAT'L L. 386, 388 (1977).

14. GAO, THE LIQUID METAL FAST BREEDER REACTOR: PROMISES AND UNCERTAINTIES 7 (1975).

15. Even some proponents of a "no growth" policy expect a two-percent growth rate. *See, e.g.*, FORD FOUNDATION ENERGY POLICY PROJECT, A TIME TO CHOOSE 325, 333-34 (1974).

16. Strip mining causes severe land use and water pollution problems. *See* Begley & Williams, *Coal Mine Water Pollution: An Acid Problem with Murky Solutions*, 64 KY. L.J. 507, 509-12 (1976); Binder, *Strip Mining, the West and the Nation*, 12 LAND & WATER L. REV. 1, 5-21 (1977); Reitze, *Old King Coal and the Merry Rapists of Appalachia*, 22 CASE W. RES. L. REV. 650, 651-57 (1971). In addition, the burning of coal in power plants

For these reasons, coal cannot provide a complete solution to the energy needs of the United States.

Thus, the United States is faced with a nuclear dilemma. On the one hand, nuclear power seems to be the only significant energy source that is presently capable of meeting the country's electrical energy needs. On the other hand, it is uncertain whether the United States has the technological and managerial capability to make nuclear power reliable and safe. In view of this situation, the United States should begin to develop less dangerous alternatives such as solar power. But development of an efficient solar energy system may require 30 years or more. In the meantime, the United States must learn to live with nuclear power. The only way to deal with the nuclear dilemma in the short run is to reduce the risks and uncertainties associated with nuclear power. Some risks, of course, are inherent and unavoidable, but others can be reduced or eliminated by better planning and the development of new technology. Radioactive waste management is such an area. The risks associated with radioactive waste management are presently much greater than they should be. This is due in part to the failure of the United States to develop an effective and comprehensive program for managing radioactive waste.

This article examines the radioactive waste problem, with particular emphasis on high-level waste. In addition, the article will discuss some of the basic features of a responsible waste management program. It will also suggest how the federal government might begin to formulate such a program.

The intention of the article is to provide lawyers and members of the legal community with certain necessary technical skills and understanding to competently follow and actively take part in waste management debates concerning the continuing nuclear controversy. Because the nuclear industry is, and must be, regulated to ensure safety, lawyers, in creating procedures for decisionmaking, have played and will continue to play an active role in the field. It is important, therefore, that as lawyers we be able to develop a certain critical level of perspective for this interdisciplinary task.

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results in the emission of particulates and sulfur dioxide into the air, contributing to the air pollution problem. 1 F. GRAD, TREATISE ON ENVIRONMENTAL LAW § 2.01[2] (1977).

17. Blaustein, Gibbon & Brown, *Increasing Coal Production and Utilization Through the Next Decade: Some Technical Aspects of the Problem*, 14 DUQ. L. REV. 549 (1976).

I. RADIOACTIVE WASTE: AN OVERVIEW

A. *The Hazards of Radiation*

Substances which emit radiation in the form of subatomic particles or electromagnetic energy are said to be radioactive.[18] Most of these substances decompose by either alpha decay or beta decay. In alpha decay, which is associated with heavy elements like radium, uranium, radon and plutonium,[19] an alpha particle[20] is ejected from the parent nucleus, leaving a daughter product whose atomic number has decreased by two.[21] In beta decay, the emission of a beta particle[22] from the nucleus transforms one of the neutrons in the nucleus into a proton, thus increasing the element's atomic number by one unit.[23] In addition, gamma rays may be emitted under either alpha or beta decay.[24] The level of radioactivity is usually measured in curies,[25] while the rate of radioactive decay for a particular element is expressed in terms of its half-life.[26]

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18. Every atom is made up of a nucleus, composed of neutrons and protons, and electrons which orbit around the nucleus. Neutrons have no electric charge. Each proton has a positive charge, while each electron bas a negative charge of equal force. Neutrons and protons are roughly the same size, but electrons are about 1800 times smaller. Normally, an atom will have the same number of protons as electrons. Ions are atoms which have lost electrons and are positively charged. A particular element may have more than one isotope. In other words, nuclei of the same element would bave the same number of protons, but a different number of neutrons. For example, all isotopes of uranium have 92 protons, but uranium-235 has 143 neutrons, while uranium-238 has 146. Different isotopes of a particular element will exhibit the same chemical properties but may behave differently in other respects.

19. D. MILLER, RADIOACTIVITY AND RADIATION DETECTION I (1972).

20. An alpha particle consists of two neutrons and two protons and has a positive electric charge.

21. The term "atomic number" refers to the number of protons in the nucleus. The term "atomic mass" refers to the number of protons and neutrons in the nucleus.

22. Beta particles, which are negatively charged, are similar to the orbital electrons that surround an atomic nucleus.

23. J. HOGERTON, THE ATOMIC ENERGY DESKBOOK 64 (1963).

24. Gamma rays are not particles, but rather are forms of electromagnetic radiation without either positive or negative electric charge. MILLER, *supra* note 19, at 50.

25. The curie is a unit of radioactivity equal to 37 billion disintegrations per second. 10 C.F.R. § 20.5 (1978). A millicurie is .001 curie; a microcurie is 10^{-6} curie; a nanocurie is 10^{-9} curie and a picocurie is 10^{-12} curie. The specific activity of a substance is the number of curies per unit mass or volume. For example, the specific activity of radium-226 is 1 curie per gram. H. CEMBER, INTRODUCTION TO HEALTH PHYSICS 85 (1969).

26. The rate at which a radioactive element decays is expressed in terms of its half-life, which is the time it takes for one half of a given quantity of the substance to decay. The shorter the half-life, the higher the rate of radioactive disintegrations. If the product resulting from this radioactive decay process is unstable, it also decays and the process continues until a stable element is formed. CEMBER, *supra* note 25, at 88-89.

1. THE SOMATIC EFFECTS OF RADIATION

Radiation causes damage to living things at the cellular level by transferring energy into tissues by means of ionization.[27] Although they have little penetrating power, alpha particles cause intense ionization along their tracks. For this reason, alpha radiation is known as high linear energy transfer (LET) radiation. Generally speaking, internal exposure to alpha radiation is considerably more harmful than external exposure.[28] Beta particles ionize less intensely, but penetrate farther than alpha particles. Gamma rays penetrate very deeply into cellular tissue and produce ionization that is sparsely but uniformly distributed along the track of the radiation. External exposure to high-energy gamma radiation can be very dangerous;[29] lead or concrete shielding is required to protect against it.

The amount of ionization produced can be measured and this measurement, which is an expression of the dose used to describe the amount of energy transferred. The roentgen is a unit of exposure stated in terms of the energy's ionizing effect in air.[30] The rad is the unit of absorbed dose of energy in tissue.[31] The rem measures the relative biological damage from various types of radiation by multiplying the absorbed dose in rads by a relative biological effectiveness factor. One rad of beta or gamma radiation is equal to one rem, but one rad of alpha radiation is equivalent to ten rems. This rem measurement reflects the potential of alpha radiation to cause greater biological harm than the same level of beta or gamma radiation.[32]

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27. CEMBER, *supra* note 25, at 47. Alpha and beta particles react with the orbital electrons of atoms which they encounter and leave these atoms in an excited or ionized state. Gamma rays cause ionization by inducing one or more electrons to escape the atom altogether.

28. While it is clear that ionizing radiation causes damage at the cellular level, scientific knowledge concerning the mechanism by which this damage is produced is incomplete. Injury may occur when a protein or nucleic acid molecule is directly hit by ionizing radiation. However, damage may also result indirectly through the formation of reactive chemical fragments called free radicals that diffuse away from the ionized track. In particular, where cellular tissue is exposed to high LET radiation, free oxygen-hydrogen radicals are formed close enough together to enable them to combine with each other to form hydrogen peroxide, a powerful oxidizing agent which can affect molecules and cells some distance from the original path of the radiation. Not only are cells destroyed by this activity, but those cells which undergo significant physical or chemical changes may reproduce their perturbated forms. CEMBER, *supra* note 25, at 179-80.

29. Moore, *The Environmentalist and Radioactive Waste*, 49 CHI.-KENT L. REV. 55, 57 (1972).

30. A dose of one roentgen is sufficient to ionize about 2 billion atoms per cubic centimeter of air. J. SCHUBERT & R. LAPP, RADIATION 33 (1957).

31. 10 C.F.R. § 20.4(b) (1978).

32. *Id.* § 20.4(c) (1978). A millirem is one-thousandth of a rem.

a. External exposure to radiation

The most immediate and dramatic biological effects are produced by whole-body exposure to high doses of penetrating radiation. Doses over 600 rems usually cause death within a few weeks of exposure.[33] Doses of 150 to 600 rems may also be fatal, but the chances of recovery are better.[34] The victim may suffer radiation sickness at exposures as low as 100 rems.[35]

External exposure to high but non-fatal levels of radiation may also have long-term consequences. Leukemia can result from sublethal levels of total body irradiation. There was a sharp increase in leukemia among the Japanese atomic bomb survivors, which reached a peak in 1951 when the disease rate of survivors was eleven times higher than that of the nonexposed population.[36] Children irradiated in the womb also have a higher leukemia rate,[37] as do radiologists and others who use radiation in their medical practice.[38] Atomic bomb survivors also had higher rates of breast, bone, lung, prostate and other cancers which suggests that these diseases can be induced by radiation exposure.[39] External exposure to x-rays or gamma rays has also caused cataracts,[40] and thyroid cancer.[41] Many of the substances in radioactive waste emit penetrating gamma radiation and, therefore, protection against external exposure is essential.

b. Internal exposure to radiation

Even very low levels of radiation exposure can be dangerous when radioactive substances enter the body by ingestion, inhala-

33. Burch, *Ionizing Radiation and Life Shortening*, 10 NUCL. SAFETY 161, 162 (1969).

34. J. SCHUBERT & R. LAPP, RADIATION 45-46 (1957).

35. Cohen, *Impacts of the Nuclear Energy Industry on Human Health and Safety*, 64 AM. SCIENTIST 550, 550 (1976). Even single whole body doses as low as 50 rems will cause a dramatic temporary drop in the number of white cells in the victim's blood. R. FAULKNER, THE SILENT BOMB 67 (1977).

36. Lewis, *Leukemia and Ionizing Radiation*, 125 SCI. 965, 967-69 (1957); Miller, *Delayed Radiation Effects in Atomic Bomb Survivors*, 166 SCI. 569, 571 (1969).

37. MacMahon, *Pre-natal X-Ray Exposure and Childhood Cancer*, 28 J. NAT'L CANCER INST. 1173 (1962).

38. Seltser & Sartwell, *The Influence of Occupational Exposure to Radiation on the Mortality of American Radiologists and Other Medical Specialists*, 81 AM. J. EPIDEMIOLOGY 2 (1966).

39. Barnaby, *The Continuing Body Count at Hiroshima and Nagasaki*, 33 BULL. OF THE ATOM. SCIENTISTS 48, 53 (Dec. 1977); Morgan, *Cancer and Low-Level Ionizing Radiation*, 34 BULL. OF THE ATOM. SCIENTISTS 30, 32 (Sept. 1978).

40. Radnot, *Effect of Irradiation on the Eye Lens*, 7 ATOM. ENERGY REV. 129, 131-32 (1969).

41. Hempelman, *Neoplasms in Persons Treated with X-Rays in Infancy for Thymic Enlargement, A Report of the Third Follow-Up Survey*, 38 J. NAT'L CANCER INST. 317 (1967).

tion or injection. Some radioactive substances, if absorbed internally, spread diffusely throughout the body and thus result in total body irradiation.[42] Others, because of their biochemical properties, concentrate in certain types of tissue and irradiate these areas. A number of these substances are found in radioactive waste. For example, radium, radioactive strontium or barium, which are chemically similar to calcium, are incorporated into the mineral structure of the bone when ingested, where they often cause bone cancer.[43] Plutonium also deposits in bone,[44] while radioactive iodine accumulates in the thyroid gland.[45]

Inhaled radioactive substances may cause lung cancer. In particular, radon decay products contained in dust particles have caused lung cancer in uranium miners.[46] The same hazard exists with respect to plutonium: inhaled small radioactive dust particles which become embedded in the lower reaches of the lungs irradiate the surrounding tissues and may eventually cause cancer.[47]

2. THE GENETIC EFFECTS OF RADIATION

Exposure to ionizing radiation can cause genetic changes by altering the molecular structure of genes. Although there is very little data on genetic damage to human beings,[48] the probability of mutation appears to be directly proportional to the amount of energy absorbed by the germ cells.[49] Therefore, small doses of radiation given to large numbers of individuals may introduce as many mutant genes into the population as large doses to small numbers of individuals do.[50] For this reason, exposure to low levels of radiation is a significant problem, particularly when such exposure is chronic.[51]

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42. M. EISENBUD, ENVIRONMENTAL RADIOACTIVITY 481-82 (2d ed. 1973).

43. S. GLASSTONE, SOURCEBOOK ON ATOMIC ENERGY 739 (3d ed. 1967).

44. EISENBUD, *supra* note 42, at 26-28.

45. Moore, *supra* note 29, at 58.

46. EISENBUD, *supra* note 42, at 28-32.

47. Blair & Thompson, *Plutonium: Biomedical Research*, 183 SCI. 715, 717-18 (1974); Edsall, *Toxicity of Plutonium and Some Other Actinides*, 32 BULL. OF THE ATOM. SCIENTISTS 26, 29-30 (Sept. 1976).

48. *See generally* Sankaranarayanan, *Recent Advances in the Assessment of Genetic Hazards of Ionizing Radiation*, 12 ATOM. ENERGY REV. 47 (1974).

49. Muller, *Genetic Damage Produced by Radiation*, 121 SCI. 837 (1955).

50. EISENBUD, *supra* note 42, at 35.

51. Ionizing radiation not only causes genes to mutate, but may also break up the chromosomes in which genes are carried. If such a break occurs, a germ cell may be formed that lacks an essential part of the gene complement. Although the germ cell may take part in the fertilization process, the ensuing embryo is usually incapable of full development.

B. The Nuclear Fuel Cycle

Human beings and other living things are exposed to radiation from both natural and man-made sources. Cosmic radiation and radiation from terrestrial sources such as granite account for most of the external exposure from natural sources.[52] Internal exposure may occur from natural radioactive substances in the body such as potassium-40.[53]

X-rays and radioactive substances used for diagnostic purposes by the medical profession are presently the greatest sources of radiation.[54] However, fallout from nuclear weapons testing also contributes to both external and internal exposure.[55] Finally, various phases of the nuclear fuel cycle generate substantial quantities of radioactive material, mostly in the form of waste by-products. Unless properly managed, this radioactive waste can pose a serious threat to the public.

The nuclear fuel cycle is the process by which nuclear fuel such as uranium is produced, used to generate electric power in nuclear reactors, and eventually disposed of. The cycle can be split into two parts: the "front-end" of the cycle and the "back-end." Mining and milling are first steps of the front-end of the nuclear fuel cycle. Uranium is mined primarily in the western United States, where the ore is extracted by both deep mine and surface mining techniques.[56] Runoff water from mining operations contains natural uranium, thorium, radium and small concentrations of other radioactive substances.[57] At mills, which are usually located near the mines, the ore is crushed, ground and chemically treated to extract and concentrate the uranium. The resulting product, known as yellowcake, contains about 70 percent uranium oxide.[58] The milling process itself produces large quantities

52. E. POCHIN, ESTIMATED POPULATION EXPOSURE FROM NUCLEAR POWER PRODUCTION AND OTHER RADIATION SOURCES 16 (Nucl. Energy Agency 1976).

53. NCRP, *Natural Background Radiation in the United States*, 17 NUCL. SAFETY 470 (1976).

54. EPA, NATURAL RADIATION EXPOSURE IN THE UNITED STATES 1960-2000, at 41, ORP/SID 72-1 (June 1972). Medical diagnosis accounts for over 90 percent of all exposure to man-made sources of ionizing radiation in America. Morgan, *Adequacy of Present Standards of Radiation Exposure*, 1 ENVT'L AFF. 91, 93 (1971).

55. Unrush, *Nuclear Radiation—Sources and Impact*, 24 NUCL. TECH. 314, 316-21 (1974).

56. ERDA, ALTERNATIVES FOR MANAGING WASTE FROM REACTORS AND POST-FISSION OPERATIONS IN THE LWR FUEL CYCLE 2.1, ERDA 76-43 (May 1976) [hereinafter cited as ALTERNATIVES].

57. Blaylock & Witherspoon, *Radiation Doses and Effects Estimated For Aquatic Biota Exposed to Radioactive Releases from LWR Fuel-Cycle Facilities*, 17 NUCL. SAFETY 351, 352 (1976).

58. Larson, *International Economic Implications of the Nuclear Fuel Cycle*, 14

of radioactive wastes known as tailings.

Following the mining and milling, the yellowcake is sent to a plant where it is converted into uranium hexafluoride gas.[59] Conversion operations result in small amounts of radium, which have separated from the yellowcake during the purification operations.[60]

After conversion, the gas is shipped in canisters to the enrichment facilities[61] to increase the concentration of the uranium-235 (U-235) isotope.[62] The gas diffusion process is the most common enrichment technique used. Uranium hexafluoride gas is forced by pressure differential through an array of porous membranes. The lighter U-235 atoms diffuse faster than the U-238 atoms. This process must be repeated more than a thousand times to increase the concentration of U-235 from 0.7% to 3%.[63] Small amounts of natural uranium are produced in the enrichment process which are released along with other gaseous and liquid effluents.[64]

The next step of the nuclear fuel cycle is fabrication, where the enriched uranium hexafluoride is converted into uranium dioxide powder. The powder is then formed into ceramic pellets, which are enclosed within metallic tubes or cladding. These tubes are assembled into fuel elements and sent to the nuclear power plant.[65] Fabrication produces waste in the form of small quantities of thorium-234 and uranium in liquid waste solution, which is discharged into settling ponds.[66]

At the nuclear power plant, the uranium fuel is fissioned to produce heat which produces steam which drives electric generators. During its operation, a nuclear power plant produces sub-

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ATOM. ENERGY L.J. 108, 110 (1972).

59. *Id.* at 111.

60. *Storage and Disposal of Radioactive Waste, Hearings Before the Joint Committee on Atomic Energy*, 94th Cong., 1st Sess. 222 (1975).

61. COMMITTEE ON GOVERNMENT OPERATIONS, NUCLEAR POWER COSTS, H.R. Doc. No. 95-1090, 95th Cong., 2d Sess. 126 (1978).

62. Most heavy nuclei are fissionable—that is, they will split apart when struck by a fast neutron. However, U-235 is the only naturally occurring uranium isotope which is fissile—that is fissionable by slow, or thermal, neutrons. No chain reaction would produce enough fast neutrons to sustain itself. Instead it produces neutrons of various speeds. Therefore, the "fuel" must be capable of fissioning when struck by slow as well as fast neutrons if it is to sustain a chain reaction. T. GREENWOOD, G. RATHJENS & J. RUINA, NUCLEAR POWER AND PROLIFERATION 3 (Adelphi Paper No. 130) (1976).

63. Larson, *International Economic Implications of the Nuclear Fuel Cycle*, 14 ATOM. ENERGY L.J. 108, 112-13 (1972).

64. AEC, ENVIRONMENTAL SURVEY OF THE URANIUM FUEL CYCLE D-5, WASH 1248 (April 1974).

65. Larson, *International Economic Implications of the Nuclear Fuel Cycle*, 14 ATOM. ENERGY L.J. 108, 119 (1972).

66. AEC, ENVIRONMENTAL SURVEY OF THE URANIUM FUEL CYCLE E14-16, WASH 1248 (April 1974).

stantial quantities of solid low-level radioactive waste and routinely discharges other radioactive substances into the water and air.[67]

High-level radioactive waste is largely associated with the "back-end" of the nuclear fuel cycle—that is treatment of nuclear fuel after it leaves the reactor. Treatment can be done in two ways: under the throwaway or once-through alternative, spent fuel assemblies are removed from the reactor and stored or disposed of without any physical or chemical alteration. The spent fuel is highly radioactive and thus may be considered as one form of high-level radioactive waste. Under the second alternative, spent fuel is recycled in order to recover plutonium and uranium for reuse as nuclear fuel.

If the nuclear fuel is recycled, the back-end of the nuclear fuel cycle begins with reprocessing.[68] At the reprocessing plant, plutonium and uranium are recovered from the spent fuel and returned to fuel fabrication plants for use in mixed oxide fuel. Reprocessing plants generate a variety of radioactive wastes, including tritium, carbon-14, iodine-129 and krypton, which are released into the atmosphere.[69] Solid and liquid low-level wastes are also produced, some of which are contaminated with transuranic elements. In addition, the remains of the fuel cladding, with their highly penetrating radiation, must be disposed of.[70] The most serious waste management problem, however, is the high-level waste produced by the extraction process. After reprocessing, the nuclear fuel cycle begins anew with conversion and enrichment of uranium and fuel fabrication of plutonium. Because of these problems with the recycling alternative, there are at the present time no commercial fuel reprocessing plants in the United States, although military reprocessing facilities have operated since World War II.

C. Problem Areas

This article is primarily concerned about high-level nuclear waste. However, this is not the only source of radiation danger

67. Cohen, *Impacts of the Nuclear Energy Industry on Human Health and Safety,* 64 AM. SCIENTIST 550, 551-53 (1976).

68. For a discussion of the status of commercial reprocessing in the United States see text accompanying notes 199-203 *infra.*

69. *See generally,* Palms, Veluri & Boone, *The Environmental Impact of I^{129} Released by a Nuclear Fuel-Reprocessing Plant,* 16 NUCL. SAFETY 593 (1978); Tadmore, *Deposition of Kr^{85} and Tritium Released from a Nuclear Fuel Reprocessing Plant,* 24 HEALTH PHYSICS 37 (1973); Veluri, Boone & Palms, *The Environmental Impact of C^{14} Released by a Nuclear Fuel-Reprocessing Plant,* 17 NUCL. SAFETY 580 (1976).

70. *See* text accompanying notes 134-36 *infra.*

from the nuclear fuel cycle. Uranium mill tailings, routine emissions from nuclear power plants, and low-level waste disposal sites also constitute potential hazards to the public. In each of these "problem areas" serious controversies have arisen about the sufficiency of the regulatory standards and the effectiveness of management practices.

1. URANIUM MILL TAILINGS

Uranium mill tailings are an undeniable threat to human safety. An estimated 140 million tons of uranium tailings have now accumulated at various mill sites.[71] These wastes contain radium, as well as such decay products as radon, thorium, polonium and radioactive isotopes of bismuth and lead. The wind releases radon gas and airborne particulates from piles of tailings. These radon decay products, particularly polonium-210 and lead-210, are deposited on crops and thus enter the food chain.[72] Radioactive elements may also be leached from tailings piles into surface and ground water by precipitation and by surface water runoff. In addition, gamma radiation from tailings piles may be harmful to those in the immediate vicinity.[73] Unless controlled, uranium tailings piles can remain hazardous for thousands of years.[74]

Unfortunately, the radiation hazards associated with uranium mill tailings have not always been appreciated. In Grand Junction, Colorado, for example, about 200,000 tons of radioactive tailings were given away to local builders for use as fill between 1952 and 1965.[75] Measurements in some homes and schools built on this fill revealed a threefold increase in external gamma radiation levels.[76] Evidence of a higher incidence of birth defects and cancer in the area was also found.[77] Eventually, the federal

71. INTERAGENCY REVIEW GROUP ON WASTE MANAGEMENT, REPORT TO THE PRESIDENT 14, TID 29,442 (Mar. 1979). About 10 to 15 million tons are produced annually by uranium mills in the United States. *Id.* at 80.

72. NUCLEAR ENERGY POLICY STUDY GROUP, NUCLEAR POWER: ISSUES AND CHOICES 174 (1977) [hereinafter cited as ISSUES AND CHOICES].

73. EPA, POTENTIAL RADIOLOGICAL IMPACT OF AIRBORNE RELEASES AND DIRECT GAMMA RADIATION TO INDIVIDUALS LIVING NEAR INACTIVE URANIUM MILL TAILINGS PILES 3, EPA 520/1-76-001 (1975).

74. Goldsmith, *Radiological Aspects of Inactive Uranium Milling Sites: An Overview*, 17 NUCL. SAFETY 722, 722 (1976).

75. Note, *Radioactive Waste: A Failure in Governmental Regulation*, 37 ALB. L. REV. 97, 98 (1972).

76. Holdren, *Hazards of the Nuclear Fuel Cycle*, 30 BULL. OF THE ATOM. SCIENTISTS 14, 17 (Oct. 1974).

77. *Hearings on the Use of Uranium Mill Tailings for Construction Purposes Before the Subcomm. on Raw Materials of the Joint Comm. on Atomic Energy*, 92nd Cong., 1st Sess. 281 (1971).

government and the state of Colorado had to spend millions of dollars to replace the radioactive fill at Grand Junction.[78]

Government regulations now require that uranium mills control tailings by covering the piles with compacted dirt in order to prevent exposure to wind blown particles and gamma radiation.[79] However, this was not done properly at many of the older milling plants which are now abandoned. About 20 percent of all uranium tailings are located at twenty-three inactive mill sites and most of these sites will require remedial action to protect against radiation exposure.[80] Congress has enacted the "Uranium Mill Tailings Radiation Control Act of 1978,"[81] which authorizes the Department of Energy (DOE) to enter into cooperative agreements with individual states concerning tailings and other material at existing sites, and provides for regulation of uranium mill tailings under the Atomic Energy Act.[82] The new statute also permits the Environmental Protection Agency (EPA) to develop rules to protect against the health hazards of tailings[83] and provides funds for cleanup operations at inactive sites.[84]

2. ROUTINE EMISSIONS FROM NUCLEAR POWER PLANTS

Another stage in the nuclear fuel cycle which presents grave dangers to human safety and must be addressed is the routine emissions problem. Nuclear power plants routinely discharge small amounts of radioactive wastes into the air and water.[85] Radioactive gases, such as iodine, krypton and xenon, are released into the primary reactor coolant stream and eventually find their way into the environment.[86] Iodine-131, a gamma ray emitter, is perhaps the most dangerous of these substances. Liq-

78. Pub. L. No. 92-314, 86 Stat. 226 (1972); Pub. L. No. 95-236, 92 Stat. 38 (1978).

79. Comment, *Uranium Mill Tailings: The Problem of Disposal—With a Special Look at New Mexico*, 18 NAT. RES. J. 431, 431-32 (1978).

80. Goldsmith, *Radiological Aspects of Inactive Uranium Milling Sites: An Overview*, 17 NUCL. SAFETY 722, 724 (1976).

81. Pub. L. No. 95-604, 92 Stat. 3021 (1978).

82. Pub. L. No. 95-604, § 103.

83. Pub. L. No. 95-604, adding § 275 to Atomic Energy Act.

84. Pub. L. No. 95-604, § 107.

85. Cohen, *Impacts of the Nuclear Energy Industry on Human Health and Safety*, 64 AM. SCIENTIST 550, 551-53 (1976). The average whole body dose from nuclear power plants, however, was only .003 millirems in 1970 and is not expected to rise above .4 millirems by the year 2000. Unrush, *Nuclear Radiation—Sources and Impact*, 24 NUCL. TECH. 314, 321 (1974).

86. About one or two fuel pins per thousand develop tiny leaks in their cladding during the operation of the reactor, releasing into the water some of the radioactive material that has diffused out of the fuel pellets. Cohen, *Impacts of the Nuclear Energy Industry on Human Health and Safety*, 64 AM. SCIENTIST 550, 551 (1976).

uid scrubbers, silver reactors and charcoal beds capture most of the radioactive iodine,[87] but some of it still escapes into the environment. It is absorbed into the body through the skin, lungs, and digestive tract, and eventually accumulates in the thyroid gland.[88] Although its half-life is only eight days, it has a biological half-life of 138 days.[89]

Krypton and xenon are also present in the coolant water. At the present time, xenon and krypton gases are separated from the steam when it is condensed to return to the reactor as water.[90] After being retained in holding tanks for a short time, these radioactive gases are vented through the power plant's stack.[91] Xenon does not present much of a problem because it has a short half-life, but krypton, which has a 10.73-year half-life, is a long-term danger. Although krypton is an inert gas and thus does not react chemically, it can enter the body by diffusion and emit both beta and gamma radiation.[92]

Exposure of the ambient air in the space between a reactor and its shielding to neutrons produced by the nuclear reaction results in the formation of radioactive carbon, nitrogen, oxygen and argon. Most of these substances have very short half-lives,[93] but radioactive carbon-14 which escapes as carbon dioxide gas, is a long-lived beta ray emitter which enters the human body through inhalation and through ingestion of food.[94]

The coolant water also contains corrosion products[95] which have been activated by neutrons. Most of this material is removed and concentrated by filters or demineralizers.[96] The re-

87. G. EICHHOLZ, ENVIRONMENTAL ASPECTS OF NUCLEAR POWER 308-11 (1976).

88. Moore, *The Environmentalist and Radioactive Waste*, 49 CHI.-KENT L. REV. 55, 58 (1972).

89. The biological half-time is the time it takes for the amount of a particular substance in the body to decrease to half of its initial value due to elimination by natural biological processes. J. SCHUBERT & R. LAPP, RADIATION 124-25 (1957).

90. Evans, *Sierra Club Involvement in Nuclear Power: An Evolution of Awareness*, 54 ORE. L. REV. 607, 615 (1975).

91. EICHHOLZ, *supra* note 87, at 313-14.

92. EISENBUD, *supra* note 42, at 485.

93. S. GLASSTONE, SOURCEBOOK ON ATOMIC ENERGY 758 (3d ed. 1967). Nitrogen-16 has a half-life of 7.3 seconds; that of oxygen-19 is 30 seconds, while that of argon-41 is 1.8 hours. The radioactive half-life of carbon-14, on the other hand, is 5,700 years. *See* Wright, *Disposal of Radioactive Wastes*, 10 ATOM. ENERGY L.J. 239, 258 (1968).

94. Veluri, Boone & Palms, *The Environmental Impact of C^{14} Released by a Nuclear Fuel-Reprocessing Plant*, 17 NUCL. SAFETY 580-83 (1976).

95. Corrosion products result from the interaction of water or steam with fuel cladding or other metal reactor components.

96. Davis, *Taming the Technological Tyger—The Regulation of the Environmental Effects of Nuclear Power Plants—A Survey of Some Controversial Issues*, 1 FORDHAM URB. L.J. 149, 154 (1972).

maining low-level waste water is stored to permit decay of short-lived substances, then is diluted and released into the environment.[97]

Another significant waste product in the water is tritium, an isotope of hydrogen, which has a half-life of 12.36 years.[98] Tritium reacts with oxygen to form tritrated water, a radioactive compound which is chemically identical to ordinary water, and which is discharged from the plant as water or water vapor.[99] Tritium is a beta emitter, and can be ingested in food and water or absorbed through the skin.[100] At the present time, no practical means of controlling tritium discharges has been developed.[101]

The Nuclear Regulatory Commission (NRC) and the EPA share the responsibility for regulating these routine emissions from nuclear power plants. The NRC has imposed radiation standards to deal with radiation inside nuclear installations.[102] Since December 1975, the NRC has imposed an overall standard on licensees to limit effluents to "as low as is reasonably achievable" (ALARA). The ALARA standard takes into account the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations. All of these factors are considered in relation to the use of atomic energy in the public interest.[103] The NRC regulations now specify numerical guides for design objectives and impose conditions for nuclear operations to meet the ALARA standard.[104]

Since 1970, the EPA has been responsible for establishing

97. *Id.*

98. The ordinary hydrogen nucleus consists of a single proton, but the tritium nucleus is made up of one proton and two neutrons. R. DORF, ENERGY RESOURCES & POLICY 478 (1978).

99. Rohwer & Wilcox, *Radiological Aspects of Environmental Tritium*, 17 NUCL. SAFETY 216 (1976). *See also* Elwood, *Ecological Aspects of Tritium Behavior in the Environment*, 12 NUCL. SAFETY 326 (1971).

100. EICHHOLZ, *supra* note 87, at 326.

101. Baram, *Radiation from Nuclear Power Plants: The Need for Congressional Directives*, 14 HARV. J. LEGIS. 905, 915 (1977).

102. 2 F. GRAD, TREATISE ON ENVIRONMENTAL LAW § 6.02 (1973); Eisenbud, *Radiation Standards and Public Health*, 12 NUCL. SAFETY 1 (1971). Maximum permissible dose rates expressed in rems per calendar quarter have been promulgated by the NRC for whole-body exposure and for partial-body exposure of persons inside such installations. 10 C.F.R. § 20.3 (1978). In addition, there are regulations which prohibit the exposure of any individual to airborne radioactive materials, which are defined as radioactive materials dispersed in the air in the form of dusts, fumes, mists, vapors, or gases. 10 C.F.R. § 20.3(a)(2) (1978).

103. 10 C.F.R. § 20.1(c) (1978). *See* Note, *The Energy Crisis: "Reasonable Assurances" of Safety in the Regulation of Nuclear Power Facilities*, 55 J. URB. L. 371, 378 (1978).

104. 10 C.F.R. § 50, app. I (1978). *See* Baram, *Radiation from Nuclear Power Plants: The Need for Congressional Directives*, 14 HARV. J. LEGIS. 905, 925 (1977).

standards to protect the general environment from radiation hazards.[105] The term "general environment" includes the total terrestrial, atmospheric and aquatic environments of areas near sites in which any operation which is part of the nuclear fuel cycle is conducted. Until relatively recently, the EPA followed the old Atomic Energy Commission (AEC) standards, but in January of 1977, it issued new, tougher standards regulating many aspects of the nuclear fuel cycle.[106] These new standards are twenty times more restrictive than earlier standards, and include provisions limiting the release of long-lived radioactive substances throughout the entire nuclear fuel cycle. They require that operations be conducted so as to provide reasonable assurances that the total quantity of radioactive materials entering the general environment from the uranium fuel cycle, per gigawatt-year[107] of electrical energy produced by the fuel cycle, will contain less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic substances[108] with half-lives greater than one year.[109] These standards become effective on December 1, 1979, except for the krypton-85 and iodine-129 requirements, which will become effective January 1, 1983.[110] These EPA standards will greatly reduce the previously acceptable level of routine radioactive emissions from nuclear power plants.

The 1977 amendments to the Clean Air Act have given the EPA additional powers over discharges of radioactive substances into the atmosphere.[111] Specifically, the law provides that the EPA Administrator must determine, by August 7, 1979, whether emissions of various radioactive pollutants will endanger the pub-

105. Reorganization Plan No. 3, 35 Fed. Reg. 15,623 (1970).

106. 40 C.F.R. § 190.02(c) (1978). The EPA regulations specify the radiation levels which are environmentally acceptable for normal operations of the uranium fuel cycle. The uranium fuel cycle includes milling, chemical conversion of uranium, isotopic enrichment of uranium, fabrication of uranium fuel, generation of electricity by a light-water-cooled nuclear power plant, and the reprocessing of spent uranium fuel. The uranium fuel cycle excludes mining operations, operations at waste disposal sites, transportation of any radioactive material in support of these operations, and the reuse of recovered non-uranium special nuclear materials and by-product materials from the cycle.

107. A megawatt is 1000 kilowatts or 1 million watts of electrical power. Most nuclear plants are rated at 1000 megawatts—that is, they can generate 1000 megawatts of electrical energy when operating at full capacity. A gigawatt is 1000 megawatts. A 1000-megawatt plant is capable of servicing a city of one million people. Gilinsky, *Military Potential of Civilian Nuclear Power, in Nuclear Proliferation: Prospects for Control* 41, 46 (B. Boskey & N. Willrich eds. 1978).

108. A transuranic element is an element which is heavier than uranium.

109. 40 C.F.R. § 190.10(b) (1978).

110. 40 C.F.R. § 190.12 (1978).

111. Pub. L. No. 95-95, 91 Stat. 719 (1977).

lic health. If the Administrator determines that a pollutant will endanger the public health, the pollutant will become subject to the Clean Air Act. Before including any source material, special nuclear material, or byproduct material[112] within the Act, however, the EPA must consult with the NRC. Within six months after including any radioactive materials under the Act, the two agencies must adopt procedures to minimize duplication of effort with regard to regulation of emissions from facilities under the jurisdiction of the NRC.[113] The ultimate effect of this legislation on nuclear power plants is uncertain, but could be significant.

3. LOW-LEVEL WASTE

Low-level waste is yet another phase of the nuclear fuel cycle which presents hazards to human safety. A typical 1000-megawatt nuclear power plant produces about 2000 to 4000 cubic feet per year[114] of contaminated glassware, containers, clothing, gloves, tools, filters, paper, rags, and other low-level solid waste.[115] This waste is usually placed in drums and filled with concrete for disposal. Liquid wastes from laundry and decontamination solutions are also produced. These wastes are immobilized in absorbant material such as vermiculite, silica gels, plaster of paris, or clay, and are then fixed in asphalt or cement for permanent disposal.[116]

112. *See* 42 U.S.C. §§ 2092, 2111, 2073 (1976). "Source material" is defined as (1) uranium, thorium, or any other material which is determined by the Commission pursuant to the provisions of section 2091 of this title to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the Commission may by regulation determine from time to time. 42 U.S.C. § 2014(z) (1976). "Byproduct material" is defined as any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material. 42 U.S.C. § 2014(e) (1976). "Special nuclear material" is defined as (1) plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material wbich the Commission, pursuant to tbe provisions of section 2071 of this title, determines to be special nuclear material, but does not include source material; or (2) any material artifically enriched by any of the foregoing, but does not include source material. 42 U.S.C. § 2014(aa) (1976).

113. 42 U.S.C. § 7422 (1976). The Nuclear Regulatory Commission has been given a limited veto power over standards or emission limitations set by EPA or by any state under an implementation plan pursuant to the Act. If, after opportunity for a public hearing, NRC decides that the application of an emission standard to a source or facility within the jurisdiction of the Commission would endanger public health or safety, the standard will not apply to the source or facility unless the President overrules the NRC decision. 42 U.S.C. § 7422(c)(3) (1976).

114. EICHHOLZ, *supra* note 87, at 341. This amount of waste would weigh 60 to 100 tons and would require 270 to 540 55 gallon drums for disposal. *Id.*

115. Lennemann, *U.S. Atomic Energy Commission Radioactive Waste Burial Program*, 9 ATOM. ENERGY L.J. 1, 25 (1967).

116. NRC, A CLASSIFICATION SYSTEM FOR RADIOACTIVE WASTE DISPOSAL—WHAT WASTE GOES WHERE? 4-5, NUREG 0456 (June 1978).

As of 1978, about 15.8 million cubic feet of solid low-level radioactive waste was buried at commercial disposal sites.[117] This figure has been growing at the rate of 2 to 3 million cubic feet per year.[118] Another 50.8 million cubic feet of solid low-level waste has been produced by military programs and buried at federal facilities. In addition, the federal government has discharged 140 billion gallons of liquid waste into cribs, seepage ponds, and deep injection wells at its facilities in Washington and Idaho.[119]

Solid low-level wastes were once disposed of by being mixed with concrete in steel drums and dumped into the sea.[120] About 100,000 drums were disposed of in this manner between 1946 and the late 1960's until protests by Mexico caused the United States to discontinue this practice.[121] One of these sites was located in the Atlantic Ocean off the Maryland-Delaware coast; the other was located in the Pacific Ocean at the Farallon Islands near San Francisco.[122] The federal government believed that the containers would be adequate to contain the wastes until the process of radioactive decay had reduced radiation to non-hazardous levels.[123] However, when the EPA examined the Farallon Islands disposal site recently, it found that many of the barrels had imploded from deep-water pressure and others had deteriorated, releasing their radioactive contents into the ocean environment.[124]

Shallow land burial is now the primary method of disposal for low-level wastes.[125] Originally, these radioactive wastes were

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117. INTERAGENCY REVIEW GROUP ON NUCLEAR WASTE MANAGEMENT, REPORT TO THE PRESIDENT 11, TID-29442 (March 1979). However, approximately 40 percent of the radioactive wastes shipped to burial sites comes from hospitals, universities, radiopharmaceutical suppliers and industrial users and not from nuclear power plants or related sources. NRC, ANNUAL REPORT 1978, at 97 (1979).

118. GAO, ISOLATING HIGH-LEVEL RADIOACTIVE WASTE FROM ENVIRONMENT: ACHIEVEMENTS, PROBLEMS, AND UNCERTAINTIES 4 (Dec. 1974). According to some estimates, this total could reach 1 billion cubic feet by the year 2000. LOW-LEVEL NUCLEAR WASTE DISPOSAL, COMMITTEE ON GOVERNMENT OPERATIONS, H.R. DOC. NO. 94-1320, 94th Cong., 2d Sess. 12 (1976).

119. Rowe & Halcomb, *The Hidden Commitment of Nuclear Wastes*, 24 NUCL. TECH. 286, 290 (1974). *Hearings Before the Subcommittee on Legislation of the Joint Committee on Atomic Energy*, 94th Cong., 2d Sess. 2326 (1976).

120. Comment, *Nuclear Waste Disposal: A Federal and State Problem*, 65 KY. L.J. 917, 922 (1977).

121. *In re* Industrial Waste Disposal Corp., 2 A.E.C. 70 (1962).

122. *Radioactive Waste Disposal Problems, Hearings Before the Subcommittee of the Committee on Government Operations*, 94th Cong., 2d Sess. 138 (1976).

123. Green, *Radioactive Wastes and the Environment*, 11 NAT. RES. J. 281, 285 (1971).

124. *Radioactive Waste Disposal Problems, Hearings Before the Subcommittee of Committee on Governmental Operations*, 94th Cong., 2d Sess. 3 (1976).

125. Note, *State Control of Low-Level Nuclear Wastes Disposal* 17 NAT. RES. J. 683, 685 (1977). Trenches for low-level waste burial range from 60 to 260 meters in length, 8 to

buried only on federal land,[126] but since 1961 privately-operated commercial burial facilities have been allowed on federal- or state-owned land.[127] At the present time, burial sites at Beatty, Nevada, Hanford, Washington, and Barnwell, South Carolina are being used. Another site at Sheffield, Illinois is now filled to its licensed capacity.[128] Low-level wastes have also been disposed of at West Valley, New York and Maxey Flats, Kentucky, but these sites are now closed.[129]

A number of instances of release of radioactive substances into the environment have occurred over the years at both government-owned and privately-operated low-level waste disposal sites. Migration of radioactive substances from the immediate disposal area has been a particular problem.[130] For example, radioactive materials from several burial trenches at the Oak Ridge, Tennessee facility leached into a creek which flows into the Clinch River, causing the level of radioactivity in the creek to exceed the maximum permissible concentrations for water.[131] Water containing tritium and strontium-90 also seeped from a burial trench at the disposal facility in West Valley, New York in 1975.[132] Moreover, tritium, cobalt-60, strontium -89, strontium-90, cesium-134, cesium-137, and plutonium-239 were all detected near the Maxey Flats, Kentucky site.[133] A very different sort of problem is illustrated by the recent experience at the waste disposal facility in Beatty, Nevada, where it was discovered that employees had been removing tools and other radioactive articles for years.[134]

Incidents like those at Oak Ridge, West Valley, Maxey Flats

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20 meters in width, and 5 to 8 meters in depth. ALTERNATIVES, *supra* note 56, at 24.7.

126. About 4 million cubic feet of commercial low-level waste is buried in the Idaho desert. Moore, *The Environmentalist and Radioactive Waste*, 49 CHI.-KENT L. REV. 55, 60 (1972).

127. Note, *State Control of Low-Level Nuclear Waste Disposal*, 17 NAT. RES. J. 683, 685 (1977).

128. 43 Fed. Reg. 49,811 (1978).

129. Note, *State Control of Low-Level Nuclear Waste Disposal*, 17 NAT. RES. J. 683, 686 (1977).

130. LOW-LEVEL WASTE DISPOSAL, COMMITTEE ON GOVERNMENT OPERATIONS, H.R. Doc. No. 94-1320, 94th Cong., 2d Sess. 7 (1976).

131. GAO, IMPROVEMENTS NEEDED IN THE LAND DISPOSAL OF RADIOACTIVE WASTES — A PROBLEM OF CENTURIES 14, RED 76-54 (Jan. 1976). [hereinafter cited as A PROBLEM OF CENTURIES].

132. EPA, REVIEW OF STATE LICENSES FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE BY SHALLOW LAND BURIAL 2, ORP/Lv-76-3 (June 1976).

133. A PROBLEM OF CENTURIES, *supra* note 131, at 14.

134. *Radioactive Waste Management, Hearings Before the Sub-Committee on Environment and Safety of Joint Committee on Atomic Energy*, 94th Cong., 2d Sess. 271-72 (1976).

and Beatty illustrate the need for better management practices regarding low-level nuclear waste. Some of the present difficulties in this area are probably due to the nature of the low-level waste regulatory framework. Regulatory authority is divided between the NRC and the states. The Atomic Energy Act authorizes state regulation of certain radioactive substances pursuant to agreements between each state and the NRC.[135] There are presently twenty-five states which have agreements with the NRC.[136] Three of the four presently operating commercial waste disposal sites are located in an agreement state, and are therefore licensed at the state level.[137] The federal government sets some guidelines, but many of the regulatory responsibilities are left to the states. Despite their best efforts, the states simply do not have the resources to supervise waste disposal activities.[138]

An NRC Task Force has recently studied the low-level waste disposal situation and made a number of recommendations. These involve improved standards for waste acceptance, site suitability, site design, site operation, environmental monitoring and post-operational maintenance and funding.[139] A study by the General Accounting Office reached similar conclusions.[140] If these recommendations are implemented, low-level waste disposal may cease to be as troublesome as it has been in the past.

II. High-Level Nuclear Waste Management

The primary focus of this article is high-level radioactive waste—a by-product of the nuclear fuel cycle which presents perhaps the greatest risk to human safety. This section will discuss each aspect of nuclear waste management: treatment, transportation, storage and disposal. Treatment refers to any change in the physical or chemical nature of radioactive waste. Transporta-

135. 42 U.S.C. § 2021 (1976).

136. These states are: Alabama, Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Kansas, Kentucky, Louisiana, Maryland, Mississippi, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Oregon, South Carolina, Tennessee, Texas and Washington. NRC, Final Task Force Report on the Agreement States A-53 (Dec. 1977).

137. These state licensed sites are at Beatty, Nevada, Hanford, Washington and Barnwell, South Carolina. The now closed sites at West Valley, New York and Maxey Flats, Kentucky, were also licensed by the states. Since Illinois is not an agreement state, the waste disposal facility at Sheffield, Illinois is licensed by the NRC.

138. NRC Task Force Report on Review of Federal-State Program for Regulation of Commercial Low-Level Waste Burial Grounds, 42 Fed. Reg. 13,366, 13,370 (1977).

139. NRC Task Force Study, NUREG-0217 (March 1977). *See also* NRC, The Nuclear Regulatory Commission's Low-Level Radioactive Waste Management Program 5-9, NUREG-0240 (Sept. 1977).

140. *See* A Problem of Centuries, *supra* note 131.

tion includes the shipment of radwaste from the reactor to reprocessing, storage or disposal facilities. Storage is the temporary deposit of radioactive waste in some sort of repository, while disposal involves permanent isolation or removal of nuclear waste material from the environment.

A. High-Level Nuclear Waste

Although it constitutes only a small part of the total volume of nuclear wastes produced, high-level radwaste accounts for about 90 percent of the radioactivity associated with the back-end of the nuclear fuel cycle.[141] There are three sources of high-level radioactive waste: fission products, activation products and transuranic elements. Fission products are produced by the fissioning of uranium-235 fuel; activation products result when impurities and fuel cladding material are exposed to neutrons in the nuclear reactor; and transuranic elements are formed when uranium-238 in the fuel absorbs neutrons.

1. FISSION PRODUCTS

One constituent of high-level nuclear waste, fission products, is created by the fissioning of uranium-235 atoms. Although more than thirty elements are produced from the uranium fuel in a nuclear reactor,[142] the principal fission products are radioactive isotopes of strontium, cesium, promethium, krypton, cerium, ruthenium, zirconium, barium, iodine and xenon.[143] Some of these substances have short half-lives and thus decay relatively quickly. Other fission products are relatively long lived.[144]

Radioactive strontium-90 and cesium-137 with half-lives of 28 and 30 years respectively, are the fission products which are the primary sources of long-term heat and radioactivity in high-level nuclear waste.[145] Strontium emits only beta radiation,[146]

141. Zeller, Saunders & Angino, *Putting Radioactive Wastes on Ice: A Proposal for an International Radionuclide Depository in Antartica*, 29 BULL. OF THE ATOM. SCIENTISTS 4, 5 (Jan. 1973).

142. J. SCHUBERT & R. LAPP, RADIATION: WHAT IT IS AND HOW IT AFFECTS YOU 28 (1957). For a partial list of these elements and their characteristics, see Wright, *Disposal of Radioactive Wastes*, 10 ATOM. ENERGY L.J. 239, 257-59 (1968).

143. J. HOGERTON, THE ATOMIC ENERGY DESK BOOK 446 (1963).

144. Cerium-144, with a half-life of 590 days, would require 16 years or 10 half-lives to decline to one-thousandth of the original amount and 32 years or 20 half-lives to decline to one millionth of the original amount. Promethium-147, with a half-life of 2.26 years would require about 22.5 years for its radioactivity level to decline by a factor of 1000 and 45 years for it to decline by a factor of one million.

145. Strontium-90 has a half-life of 28 years, while cesium-137 has a half-life of 30 years. Assuming that a period of twenty half-lives is necessary before radioactive sub-

while cesium emits both beta and gamma radiation.[147] Most of the experience with strontium and cesium has been with radioactive fallout from nuclear weapons. Radioactive strontium is chemically similar to calcium and, like calcium, concentrates in bone tissue when absorbed by the human body.[148] Since bone tissues are extremely radiosensitive, strontium, when ingested, may eventually cause bone cancer.[149] Radioactive cesium is chemically similar to potassium and, like potassium, when ingested it disperses throughout all the body's tissues.[150] Once ingested, cesium is usually excreted within a few months,[151] but strontium has a biological half-life of many years.[152]

Both strontium and cesium enter the human body through the food chain.[153] In the case of radioactive fallout, strontium and cesium are deposited on growing plants and enter the food chain by way of foliar absorption. Strontium may also enter the food chain by means of root uptake through the soil,[154] but cesium is so tightly bound by the clay minerals of the soil that root uptake of cesium is slight except in potassium deficient soil.[155] High concentrations of radioactive cesium, however, have sometimes been found in aquatic environments.[156]

2. ACTIVATION PRODUCTS

Activation products comprise another type of high-level nuclear waste. Material from the fuel cladding is a major source of high-level activation products. The various components of the fuel assemblies contain zircaloy, stainless steel and inconel. Zircaloy is made up primarily of zirconium and chromium along

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stances are considered to be safe, these substances must be isolated from the environment for about 600 years. By that time, only one-millionth of the original quantity would be left, and a similar decline in the level of radioactivity would be expected.

146. CEMBER, *supra* note 25, at 71. Strontium-89, another radioactive isotope of strontium, is also present in high-level radwaste. However, its radioactive half-life is only 54 days. J. HOGERTON, *supra* note 143, at 446.

147. EISENBUD, *supra* note 42, at 488.

148. *Id.* at 129.

149. Eckelman, Kulp & Schulert, *Strontium-90 in Man*, 125 SCI. 219, 219 (1957).

150. EISENBUD, *supra* note 42, at 132.

151. GAO, ISOLATING HIGH-LEVEL RADIOACTIVE WASTE FROM THE ENVIRONMENT: ACHIEVEMENTS, PROBLEMS, AND UNCERTAINTIES 7, RED 309 (Dec. 1974).

152. EISENBUD, *supra* note 42, at 485. *See* note 89 *supra*.

153. *See generally*, Reichle, Dunaway & Nelson, *Turnover and Concentration of Radionuclides in Food Chains*, 11 NUCL. SAFETY 43 (1970).

154. EISENBUD, *supra* note 42, at 129-35.

155. *Id.* at 132.

156. Gustafson & Miller, *The Significance of 137 Cs in Man and His Diet*, 16 HEALTH PHYSICS 167 (1969).

with small portions of tin and iron. Stainless steel contains iron, chromium and nickel, along with much smaller amounts of manganese, silicon, phosphorus, carbon, sulfur and selenium. Inconel is an alloy of nickel, chromium and iron. There are also small quantities of niobium, tantalum and molybdenum, and trace amounts of cobalt, titanium, aluminum and carbon in the inconel.[157]

When these elements in the fuel cladding come into contact with neutrons, they are activated or transmuted into radioactive isotopes. Tin, antimony, zirconium, cobalt, iron, niobium, manganese, and tellurium are among the most radioactive elements in the spent fuel assemblies.[158] Even after 10 years, long-lived isotopes of cobalt, antimony, iron and tellurium continue to generate substantial amounts of heat and radiation. Nickel is another long-lived radionuclide.[159]

3. TRANSURANIC ELEMENTS

Transuranic elements are the third constituent of high-level nuclear waste.[160] These include isotopes of plutonium, neptunium, americium, curium, berkelium, and californium. Unlike fission and activation products, transuranics are relatively low in heat generation and penetrating radiation, but they are extremely long-lived.[161] Plutonium-239, an alpha emitter with a half-life of 24,000 years,[162] is the most common transuranic substance in high-level waste. It is formed in the reactor when neutrons released during the chain reaction are captured by uranium-238 in the fuel.[163]

Although plutonium is one of the most dangerous substances

157. ALTERNATIVES, *supra* note 56, at 2.33.

158. *Id.* at 2.35.

159. *Id.*

160. Strictly speaking, transuranic elements are not included within the definition of high-level waste according to NRC regulations. These regulations define high-level radioactive wastes as "those aqueous wastes resulting from the operation of the first solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles . . . ." 10 C.F.R. § 50, app. F. (1978).

161. Note, *State Control Over Low-Level Waste Disposal,* 17 NAT. RES. J. 683, 684 (1977).

162. Plutonium-239 is the most common isotope of plutonium found in spent fuel. Plutonium-240 and plutonium-242 are also long-lived alpha emitters, with half-lives of 6,600 and 390,000 years respectively, while plutonium-238, also an alpha emitter, has a half-life of only 86.4 years. Another isotope, plutonium-241, is a beta emitter with a 13.2 year half-life. Edsall, *Toxicity of Plutonium and Some Other Actinides,* 32 BULL. OF THE ATOM. SCIENTISTS 26, 28 (Sept. 1976).

163. GARVEY, NUCLEAR POWER AND SOCIAL PLANNING 13 (1977).

known to man,[164] it emits no penetrating gamma radiation, and, therefore, may be handled in an ordinary glove box.[165] Ingested plutonium is absorbed poorly from the gastrointestinal tract, and less than one part in 30,000 enters the bloodstream in this manner.[166] Absorption through normal skin is also slight,[167] although injection of plutonium directly into the bloodstream through open wounds or broken skin could be dangerous.[168] Studies reveal that the uptake of plutonium from the soil by plants, though measurable, is exceedingly small; thus serious radiation exposure is unlikely to occur from eating such plants.[169]

Nevertheless, plutonium can be exceedingly dangerous when inhaled. Tests with animals have indicated that extremely small quantities of plutonium inhaled in aerosol form could be lethal. Dogs which were given a dose of 100 to 1000 nanocuries per gram of lung tissue died of pulmonary fibrosis within a year or two. At lower doses, death occurred within 6 years. Doses of 3 to 20 nanocuries per gram of lung tissue caused lung cancer within 6 to 13 years for all animals tested.[170] From such evidence, scientists estimate that a dose as small as 50 micrograms of plutonium could be lethal to humans.[171]

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164. Note, *Plutonium Society: Deterrence and Inducement Factors*, 41 ALB. L. REV. 251, 259 (1977).

165. Comment, *Policing Plutonium: The Civil Liberities Fallout*, 10 HARV. C.R.-C.L. L. REV. 369, 383 (1976). A "glove box" is an enclosure used for the safe handling of alpha and some beta emitting materials. One can handle the radioactive material by using rubber gloves connected to an opening in the apparatus. J. HOGERTON, THE ATOMIC ENERGY DESKBOOK 214 (1963).

166. Bethe, *The Necessity of Fission Power*, 234 SCIENTIFIC AM. 21, 29 (Jan. 1976).

167. Edsall, *Toxicity of Plutonium and Some Other Actinides*, 32 BULL. OF THE ATOM. SCIENTISTS 26, 29 (Sept. 1976).

168. Injection of plutonium compounds into the bloodstream has caused bone cancer in laboratory animals. A. TAMPLIN & J. GOFMAN, "POPULATION CONTROL" THROUGH NUCLEAR POLLUTION 177-78 (1970).

169. FINAL GENERIC ENVIRONMENTAL STATEMENT ON THE USE OF RECYCLE PLUTONIUM IN MIXED OXIDE FUEL IN LIGHT WATER COOLED REACTORS—HEALTH, SAFETY AND ENVIRONMENT S-7, NUREG-0002 (Aug. 1976) [hereinafter cited as GESMO].

170. Edsall, *Toxicity of Plutonium and Some Other Actinides*, 32 BULL. OF THE ATOM. SCIENTISTS 26, 29 (Sept. 1976).

171. Note, *Plutonium Society: Deterrence and Inducement Factors*, 41 ALB. L. REV. 259 (1977). Plutonium may be even more dangerous, according to those who espouse the "hot particle" theory. Proponents of this theory claim that plutonium, when exposed to air, ignites spontaneously to form tiny, intensely radioactive particles which can remain suspended in the air for a long period of time. When these particles are inhaled by humans, they are deposited in the very deep portions of the lung, where they may be immohilized for bundreds of days. J. GOFMAN & A. TAMPLIN, POISONED POWER: THE CASE AGAINST NUCLEAR POWER PLANTS 197-98 (1971). Tbe hot particle theory, however, is highly controversial, and is not accepted by most scientists. For a good summary of the scientific literature on this subject, see Richmond, *Current Status of the Plutonium Hot Particle Problem*, 17 NUCL. SAFETY 464 (1976).

In addition to plutonium, high-level waste contains small quantities of other transuranics such as neptunium, americium and curium. Neptunium-237, which is formed from uranium-235 in the nuclear reactor, is an alpha emitter with a half-life of 2,140,000 years.[172] Americium-241, a decay product of plutonium-241, is also an alpha emitter, with a half-life of 433 years, which accumulates in human tissues and behaves like plutonium.[173] Curium-242 and curium-244, which both emit alpha radiation, are also found in high-level nuclear waste. The former is produced when an atom of americium-241 absorbs a neutron; the latter results from neutron irradiation of plutonium-239. Neither of these isotopes has a very long half-life, although others are extremely long-lived.[174]

B. The Regulatory Framework

One of the problems which impedes development of a comprehensive nuclear waste management program is the conflicting jurisdiction of the agencies responsible for formulating nuclear regulations. Four separate federal agencies, the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), and the Department of Transportation (DOT), play an important role in the nuclear waste management process.

DOE is responsible for existing government treatment and storage facilities, as well as all existing nuclear waste in the possession or control of the government. Congress has also authorized DOE to establish treatment, storage and disposal facilities for commercially produced radwaste and has directed DOE to develop a nuclear waste management program.[175] Pursuant to this statutory authority, DOE now operates a number of military fuel reprocessing and waste storage facilities[176] and is planning to construct storage and disposal facilities for commercially produced nuclear waste.[177]

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172. 16 ENCYCLOPEDIA BRITANNICA, *Neptunium*, 228 (1972). There are numerous other isotopes of neptunium, but most have very short half-lives.

173. Blair & Thompson, *Plutonium: Biomedical Research*, 183 SCI. 715, 715 (1974). Most of the other isotopes of americium are short-lived; however, americium-242 has a 152-year half-life and americium-243 has one of 7,700 years. 1 ENCYCLOPEDIA BRITANNICA, *Americium*, 786 (1972).

174. Curium-242 has a half-life of 162.5 days, while curium-244 has a half-life of 17.6 years. However, curium-247, -248, and -250 have half-lives of 16 million, 470 thousand, and 17 thousand years respectively. 6 ENCYCLOPEDIA BRITANNICA, *Curium*, 905, 906 (1972).

175. 42 U.S.C. § 7133(a)(8) (1978).

176. Malaro, *High-Level Nuclear Waste Management in the United States: A Time for Decisions*, 19 NUCL. SAFETY 356, 357 (1978).

177. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE

The EPA has adopted standards which regulate radioactivity levels for most phases of the nuclear fuel cycle.[178] Although EPA standards do not presently cover waste disposal sites, the agency is now developing criteria and standards for radioactive waste management. Since the EPA would not directly regulate waste disposal facilities, the NRC would be required to enforce these EPA standards through its own licensing authority.[179]

The EPA published proposed criteria in November, 1978. These criteria define radioactive wastes, indicate which types of wastes should be controlled, state the goal of radioactive waste control and define limitations on institutional and other controls over certain time periods.[180] The proposed criteria also deal with risk assessment and require that the selection, design and operation of a disposal site enhance the isolation of radioactive waste.

The DOT regulates the shipment of radioactive materials.[181] Under an agreement with the NRC,[182] DOT is responsible for promulgating and enforcing safety standards for Type A packaging and shipping containers, and for the labeling, classification and marking of all packages.[183] DOT also implements safety standards for the mechanical condition of carrier equipment and sets qualifications for carrier personnel.

Of all of the federal agencies involved in nuclear waste management, the NRC probably has the most important and pervasive role. Under the provisions of the Atomic Energy Act, the NRC licenses the transfer, removal and possession of source, by-product or special nuclear material.[184] As part of this authority, the NRC regulates spent fuel storage at nuclear power plants and exercises jurisdiction over high-level liquid wastes from commer-

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SAFELY 9-12, EMD 77-41 (Sept. 1977).

178. *See* text accompanying notes 105-13 *supra*.

179. Hallmark, *Radiation Protection Standards and the Administrative Decision-Making Process*, 8 ENVT'L L. 785, 804 (1978).

180. EPA, Criteria for Radioactive Waste Disposal, 43 Fed. Reg. 53,262 (1978).

181. *See generally* England, *Recent Regulatory Developments Concerning the Transportation of Nuclear Fuel and Other Radioactive Materials*, 7 ENVT'L L. 203 (1977).

182. Memorandum of Understanding Between the U.S. Department of Transportation and the U.S. Atomic Energy Commission for Regulation of Safety in the Transportation of Radioactive Materials Under the Jurisdiction of the Department of Transportation and the Atomic Energy Commission, 38 Fed. Reg. 8,466 (1973).

183. Generally speaking, small quantities of low-level radioactive material would require Type A packaging. Standards for Type B and large quantity classifications are much more rigorous. *See* 49 C.F.R. § 173.389(j) (1977) for a definition of Type A packaging; 49 C.F.R. § 173.389(k) (1977) for a definition of Type B packaging and 49 C.F.R. § 173.389(b) (1977) for a definition of "large quantity" of radioactive material. *See also* 49 C.F.R. § 173.389(l) (1977); GAO, FEDERAL ACTIONS ARE NEEDED TO IMPROVE SAFETY AND SECURITY OF NUCLEAR TRANSPORTATION, 6-8, EMD 79-18 (May 1979).

184. *See* note 112 *supra*.

cial reprocessing operations.

The NRC has recently proposed licensing procedures for some geologic repositories for high-level radioactive waste.[185] However, the NRC's jurisdiction over DOE waste storage and disposal facilities is limited. According to the 1974 Energy Reorganization Act, the NRC may only regulate DOE facilities which are used primarily for the receipt and storage of high-level radioactive wastes resulting from activities licensed under the Atomic Energy Act.[186] Thus the NRC may regulate DOE facilities used for the storage and disposal of high-level waste from nuclear power plants, but it may not regulate facilities used for the short-term storage of government high-level waste, or facilities used for disposal of such waste by DOE as part of a research and development program. Furthermore, the NRC does not have the power to license disposal of transuranic wastes produced by DOE since they are not presently considered to be high-level wastes.[187]

With so many federal agencies involved in nuclear waste management there is an urgent need to coordinate the development of basic policy. For this reason, the President on March 15, 1978, appointed an Interagency Review Group (IRG). The IRG is headed by the Secretary of DOE and consists of representatives from thirteen other federal agencies including the Department of State, the Department of the Interior, the DOT, the Council on Environmental Quality, the NRC, and the Office of Management and Budget.[188] The IRG is presently considering alternative technology strategies, the nature of federal regulatory involvement in

185. NRC, Licensing Procedures for Geologic Repositories for High-Level Radioactive Wastes, 43 Fed. Reg. 53,869 (1978). The first stage is an informal review on site suitability, after DOE has made tentative site selection. The formal licensing process would begin when DOE applies for permission to construct the repository shaft. The application would include information on site suitability and repository design features, as well as an environmental impact statement. The NRC would authorize construction only if it determined that the benefits of the proposal exceeded the costs under the National Environmental Policy Act (NEPA) and that there was reasonable assurance that the wastes described in the application could be stored in the proposed repository without unreasonable risk to the health and safety of the public. The NRC would allow DOE to receive radioactive material at the repository after it conducted a final review of health and safety issues. Under the terms of the operating license, DOE would be required to conduct and monitor the activities of the site, to keep records, submit reports and submit to NRC inspections. When the repository was filled to capacity, DOE would have to comply with NRC regulations governing sealing of the underground repository, decommissioning of surface facilities, storage of permanent records and provisions for a long-term monitoring.

186. 42 U.S.C. § 5842(3)-(4) (1976).

187. Note, *Federal and State Regulation of Radioactive Waste Disposal: The Emerging Conflict, in* ENERGY PRODUCTION: SELECTED LEGAL ISSUES 249, 261 (Stan. Env. L. Ann. 1978).

188. 21 NUCL. NEWS 18 (Apr. 1978).

nuclear waste disposal, the problem of waste from defense programs, spent fuel storage, transportation problems and international aspects of radioactive waste.[189]

C. Treatment of High-Level Nuclear Waste

The first phase of nuclear waste management generally is treatment of nuclear waste. Treatment includes any significant change in the physical or chemical character of the reactor fuel, regardless of purpose. Thus, treatment does not necessarily imply that the radioactive waste material is made less dangerous, but only that it is changed in some way.

There is no treatment phase under the throwaway option because spent fuel is disposed of without any alteration in its original state. However, under the recycling approach, radioactive waste is altered by reprocessing operations and may subsequently be transformed into calcine or glass. Both reprocessing and the various forms of waste solidification are examined below.

1. REPROCESSING

Although this article treats reprocessing as an aspect of nuclear waste management, the primary purpose of reprocessing is to recover plutonium from spent fuel. Nuclear waste management considerations are usually secondary. Nevertheless, the decision to reprocess has significant consequences in terms of waste management policy.

The reprocessing operation begins with the arrival of spent fuel assemblies at the plant. In the first stage of the reprocessing operation, the structural components of the fuel assemblies are removed and the fuel elements are chopped into small sections.[190] Next, these pieces are placed in a nitric acid solution to leach out the uranium and plutonium. An organic solvent such as tributyl phosphate is then used in a series of extraction processes to recover the plutonium and uranium from the acid solution. The uranium and plutonium are separated from each other and purified.[191] Finally, the plutonium and uranium are shipped to a mixed oxide fuel fabrication plant where they are combined in new fuel elements for reuse in light water reactors.[192]

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189. 21 NUCL. NEWS. 119 (Sept. 1978).

190. *Extent and Significance of the Impact on Reactor Licensing of Recent Court Decisions, Hearing Before the Joint Comm. on Atomic Energy*, 94th Cong., 2d Sess. 337 (1976).

191. Bebbington, *The Reprocessing of Nuclear Fuels*, 235 SCIENTIFIC AM. 30 (Dec. 1976); Metz, *Reprocessing: How Necessary Is It for the Near Term?*, 196 SCI. 43 (1977).

192. *Oversight Hearings on Nuclear Energy—Overview of the Major Issues, Hear-*

Reprocessing operations produce both solid and liquid high-level waste. Fuel cladding or hulls comprise most of the solid waste from reprocessing operations, and activation products account for most of this radioactivity.[193] The only commercial treatment of solid waste used in the United States thus far has been shallow burial of barrels containing untreated hull residues.[194] Possible methods of treatment in the future might include embedding the fuel cladding wastes in a concrete or sand matrix, melting, or dissolving them to produce oxide for conversion to a glass product.[195]

Along with solid wastes, reprocessing also generates about 5000 liters of high-level liquid waste for each metric ton of spent fuel dissolved.[196] Almost all of the transuranics and fission products are contained in this liquid waste, which is characterized by intense radioactivity and high heat generation.[197]

Although reprocessing of spent fuel to recover plutonium for military purposes has occurred in the United States since World War II, reprocessing of spent fuel from civilian nuclear power plants as part of a commercial plutonium recycling program has not yet become reality.[198] Serious legal problems developed with recycling in 1975 when the AEC proposed to issue licenses for commercial use of mixed oxide fuel. Use of this fuel is essential to full scale plutonium recyling.[199] The AEC issued a generic environmental impact statement (GESMO) on the proposed action, but failed to examine non-nuclear alternatives to recyling or to discuss the problem of protecting nuclear plants and material from sabotage or diversion by terrorists. The AEC, or rather its successor, the NRC, agreed to produce a supplement to GESMO

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ings Before the Subcomm. on Energy and the Environment of the Comm. on Interior and Insular Affairs, 94th Cong., 1st Sess. 544 (1975). Spent fuel from military plutonium production reactors is also reprocessed to recover plutonium for use in fabricating nuclear weapons. Most of the high-level waste, other than spent fuel, produced in the United States has come from military rather than civilian reprocessing operations.

193. *Radioactive Waste Management, Hearings Before Subcommittee on Environment and Safety of Joint Committee on Atomic Energy*, 94th Cong., 2d Sess. 47 (1976).

194. ALTERNATIVES, *supra* note 56, at 7.8.

195. *Id.* at 7.8-43.

196. *Id.* at 6.1. This volume can be reduced to 600-1100 liters by a process concentrator prior to transfer to a storage tank. *Id.*

197. Swan, *Management of High-Level Radioactive Wastes: The AEC and the Legal Process*, 1973 LAW & SOC. ORD. 263, 265. These liquid wastes are self-boiling for the first five years and water must be periodically added to prevent further concentration. Wright, *Disposal of Radioactive Wastes*, 10 ATOM. ENERGY L.J. 239, 247 (1968).

198. A plant at West Valley, New York reprocessed small amounts of commercial spent fuel from 1966 to 1972, but is now closed. No commercial plants are operating in the United States at the present time.

199. 39 Fed. Reg. 5,356 (1974).

on this issue, but also planned to issue "interim" licenses while the study was being completed. This NRC decision was challenged in court in *Natural Resources Defense Council v. Nuclear Regulatory Commission.*[200] The court held that the interim licensing proposal was improper.

During this time, the federal government's policy position on recycling shifted dramatically. On April 7, 1977, President Carter in his energy message to Congress declared: ". . . we will defer indefinitely the commercial reprocessing and recycling of the plutonium produced in the U.S. nuclear power programs. From our own experience we have concluded that a viable and economic nuclear power program can be sustained without such reprocessing and recycling."[201] The NRC, after consulting with the President, formally terminated the GESMO hearings on December 23, 1977,[202] along with proceedings on virtually all pending and future recycle-related license applications.[203] If the President's decision on recycling stands, the throwaway alternative would be the only remaining nuclear waste management option for commercially produced radioactive waste. Military reprocessing operations, now carried out by DOE, however, are not affected by the President's decision.

2. SOLIDIFICATION OF REPROCESSING WASTE

Because of the difficulties of dealing with high-level liquid wastes, federal regulations require that commercial reprocessing wastes be solidified prior to their ultimate disposal.[204] Solidification involves removal of dissolved or suspended radioactive material from the liquid solution by physical or chemical means.[205] Various forms of waste solidification include in-tank solidification, calcination and vitrification.

The simplest technique is in-tank solidification, in which the water containing the radioactive waste is evaporated, leaving

200. 539 F.2d 824 (2d Cir. 1976).

201. 2 NUCL. REG. REP. (CCH) ¶ 20,051 (1977).

202. 42 Fed. Reg. 65,334 (1977).

203. 2 NUCL. REG. REP. (CCH) ¶ 30,296 (1978). The United States is sponsoring an International Nuclear Fuel Cycle Evaluation (INFCE), a multinational study of fuel cycles aimed at minimizing the danger of the proliferation of nuclear weapons without jeopardizing the development of nuclear power for peaceful purposes. As part of the INFCE study, DOE has initiated an interagency Non-Proliferation Alternative System Assessment Program (NASAP), which will analyze various fuel cycle options emphasizing proliferation risks and considering technical, economic and commercial feasibility, resource use, safety and environmental factors. It is doubtful that any final decision on reprocessing will be made until the INFCE study is completed.

204. 10 C.F.R. § 50, app. F. (1978).

205. Wright, *Disposal of Radioactive Wastes,* 10 ATOM. ENERGY L.J. 239, 247 (1968).

behind a salt-cake or sludge. This is being done to liquid reprocessing wastes from military programs at Hanford, Washington where compressed air, heated to 1200° F, is sparged through the wastes, leaving the underground tank through a de-entrainer, filter and condenser before being exhausted into the atmosphere.[206] If the program continues on schedule, most of the remaining liquid high-level waste at Hanford will be solidified in this manner by 1982.[207]

While salt-cake is easier to contain than liquid radioactive waste, it should eventually be removed from the underground tanks for permanent disposal elsewhere. If the salt-cake were left in the tanks indefinitely, a combination of tank corrosion and erosion of the earth above the tanks might destroy the effectiveness of the containment system and the waste could be spread over the surrounding area by the wind.[208] Consequently, in-tank conversion of liquid reprocessing waste into salt-cake should be regarded as an intermediate rather than a final step in the waste management process.

a. Calcination

Calcination reduces liquid waste to a granular powder. The calcine form is preferable to salt-cake because it permits greater volume reduction, relative ease of handling, and because calcined waste may be easily converted into glass or ceramic form.[209] The government has been solidifying military waste by calcination at its Idaho Chemical Processing Plant since 1963.[210]

There are four popular methods of calcining radioactive waste: fluidized bed calcination, rotary kiln calcination, spray calcination, and pot calcination. In the fluidized bed process, liquid wastes are atomized and sprayed into a heated bed of granular solids where the metallic nitrate salts are converted into oxides and deposited layerwise on the bed particles. The calcined particles are continously removed from the calciner vessel and pneumatically transported to storage bins.[211] The volatile constit-

206. Parker, *Management of Radioactive Wastes,* 5 ATOM. ENERGY REV. 93, 107 (1967).

207. ISSUES AND CHOICES, *supra* note 72, at 251.

208. Swan, *Management of High-Level Radioactive Wastes: The AEC and the Legal Process,* 1973 LAW & SOC. ORD. 263, 274.

209. ISSUES AND CHOICES, *supra* note 72, at 250.

210. ALTERNATIVES, *supra* note 56, at 6.13. The government has continued to use the in-tank salt-cake process at Hanford because the liquid wastes stored there are too alkaline to be calcined effectively. GAO, ISOLATING HIGH-LEVEL RADIOACTIVE WASTE FROM THE ENVIRONMENT: ACHIEVEMENTS, PROBLEMS, AND UNCERTAINTIES 21, RED 75-309 (Dec. 1974).

211. Dickey, Wheeler & Buckham, *High-Level Waste Solidification: Applicability*

uents of the liquid waste, along with the fluidizing gases are processed in an off-gas cleanup system before being released into the environment.[212]

In rotary-ball kiln calcination, the waste solution is fed onto a bed of metal balls in a slowly rotating cylinder. The calcinator is electrically heated to between 600 and 800° C. The product formed from deposition of metallic oxides on the moving balls is pulverized during kiln rotation into small particles.[213]

Spray calcination is another technique of calcination. In this process, liquid waste is atomized by spraying it with either steam or air through nozzles at the top of a stainless steel column. The walls of the column are kept at 600 to 800° C. The droplets are calcined into a powder as they fall through the barrel or column.[214]

Finally, in pot calcination, the process canister, which also serves as the storage vessel, is heated in a furnace so that the liquid waste boils and concentrates. When the liquid is sufficiently concentrated, it begins to form a scale on the inside walls of the canister. As the can becomes full of this scale, the flow of liquid waste is shifted to another canister.[215] This would seem to be the most secure method of collecting calcined wastes unless further steps, such as vitrification, are contemplated.

b. Vitrification

Radioactive wastes can also be mixed in a glass matrix by various vitrification processes. Vitrification is desirable because glass has low leachability and volatility, high impact resistance, and good thermal and radiolytic stability.[216] A number of vitrification methods are potentially available, and some of them were tested on an experimental basis in the Waste Solidification Engineering Prototypes (WSEP) program between 1966 and 1970.[217]

With the in-can melting process, the storage canister is placed in a multizone furnace and coupled directly to a calciner. Glassforming frit is fed into the canister along with the calcined

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of Fluidized-Bed Calcination to Commercial Wastes, 24 NUCL. SAFETY 371, 372 (1974).

212. Thompson, Lohse & Wheeler, *Fluidized Bed Calcination of Radioactive Wastes Using In-Bed Combustion Heating*, 16 NUCL. TECH. 396, 397 (1972).

213. Dickey, Wheeler & Buckham, *High-Level Waste Solidification: Applicability of Fluidized-Bed Calcination to Commercial Wastes*, 24 NUCL. SAFETY 371, 374-75 (1974).

214. Parker, *Management of Radioactive Wastes*, 5 ATOM. ENERGY REV. 93, 99 (1967).

215. ALTERNATIVES, *supra* note 56, at 6.21.

216. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE SAFELY 32, EMD 77-41 (Sept. 1977).

217. McElroy, Blasewitz & Schneider, *Status of the Waste Solidification Demonstration Program*, 12 NUCL. TECH. 69 (1971).

waste and the blend is melted at 1000-1100° C in the canister. As the melt level rises, the furnace zones below that level are turned off and cooling is started to remove heat generated by the waste.[218] One canister of vitrified waste would contain the waste from about 3.2 metric tons of processed fuel. The canister would contain about 6.28 cubic feet of waste and would be 10 feet long with an inside diameter of 1 foot.[219] Ten canisters would contain 1 year's waste from a 1000 megawatt reactor.[220]

In the continuous ceramic melting process, glass frit is slurried with liquid waste and fed directly into the melter. Water, nitric acid and nitrous oxides escape through the off-gas system, while the waste oxide residue and frit are fused into homogeneous vitreous glass at temperatures ranging from 1100 to 1200° C.[221]

Another vitrification process results in phosphate glass. Liquid waste is mixed with phosphoric acid, and water and nitric acid are vaporized. The solution is then fed to a platinum crucible, melted at 1100 to 1200° C, andpoured into a storage canister where it cools and solidifies.[222]

A recent study by the National Academy of Science, which was released in August, 1978, suggested that ceramic material might be a better medium for waste disposal than glass.[223] Ceramics are inorganic insoluble nonmetallic substances which are crystalline or semicrystalline in structure. Glass is noncrystalline and therefore has inferior high-temperature properties. A glass-ceramic results from glass being subjected to controlled crystallization, which produces a fine-grained crystalline body with some residual glass phase. The glass-ceramic would be formed in thin cross-sections which may be contained in a metal matrix.[224]

Another technique is to produce pellets of solidified waste oxides and to completely seal them within a nonradioactive coating of leach-resistant material, which would protect the waste

218. Cohen, *The Disposal of Radioactive Wastes From Fission Reactors*, 236 SCIENTIFIC AM. 21, 24 (June 1977).

219. GESMO, *supra* note 169, at IV, G-23.

220. Cohen, *High-Level Radioactive Waste From Light Water Reactors*, 49 REV. MOD. PHYSICS 1, 5 (1977).

221. ALTERNATIVES, *supra* note 56, at 6.42.

222. AEC, HIGH LEVEL RADIOACTIVE WASTE MANAGEMENT ALTERNATIVES 1.8, BNWL-1900 (May 1974); Parker, *Management of Radioactive Wastes*, 5 ATOM. ENERGY REV. 93, 99 (1967).

223. *Panel Throws Doubt on Vitrification*, 201 SCI. 599 (1978). *See also* Kerr, *Nuclear Waste Disposal: Alternatives to Solidification in Glass Proposed*, 204 SCI. 289 (1979). This study has proved to be highly controversial. *See* Carter, *Academy Squabble over Radwaste Report*, 205 SCI. 287 (1979).

224. ALTERNATIVES, *supra* note 56, at 6.76.

from leaching or vaporization for long periods. These pellets could be embedded in a metal matrix to provide increased strength, impact resistance and high thermal conductivity.[225]

It should be emphasized that none of these vitrification processes have been tried in the United States on a commercial scale. However, there is no reason to believe that one or more of these techniques could not be employed successfully if enough funds were committed by the government to research and development programs.[226]

D. Transportation of High-Level Nuclear Waste

The second phase of nuclear waste management involves transportation of nuclear waste. The transportation phase includes the shipment of spent fuel or radioactive waste to treatment, storage and disposal sites. Under the throwaway cycle, spent fuel would be shipped to a storage facility and then to a permanent disposal site. Casks for shipping spent fuel usually hold 3.2 tons of spent fuel and weigh about 100 tons. Such a cask of spent fuel may contain up to 20 million curies of radioactivity, including 50,000 curies of gaseous fission products.[227] These cylindrical casks are five feet in diameter and fifteen to eighteen feet long. They are constructed of thick steel walls filled with dense shielding material, such as lead, and are equipped with coolant or heat dissipation equipment.[228] Because of their size and weight, spent fuel shipping casks are normally shipped by rail, although smaller casks can be shipped by truck.

The transportation scheme is more complex under the recycling alternative. First, spent fuel would be shipped to a reprocessing plant. Later, the solidified reprocessing waste would be shipped by truck or rail to storage or disposal facilities. These wastes would be enclosed in thick stainless steel canisters. Each canister would be ten feet long with an inside diameter of one foot. A single canister would hold the solidified waste from the

225. *Id.* at 6.79.

226. It should be noted that reprocessing waste from military reactors is less radioactive than waste from commercial facilities. This is because spent fuel is removed less frequently from civilian power reactors and therefore contains a higher concentration of fission products. Consequently, it may be more difficult to solidify commercial reprocessing wastes than those from military programs. Virtually all the programs described above involved military waste.

227. Note, *Federal, State, and Common Carrier Efforts to Safeguard the Transportation of Radioactive Materials, in* ENERGY PRODUCTION: SELECTED LEGAL ISSUES 202, 221 (Stan. Env. L. Ann. 1978).

228. Brobst, *Transportation of Nuclear Fuel and Waste,* 24 NUCL. TECH. 343, 346-47 (1974).

reprocessing of about 3.2 metric tons of spent fuel.[229] Thus, a year's waste from a 1000-megawatt nuclear reactor could be contained in ten canisters. These reprocessing waste canisters would be shipped to storage or disposal sites in casks similar to those used to transport spent fuel. Rupture of a waste canister would cause less harm than rupture of a spent fuel cask, because no radioactive gases would be released upon rupture of a waste canister, and also because the level of radioactivity would normally be lower.[230]

If spent fuel is recycled, plutonium would be extracted as part of the reprocessing operation and would be shipped separately in solid oxide form to fuel fabrication plants by truck or rail. Since plutonium does not emit penetrating radiation, plutonium containers do not require heavy shielding although care must be taken to prevent criticality.[231] Nevertheless, the shipment of plutonium involves the hazard of exposure to radiation from the accidental rupture of the waste containers and the danger of attempted hijacking by criminal or terrorist groups.

E. Storage of High-Level Nuclear Waste

Storage is the third phase of the nuclear waste managment process. It involves the safeguarding of radioactive waste until it can be disposed of permanently. Spent fuel can be stored at the nuclear power plant or at an away-from-reactor (AFR) facility designed for that purpose. Liquid reprocessing wastes are stored in large underground tanks, while solidified reprocessing wastes could be stored in a variety of above-ground facilities.

1. SPENT FUEL

Each year about thirty metric tons of spent fuel must be replaced in a typical 1000-megawatt nuclear reactor.[232] After removal from the reactor core, these spent fuel assemblies are stored at the plant in racks in water-cooled stainless steel-lined pools[233] where the radioactivity of the fission products decays. The

229. GESMO, *supra* note 169, at IV, G-23.

230. Cohen, *Impacts of the Nuclear Energy Industry on Human Health and Safety*, 64 AM. SCIENTIST 550, 556 (1976).

231. Comment, *Policing Plutonium: The Civil Liberties Fallout*, 10 HARV. C.R.-C.L. L. REV. 369, 382-83 (1976).

232. R. NADER & J. ABBOTTS, THE MENACE OF ATOMIC ENERGY 143 (1977).

233. The temperature of the basin water is maintained below 50 degrees centigrade (122° F) by circulating part of the water through heat exchangers and back to the basin. ALTERNATIVES, *supra* note 56, at 17.6.

water serves as a medium for the removal of residual heat.[234] Spent fuel may be stored in this fashion for a few months to 20 years or more.

Spent fuel is now accumulating in storage pools at the rate of 1700 metric tons per year.[235] On-site storage capacity is limited in many plants, and some utilities have requested permission from the NRC to reduce the space between spent fuel elements in the storage pool.[236] Other utilities are sharing storage space by shipping their excess spent fuel to other plants.[237] General Electric has received permission to increase the storage capacity of its inoperative reprocessing plant at Morris, Illinois from 100 to 750 metric tons.

Clearly the present spent fuel situation is unsatisfactory and requires prompt action. The NRC is now studying the problem and has issued a draft environmental impact statement on spent fuel storage.[238] The draft statement suggested siting, design, operation and record-keeping requirements for spent fuel storage facilities. The NRC has now proposed regulations to carry out these recommendations.[239] DOE has proposed to accept spent fuel from utilities and store it at a federal repository in return for a one-time fee. The federal government would pay for the value of any plutonium or uranium recovered if the spent fuel is ever reprocessed.[240] If the DOE plan is adopted, the government will have to construct one or more AFR facilities for spent fuel storage. The most obvious solution is to construct additional spent fuel storage pools, similar to the one planned at Morris, Illinois. Another possibility, which was once proposed by ERDA, is to store spent fuel in a near-surface facility (SURFF) with forced draft cooling.[241] After being held in storage pools for three or four years, spent fuel would be packaged in canisters and stored above ground in natu-

234. This amount of spent fuel initially contains about 5 billion curies of radioactivity. After 150 days, this level has declined to 135 million curies, and after 10 years the level is only 13 million curies. D. Bodansky & F. Schmidt, *Safety Aspects of Nuclear Energy, in* THE NUCLEAR POWER CONTROVERSY 8, 19 (A. Murphy ed. 1976).

235. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE SAFELY 52, EMD 77-41 (Sept. 1977).

236. This is known as compaction. By January, 1977, utilities operating 36 nuclear reactors had asked the NRC to allow them to increase their storage space by the compaction of spent fuel. *Id.* at 52.

237. *Id.* at 55-56.

238. NRC, DRAFT GENERIC ENVIRONMENTAL STATEMENT ON HANDLING AND STORAGE OF SPENT LIGHT WATER REACTOR FUEL, NUREG 0404 (March 1978).

239. 2 NUCL. REG. REP. (CCH) ¶ 4055 (1978). If adopted, the proposed regulations will comprise 10 CFR § 72.

240. 1 NUCL. REG. REP. (CCH) ¶ 1021 (1977).

241. ALTERNATIVES, *supra* note 56, at 17.11.

ral draft air-cooled vaults or concrete surface silos, or placed into lined holes in the earth.[242]

2. LIQUID REPROCESSING WASTE

Storage of liquid reprocessing waste presents a major problem because reprocessing operations generate such large quantities of high-level liquid waste. One solution is to store this waste in liquid form. At the present time, military reprocessing programs generate about 7.5 million gallons of high-level liquid waste per year.[243] Although some of this waste has now been solidified, more than 80 million gallons remain stored in underground tanks at government facilities.[244] These tanks are sheathed in concrete and cooled by a network of immersion coils.[245] During the past several years, nine of the older carbon steel tanks at the Hanford, Washington site have developed leaks.[246] The most serious incident involved the loss of 115,000 gallons of liquid waste from one tank. The leak occurred in April, 1973, but was not discovered until June of that year.[247] Fortunately, although radioactivity had penetrated at least 80 feet into the ground below the tank bottom and 90 feet laterally, the liquid waste did not come into contact with ground water and, therefore, did not reach the surface environment.[248] None of the newer stainless steel tanks at other federal facilities have leaked yet.[249]

Very little high-level liquid waste has been generated yet by commercial reprocessing operations in the United States. However a reprocessing plant at West Valley, New York which reprocessed 620 metric tons of spent fuel from 1966 to 1972 still has about 600,000 gallons of high-level liquid waste stored in a single carbon steel tank on the site.[250] Neutralization of the acid in the

242. *Id.* at 17.17-43.

243. GAO, THE LIQUID METAL FAST BREEDER REACTOR: PROMISES AND UNCERTAINTIES 76 (1975).

244. Rowe & Holcomb, *The Hidden Commitment of Nuclear Wastes*, 24 NUCL. TECH. 286, 288 (1974). Over the years about 230 million gallons of high-level liquid waste has been produced. However, the waste volume has been reduced to 80 million gallons. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE SAFELY 4, EMD 77-41 (Sept. 1977).

245. Comment, *Nuclear Waste Disposal: A Federal and State Problem*, 5 KY. L.J. 917, 920 (1977).

246. Note, *Harnessing the Atomic Juggernaut: The Need for Multi-Lateral Input in Nuclear Energy Decision-Making*, 14 NAT. RES. J. 411, 419 (1974).

247. Robinson, *The Leak of Tank 106-T at Hanford*, 15 NUCL. SAFETY 460 (1974).

248. G. Kistiakowsky, *Nuclear Power: How Much Is Too Much?*, *in* THE NUCLEAR POWER CONTROVERSY 157, 167-68 (A. Murphy ed. 1976).

249. Swan, *Management of High-Level Radioactive Wastes: The AEC and the Legal Process*, 1973 LAW & SOC. ORD. 263, 273.

250. Shea, *New Nuclear Policy Under the National Energy Plan*, 29 BAYLOR L. REV.

waste has produced a sludge at the bottom of the tank, which will be extremely difficult to remove for permanent disposal.[251]

Virtually no one advocates permanent storage of high-level wastes in underground tanks because of problems with periodic replacement and perpetual maintenance.[252] Failure of cooling and venting systems could result in pressure build-ups and possibly tank ruptures. Furthermore, liquid waste stored in such tanks is vulnerable to earthquakes, bombing and sabotage.[253] Instead, calcination, vitrification or some other method of solidification would be necessary for long-term storage of reprocessing wastes.

3. SOLIDIFIED REPROCESSING WASTE

Once reprocessing waste has been solidified, it may be stored more or less indefinitely. Several years ago, the AEC developed a plan for a retrievable surface storage facility (RSSF) large enough to store all commercial reprocessing waste generated through the year 2000. The proposed facility was to be capable of storing this waste for 100 years or more.[254] The AEC felt that such a facility was desirable because it would allow time for an orderly exploration of permanent storage alternatives. However, the AEC's draft environmental impact statement on the proposal was criticized by the EPA and others.[255] ERDA, which subsequently assumed the AEC's responsibilities in this area, abandoned plans for an RSSF in April, 1975.[256] The retrievable storage options which had been considered by the AEC included water cooled basins, air-cooled vaults and sealed storage casks.

The water-cooled basin concept consists of suspending canisters of solidified waste in steel-lined concrete basins filled with circulating water. A basin would contain 500 canisters. High water purity would be necessary to prevent corrosion of the canisters and a very reliable system of pumps would be needed to keep

689, 694 (1977). Twelve thousand gallons of thorium waste is also stored at West Valley in a single stainless steel tank. ISSUES AND CHOICES, *supra* note 72, at 252.

251. Lash, *A Comment on Nuclear Waste Disposal*, 4 J. CONTEMP. L. 267, 274 (1978).

252. *Id.* at 267.

253. Pleat & Lennemann, *Considerations for Long Term Waste Storage and Disposal at USAEC Sites*, 8 ATOM. ENERGY L.J. 1, 2 (1966).

254. GAO, ISOLATING HIGH-LEVEL RADIOACTIVE WASTE FROM THE ENVIRONMENT: ACHIEVEMENTS, PROBLEMS AND UNCERTAINTIES 27, RED 75-309 (Dec. 1974).

255. AEC, DRAFT ENVIRONMENTAL STATEMENT, MANAGEMENT OF COMMERCIAL HIGH-LEVEL AND TRANSURANIUM-CONTAMINATED RADIOACTIVE WASTE WASH-1539 (1974); Lash, *A Comment on Nuclear Waste Disposal*, 4 J. CONTEMP. L. 267, 273 (1978). The EPA apparently was concerned that the interim facility would be converted into a permanent disposal facility for economic reasons. Malaro, *High-Level Nuclear Waste Management in the United States: A Time for Decisions*, 19 NUCL. SAFETY 356, 357-58 (1978).

256. *ERDA Shelves a Nuclear Waste Storage Plan*, 188 SCI. 345 (1975).

the water circulating, since each canister would produce about 5 kilowatts of decay heat. This decay heat would be great enough to cause the water to boil in 12 to 16 hours if the cooling system became inoperative.[257]

The air-cooled vault concept would involve the storage of 500 waste canisters in an underground vault. Waste canisters would be sealed inside half-inch thick carbon steel overpacks. Heat would be removed by air entering the bottom of the vault, flowing up past the overpacked waste canisters and then out an exhaust port.[258] This system is more attractive than the water-cooled basin concept because air is normally less corrosive than water and because a passive cooling system is utilized.

According to the sealed storage cask proposal, individual waste canisters would be enclosed inside steel overpacks and then placed inside concrete shields on concrete pads in open areas. Cooling would be by natural convection.[259] This approach would provide good access to the waste material, but would require a considerable amount of land.[260]

F. Permanent Disposal of High-Level Nuclear Waste

The final and most critical phase of nuclear waste management is permanent disposal of the waste. Permanent disposal of any radioactive waste requires that the waste be segregated until its radioactivity has declined to a safe level. Generally, this period should be equivalent to twenty half-lives.[261] Of course, the requisite length of isolation depends upon the particular substance involved. Fission products, such as strontium-90 and cesium-137 with 30-year half-lives, require a 600-year period before they are safe. Long-lived transuranics, such as plutonium-239, would have to be isolated from the environment for at least 240,000 years and perhaps for as long as 500,000 years. Several

257. Nelson & Wodrich, *Retrievable Surface Storage Facility for Commercial High-Level Wastes*, 24 NUCL. TECH. 391, 392 (1974).

258. GAO, ISOLATING HIGH-LEVEL RADIOACTIVE WASTE FROM THE ENVIRONMENT: ACHIEVEMENTS, PROBLEMS, AND UNCERTAINTIES 28, RED 75-309 (Dec. 1974). For this system, the canister surface temperature would be 620° F; the overpack surface temperature would be about 400 degrees; the concrete surface temperature would be 200 degrees; and the exhaust air temperature would be 210 degrees. Nelson & Wodrich, *Retrievable Surface Storage Facility for Commercial High-Level Wastes*, 24 NUCL. TECH. 391, 394 (1974).

259. Bethe, *The Necessity of Fission Power*, 234 SCIENTIFIC AM. 21, 27 (Jan. 1976).

260. Some of these storage options resemble the SURFF proposal. *See* text accompanying notes 241-42 *supra*. The primary difference between SURFF and RSSF is that the former is designed for spent fuel storage, while the latter is concerned with the storage of solidified reprocessing waste.

261. P. EHRLICH, THE END OF AFFLUENCE 292 (1974). Nathanson, *International Management of Radioactive Wastes*, 5 ENVT'L AFF. 363, 364 (1974).

proposals for permanent disposal of radioactive waste have been forwarded. The technology of disposal must be uniquely tailored to meet the particular needs of the type of waste involved.

1. SPENT FUEL

Until recently, very little thought has been given to disposal of spent fuel in the United States, although experiments with burial in salt mines have been performed elsewhere. At the present time, the Department of Energy is planning to construct a nuclear waste depository in New Mexico in order to evaluate the behavior of spent fuel elements in bedded salt.[262] If these tests are successful, deep burial in bedded salt and other geological formations is likely to become the accepted method of spent fuel disposal.[263]

2. LIQUID REPROCESSING WASTE

Liquid reprocessing waste requires disposal techniques vastly different from those proposed for spent fuel. Several proposals have been made for onsite disposition of high-level waste from reprocessing plants. One approach would be to store this waste in unlined vaults underground in crystalline rock. It would be necessary to drill a 15 foot diameter access shaft about 1500 feet deep and excavate a series of 30- by 18-foot tunnels radially from this shaft. Each tunnel would be isolated from the main shaft by 10-foot monolithic concrete bulkheads. Waste stored in this fashion would be transported up through the rock formation at slow rates and would remain isolated from the environment for at least 600 years.[264]

Liquid waste could also be disposed of in deep underground rubble-filled voids or chimneys. The chimney would be created

262. 21 NUCL. NEWS 28 (Apr. 1978). *See also* DOE, WASTE ISOLATION PILOT PLANT, DRAFT ENVIRONMENTAL IMPACT STATEMENT, DOE/EIS-0026-D (April 1979).

263. In 1976, ERDA announced an expanded program to identify suitable sites for six commercial waste disposal pilot facilities. 2 NUCL. REG. REP. (CCH) ¶ 20,046 (1976). DOE is presumably going forward with this program at the present time. Two of these facilities, which would cost $200 million each, were once expected to be in operation by 1985. Two salt formations are presently being surveyed for use as potential sites. One is the Salina formation, which underlies parts of Michigan, Ohio, Pennsylvania, West Virginia and New York. The other formation is the interior Gulf Coast salt domes underlying Louisiana, Texas and Mississippi. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE SAFELY 9-12, EMD 77-41 (Sept. 1977). Geologic formations other tban salt will be selected for tbe next two pilot facilities in order to determine their suitability for waste disposal.

264. Parker, *Management of Radioactive Wastes*, 5 ATOM. ENERGY REV. 93, 100 (1967).

by exploding a 5 kiloton nuclear device 2000 meters underground. Liquid waste would be injected into the chimney and the heat from radioactive decay would cause the liquid waste to boil continously. As the process continued, radioactivity would accumulate and require additional cooling water to prevent the chimney rock from melting. At the surface, steam issuing from the outlet would be condensed and recirculated. Because the process operates as a closed system, no radioactive material would be released into the environment. When the chimney became filled, the inlet and outlet shafts would be permanently sealed. Once water was no longer injected into the chimney, the temperature inside the chimney would rapidly rise, causing the rubble within as well as the surrounding rock to melt. The radioactive waste would dissolve in this molten rock. Eventually as the level of radioactivity declined, the rock would cool and solidify. Heat surrounding the radioactive material would prevent the intrusion of ground water, and the radioactive waste would be permanently incorporated in an insoluble silicate rock matrix deep underground.[265] This approach seems promising, but since no large scale experiments have been performed using this method, it would not be prudent at this time to base any nuclear waste management program on this technique.

3. SOLIDIFIED REPROCESSING WASTE

If reprocessing waste is solidified, new methods must be developed to dispose of it safely. Extraterrestrial disposal, deep seabed disposal, disposal in polar ice-packs, rock melting and disposal in salt beds and other underground formations have each been proposed for this purpose.

Disposal into outer space might be feasible when the space shuttle becomes operational. The cost would approximate $2000 per kilogram, which is considerably higher than other types of disposal. While this high cost makes extraterrestrial disposal impractical for most types of high-level waste, it might be a viable option for disposal of transuranic wastes if they were separated from fission products in the waste stream.[266] A second possibility is deep seabed disposal. This method would involve depositing waste canisters in deep ocean trenches at depths of at least 6000 feet. Following submersion, the canisters would bury

265. Cohen, Lewis & Braun, *In Situ Incorporation of Nuclear Waste in Deep Molten Silicate Rock*, 14 NUCL. TECH. 76 (1972).

266. Drumheller, *Extraterrestrial Disposal of Nuclear Wastes*, 24 NUCL. TECH. 418 (1974).

themselves in the deep silt below the ocean floor.[267] This approach presents an obvious risk to the marine environment.

Ice cap disposal is a third alternative. Containers of solidified high-level waste would be placed on the surface of the ice and allowed to melt their own emplacement shafts. The containers would sink at the rate of approximately one meter per day, and in three to five years would come to rest one to two kilometers below the surface. Snow, melt water and the plastic flow of the ice would permanently seal the shafts behind the sinking containers.[268] The primary disadvantage of this proposal is the danger that ships carrying radioactive material to the ice cap might sink and release huge amounts of radioactivity into the ocean.[269]

Another approach to permanent disposal of solidified waste is to drill a shaft about two kilometers deep and lower containers of solidified waste into it. The radioactive decay heat would be high enough to melt the rock.[270] Descent into basalt would require a container temperature of 1200° C, while a temperature of 1500 to 1700°C would be necessary to melt granite. The initial velocity of the descent would be less than a few meters per day, but descent would continue for many years, depending on the corrosion life of the canister and the radioactive decay characteristics of the waste.[271] Descent of up to 10 kilometers is possible. Successive capsules could be released into the same disposal shaft, if enough time is provided between each release to allow the rock to resolidify.[272]

Salt formations were first proposed as sites for radioactive solidified waste storage by an advisory committee of the National Academy of Sciences in 1955. This recommendation has been reaffirmed by three subsequent committees as research and development in waste management has progressed.[273] There are two types of underground salt formations that might be suitable for nuclear waste disposal, salt tables and salt domes. Salt tables are

267. ALTERNATIVES, *supra* note 56, at 25.31-.50. Bishop & Hollister, *Seabed Disposal—Where to Look*, 24 NUCL. TECH. 425 (1974).

268. Zeller, Saunders & Angino, *Putting Radioactive Wastes on Ice: A Proposal for an International Radionuclide Depository in Antartica*, 29 BULL. OF THE ATOM. SCIENTISTS 4, 7-8 (Jan. 1973).

269. Michlin, *Environmental Hazards of Nuclear Wastes*, 30 BULL. OF THE ATOM. SCIENTISTS 36, 41 (Apr. 1974).

270. Kubo & Rose, *Disposal of Nuclear Wastes*, 182 SCI. 1205, 1210-11 (1973).

271. Logan, *Deep Self-Burial of Radioactive Wastes by Rock-Melting Capsules*, 21 NUCL. TECH. 111, 121 (1974).

272. *Id.*

273. Culler, Blomeke & Belter, *Current Developments in Long-Term Radioactive Waste Management*, 11 PROC. OF 4TH INT'L CONF. ON THE PEACEFUL USES OF ATOM. ENERGY 427, 432 (1972).

embedded in other sedimentary rocks. They can be hundreds of meters thick and extend over thousands of square kilometers. Salt domes are forced up, like mushrooms, out of weak spots in horizontal deposits into younger formations by pressure from overlying rock. They are usually round or oval in configuration and range from one to six kilometers in diameter and up to one kilometer in height.[274]

Salt is an excellent medium for nuclear waste storage. It has good compression strength, is impermeable to water, conducts heat well, offers good radiation shielding, and flows plastically so as to seal fissures and relieve stress. Salt is usually found in areas of considerable geographical stability,[275] and there are more than 50,000 square miles of salt beds in the United States, so that a good choice of sites is available.[276] Disposal in salt would require the excavation of a series of rooms 500 to 2000 feet underground. Waste canisters would be placed in holes in the floor of these rooms and spaced to avoid excessive heat generation in one area.[277] After a room was filled to capacity, it would be backfilled with crushed salt. It would take approximately 50 years for the salt to fuse and to recrystallize.[278] Once the site was abandoned, the access shaft would be backfilled and plugged to prevent the entry of water into the formation.

Despite its many advantages over other solidified waste disposal alternatives, storage in salt formations is not entirely free of risk. Salt is corrosive, chemically reactive and will dissolve if exposed to circulating water. Salt formations are often located in areas where oil, gas or potash are found, so there is always the possibility of human intrusion. In addition, heat from the wastes may cause migration of brines to the heat source and reaction of brines with the waste material.[279]

The AEC and its successor agencies ERDA and DOE have been experimenting with nuclear waste disposal in salt formations for more than ten years. During 1966-67, high-level waste

274. Krause, *Disposal of Radioactive Wastes into Deep Geological Formations*, 7 ATOM. ENERGY REV. 47, 56 (1969).

275. D. Bodansky & F. Schmidt, *Safety of Nuclear Energy, in* THE NUCLEAR POWER CONTROVERSY 8, 22 (A. Murphy ed. 1976).

276. Bethe, *The Necessity of Fission Power*, 234 SCIENTIFIC AM. 21, 28 (Jan. 1976).

277. The temperature at the midpoint between buried canisters should not exceed 200 degrees centigrade. Swan, *Management of High-Level Radioactive Wastes: The AEC and the Legal Process*, 1973 LAW & SOC. ORD. 263, 275.

278. The canisters would corrode away within the first year. Cohen, *High-Level Radioactive Waste from Light-Water Reactors*, 49 REV. MOD. PHYSICS 1, 5 (1977).

279. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE SAFELY 17, EMD 77-41 (Sept. 1977).

disposal simulation tests were conducted in abandoned salt mines under a program known as "Project Salt Vault." Irradiated fuel assemblies were used with electric heaters to simulate radiation and heat conditions during storage.[280] The AEC was satisfied with the test results and budgeted $25 million to build a 1000-acre national waste depository near Lyons, Kansas.[281] The site was abandoned, however, in 1972 after evidence of the possibility of ground water intrusion was discovered.[282] Despite this setback, salt beds remain the most attractive alternative for permanent disposal of nuclear waste.

III. Goals for High-Level Nuclear Waste Management

The principal goal of nuclear waste management is to ensure that radioactive material is completely isolated from the environment during its hazardous lifetime. To achieve this objective, the avoidance of unnecessary risk and the equitable distribution of risk are the most crucial specific goals to address in formulating America's nuclear waste management program.

A. Avoidance of Unnecessary Risk.

Risk is a general concept which includes both the probability of an occurrence and the severity of its consequences.[283] In the case of nuclear waste disposal, risk involves the probability of radioactive wastes entering the environment and the potential adverse effects on living organisms of exposure to radiation. Although "zero risk" is highly desirable as an abstract proposition, it is neither technically nor economically achievable in the context of nuclear waste management. No method of waste management is absolutely foolproof. Consequently, intelligent choices must be made among the various waste management alternatives available, choosing where possible the approach which involves the least risk.

1. TREATMENT

Assuming that we decide to reprocess nuclear fuel, the prin-

280. Micklin, *Environmental Hazards of Nuclear Wastes*, 30 Bull. of the Atom. Scientists 36, 40 (Apr. 1974).

281. Note, *Radioactive Waste: A Failure in Governmental Regulation*, 37 Alb. L. Rev. 97, 130 (1972).

282. Lash, *A Comment on Nuclear Waste Disposal*, 4 J. Contemp. L. 267, 273 (1978); Note, *Harnessing the Atomic Juggernaut: The Need for Multi-Lateral Input in Nuclear Energy Decision-Making*, 14 Nat. Res. J. 411, 419 (1974).

283. W. Lawrence, Of Acceptable Risk 70 (1976).

cipal question to be addressed in the treatment phase of waste management is whether to solidify reprocessing waste. Unless liquid reprocessing waste is disposed of in deep underground chimneys,[284] this waste must be stored in underground tanks or be converted into solid form. Solidification is the better course of action because there is less risk that migration or dispersion of waste material will occur. Furthermore, since glass and ceramic forms are more stable than salt-cake or calcine, they are preferable.

2. TRANSPORTATION

Risk avoidance in the transportation phase of nuclear waste management involves choices with respect to modes of transportation, methods of operation and packaging standards. Land transportation is generally safer than shipment by sea or air because the consequences of an accident are usually less severe. Not only are nuclear waste containers less likely to rupture during land transportation, but cleanup or recovery operations are normally more effective. Thus, ice-cap melting, deep ocean, and extraterrestrial methods of disposal are unsatisfactory because they require transport by ship or spacecraft.

In general, it seems desirable to minimize the number of trips. Thus, railroads offer the greatest advantage of the various forms of land transportation because they can transport large quantities of radwaste at a time. A railroad flatbed car can transport a 100 ton cask containing more than 3 tons of waste material, while a truck can carry only one ton of material in a 25 ton shipping cask.[285]

Packaging is another means by which transportation risks can be reduced.[286] Regardless of the number of precautions taken, some accidents will occur in transport. Since railroads have a derailment rate of 10^{-6} per car mile, two derailments per year should be expected if 1000 casks of radwaste are shipped by rail for a distance of 2000 miles annually.[287] Since derailments are

284. *See* text accompanying notes 264-65 *supra*.

285. Note, *Federal, State, and Common Carrier Efforts to Safeguard the Transportation of Radioactive Materials, in* ENERGY PRODUCTION: SELECTED LEGAL ISSUES 202, 221 (Stan. Env. L. Ann. 1978). The AEC has estimated that removal of spent fuel from a 1000-megawatt nuclear plant would require only 10 shipments by rail, while 40 shipments by truck would be required. AEC, SHIPMENTS OF NUCLEAR FUEL AND WASTE: ARE THEY REALLY SAFE? WASH 1339 (1972).

286. Note, *Federal, State, and Common Carrier Efforts to Safeguard the Transportation of Radioactive Materials, in* ENERGY PRODUCTION: SELECTED LEGAL ISSUES 202, 221 (Stan. Env. L. Ann. 1978).

287. Weinberg, *Social Institutions and Nuclear Energy*, 177 SCI. 27, 31 (1972). At

statistically certain to occur, packaging standards must be high enough to prevent such accidents from becoming disasters. NRC regulations currently provide that shipping casks must be designed to withstand a 30 mph "free drop" crash onto a solid and unyielding surface, exposure to a thermal test 30 minutes, a puncture test and submersion in water for 8 hours.[288]

Further improvements are possible.[289] A sound waste management policy must not only continue to require rigid adherence to "state of the art" standards for shipping containers, but must also encourage research and development efforts in this area.

3. STORAGE

Before disposal, some period of interim storage, usually at the power plant, is necessary to permit heat and radioactivity from short-lived substances to decline. Storage for relatively long periods of time may also be part of an overall waste management program.

There are a number of ways in which risks may be reduced in connection with nuclear waste storage. Both the SURFF[290] proposal for storage of spent fuel and the RSSF[291] plan for solidified reprocessing waste contemplate a variety of storage options including water-cooled basins, natural draft air-cooled vaults and sealed storage casks. Although water-cooled basins have proven to be reliable in the past, these other methods are preferable because they use passive sources of cooling and thus are less vulnerable to mechanical breakdowns. Risks may be further reduced by locating storage facilities away from population centers and areas which are subject to floods, earthquakes and other natural disturbances. In addition, the premises can be monitored to detect radiation leakage and to prevent intrusion by unauthorized persons.

Institutional failure presents the greatest risk with long-term storage of high-level nuclear waste. Storage facilities can be designed to withstand the effects of heat, radiation and even earthquakes, but no engineer can provide against the consequences of

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the present time there are 72 nuclear power plants in the United States. At 10 shipments per plant, only 720 casks would be shipped per year. In fact, most of the spent fuel is presently stored at the power plant.

288. 10 C.F.R. § 71, app. B (1975).

289. 20 NUCL. NEWS 90B (Apr. 1977). In an experiment, a 22 ton cask designed for shipment of spent fuel was crashed into a 690 ton earthbacked concrete target at 84 miles per hour without rupturing.

290. *See* text accompanying notes 241-42 *supra*.

291. *See* text accompanying notes 254-60 *supra*.

war, revolution or neglect. Thus, long-term storage is inconsistent with a goal of avoiding unnecessary risk. The EPA has warned that institutional controls, such as storage, should not be relied upon to isolate radwaste from the environment for longer than 100 years.[292] To minimize risks, the maximum storage time for both spent fuel and reprocessing waste should be limited even further. Thirty years should be considered the maximum acceptable period of time for radwaste storage.

4. DISPOSAL

Because of the long time periods involved, the disposal phase is probably the area of greatest uncertainty in the waste management process. Fission products such as radioactive strontium and cesium must be isolated from the environment for 600 years, while plutonium and other transuranic elements can be hazardous for 250,000 years or more. Obviously, human institutions cannot be depended on to safeguard nuclear waste for such a long period of time. Reliance must instead be placed on natural geographic geophysical barriers.

A number of disposal methods have been reviewed.[293] Icecap, deep ocean and extraterrestrial disposal have been questioned because of their high transportation risks. While disposal of liquid reprocessing waste in underground chimneys has the advantage of eliminating the transportation and storage phases of the waste management process along with their consequent risks, there is insufficient data on the behavior of high-level liquid waste under these conditions. More knowledge is required before this method can be approved. The *in situ* rock melting approach looks quite promising, but more information is also needed here before the safety of this alternative can be evaluated.

Burial deep inside geologic formations is the remaining disposal method and currently appears to be the safest and most reliable means of achieving the goal of permanent isolation of radwaste. A 24 volume report issued by DOE in October, 1978, which considered granite, shale, basalt and bedded salt formations, concluded that a geologic repository for nuclear wastes could be built and operated safely using existing design concepts.[294] Another report by the Interagency Review Group declared that "successful isolation of radioactive waste from the

292. EPA, Criteria for Radioactive Waste, 43 Fed. Reg. 53,262 (1978).

293. *See* text accompanying notes 262-82 *supra*.

294. DOE, TECHNICAL REPORT FOR GEIS: RADIOACTIVE WASTE ISOLATION IN GEOLOGIC FORMATIONS (Oct. 1978), *discussed in* 21 NUCL. NEWS 51 (Oct. 1978).

biosphere appears feasible for periods of thousands of years provided that a systems approach for selecting the geologic environment, repository site, and waste form is utilized rigorously."[295]

Of all of the various geological media studied, the most information is available about bedded salt formations. In particular, the Project Salt Vault experiments[296] suggest that salt is the best medium for nuclear waste disposal. Of course, even disposal in bedded salt formations involves some risk of contamination, particularly where long-lived transuranics are involved.[297] Predictions about the long-term geologic stability of an area necessarily involve an element of uncertainty. Though a major geologic upheaval may be extremely unlikely in an area, contamination by means of ground water transport is always possible. Fortunately, even if nuclear waste would come into contact with ground water, radioactive material would probably take a thousand years or more to reach the surface and, therefore, strontium and cesium would not pose a serious threat to the environment.[298] Moreover, since uptake by plants of plutonium from the soil is slight, and since plutonium is not absorbed well through ingestion, entry of plutonium into the food chain will not occur. However, americium, another long-lived transuranic element, may find its way into the food chain in this fashion.[299]

Eventually, most of the transuranics may be removable from high-level liquid wastes by partitioning. Some studies have been made at government laboratories, but very little is presently known about the commercial feasibility of various partitioning methods.[300] However, if it does become practical to extract transuranics from high-level wastes by partitioning, these substances, after solidifiction, could either be put to some commercial use or disposed of separately.[301] If the permanent disposal option is chosen, extraterrestrial disposal, which would be too expensive for disposal of all high-level waste, might be feasible, since a relatively small amount of waste would be involved and because rela-

295. 21 NUCL. NEWS 23 (Nov. 1978).

296. *See* text accompanying notes 280-82 *supra.*

297. Culler, Blomeke & Belter, *Current Developments in Long-Term Radioactive Waste Management,* 11 INT'L CONF. ON THE PEACEFUL USES OF ATOM. ENERGY 427, 437-42 (1971).

298. Cohen, *Impacts of the Nuclear Energy Industry on Human Health and Safety,* 64 AM. SCIENTIST 550, 556 (1976).

299. Edsall, *Toxicity of Plutonium and Some Other Actinides,* 32 BULL. OF THE ATOM. SCIENTISTS 26, 28 (Sept. 1976).

300. ALTERNATIVES, *supra* note 56, at 16.7.

301. *See generally* Baybarz, *Recovery and Application of the Transuranium Elements* ^{237}Np, ^{238}Pu, ^{241}Am, ^{242}Cm, ^{244}Cm *and* ^{252}Cf, *8* ATOM. ENERGY REV. 327 (1970).

tively little shielding is required for most transuranics.[302] Transmutation of these transuranic wastes into less hazardous substances is another possibility, although more information is needed about tbe economic and technological aspects of this approach.[303]

If transuranics are removed, the remaining bigh-level waste would be primarily fission products, which would require isolation from the environment for "only" 600 years until their radioactivity declined to safe levels. This relatively short timeframe would provide a variety of disposal options, although geologic disposal would probably still be the safest.

B. Equitable Distribution of Risk

A basic principle of distributive justice is that, where possible, the people who benefit from an activity should also bear the risks associated with that activity. In cases where it is impossible to achieve a congruence of risk and benefit, the beneficiaries of the activity should be prepared to compensate those who must bear its costs. Any nuclear waste management program involves a certain amount of unavoidable risk. However, those who now benefit from nuclear power do not necessarily share in the risks of radioactive waste disposal. There are at least two aspects of this risk distribution problem: the first is geographical and the second is generational.

The geographical aspect of the risk distribution problem stems from the fact that nuclear power use is concentrated along the eastern seaboard and the Great Lakes.[304] However, most of the desirable sites for the storage and disposal of nuclear waste are found in the remote, sparsely populated or arid areas of the United States, primarily in the West.[305] Many of the residents of these areas are deeply opposed to the construction of storage and disposal facilities near them. Some states have passed legislation restricting or completely prohibiting the disposal of radwaste.[306]

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302. A 1000-megawatt nuclear power plant would produce between 200 and 300 kilograms of plutonium and other transuranics per year. Willrich, *Worldwide Nuclear Industry*, *in* INTERNATIONAL SAFEGUARDS AND NUCLEAR INDUSTRY 45, 54 (M. Willrich ed. 1973). If a minimal weight for shielding and packaging is assumed, extraterrestrial disposal would cost about $400,000 to $600,000 annually for a plant of that size. The figure would be much less if only transuranics other than plutonium were disposed of in this fashion.

303. ALTERNATIVES, *supra* note 56, at 27.1-.14.

304. *See* map in W. RODGERS, ENERGY AND NATURAL RESOURCES LAW 822 (1979).

305. GAO, NUCLEAR ENERGY'S DILEMMA: DISPOSING OF HAZARDOUS RADIOACTIVE WASTE SAFELY 9-12, EMD 77-41, app. II, at 64-66 (Sept. 1977).

306. LA. REV. STAT. ANN. § 51.1071 (West 1978); 1977 MINN. LAWS ch. 417, 116C.72; MONT. REV. CODES ANN. § 69-5818 (1977); OR. REV. STAT. § 469.525 (1977); S.D. COMPILED

Others have attempted to regulate the transportation of nuclear waste within their boundaries.[307] Although the validity of these state statutes has not yet been tested in court, most commentators agree that the federal government could pre-empt this area of regulatory activity if it chose to.[308]

The underlying issue, however, is not legal but political and ethical. One solution is to adopt nuclear waste management alternatives that reduce these geographical inequities. Geographical decentralization of waste disposal activities would not only spread the risks more evenly, but it would also reduce some of the hazards of long-distance transportation of radioactive material. However, geologic conditions in many areas of the country are not ideal for waste disposal. Thus, a trade-off between competing risk avoidance and risk distribution objectives would have to be made.

If nuclear waste disposal activities are confined to certain areas of the country for risk avoidance purposes, distributional equity should be achieved by means of a compensation mechanism. The Price-Anderson Act currently provides for compensation in the case of "nuclear incidents" involving activities licensed by the NRC.[309] The statute would probably cover injuries which arise during the treatment and transportation phases of waste management, but its application to government-owned storage and disposal facilities is unclear. Moreover, the Price-Anderson Act limits total compensation to $560 million per incident, a figure that seems woefully inadequate by today's inflationary standards.[310] Accordingly, the Price-Anderson Act should be modified if it is to serve as an appropriate risk-spreading mechanism for nuclear waste management operations.

Nuclear waste management also raises questions of intergenerational equity. If nuclear power will only be used as a stop-

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LAWS ANN. § 34.21-1.1 (1977); VT. STAT. ANN. tit. 10, § 6501 (Supp. 1977). *See also* Note, *Federal and State Regulation of Radioactive Waste Disposal: The Emerging Conflict, in* ENERGY PRODUCTION: SELECTED LEGAL ISSUES 249, 266-70 (Stan. Env. L. Ann. 1978).

307. *See* Note, *Federal, State, and Common Carrier Efforts to Safeguard the Transportation of Radioactive Materials, in* ENERGY PRODUCTION: SELECTED LEGAL ISSUES 202, 233-41 (Stan. Env. L. Ann. 1978).

308. *See* Murphy & La Pierre, *Nuclear "Moratorium" Legislation in the States and the Supremacy Clause: A Case of Express Preemption*, 76 COLUM. L. REV. 392 (1976); Comment, *Federal Preemption of State Laws Controlling Nuclear Power*, 64 GEO. L.J. 1323 (1976).

309. 42 U.S.C. § 2012(i) (1978).

310. *See* Note, *Nuclear Power and the Price-Anderson Act: Promotion Over Public Protection*, 30 STAN. L. REV. 393 (1978). The constitutionality of the statute was upheld recently in Duke Power Co. v. Carolina Environmental Study Group, 438 U.S. 59 (1978).

gap source of energy, only the present generation will share its benefits. However, since some forms of radwaste remain hazardous for 250,000 years or more, future generations will be forced to bear the risks of nuclear waste even though they have received none of the benefits of nuclear power. Of course, to some extent, each generation bequeaths to later generations both its accomplishments and its mistakes. However, nuclear waste presents such unique dangers to safety that some obligation to future generations must be recognized.

One criterion of social responsibility dictates that the present generation should not subject future generations to a greater degree of risk than it bears itself.[311] Unfortunately, the current state of nuclear knowledge is such that no guarantees can be made that future risks will be less. In fact, the current knowledge about the transport of radioactive material through ground water aquifers would seem to indicate that the risk of contamination from transuranics buried in geological formations will increase rather than decrease as time goes on.

According to the EPA, the current generation should not pose greater risks to future generations than it would be willing to accept for itself. This does not mean that the risk has to be the same in future generations, but only that the risk would not be unacceptable to the current generation if imposed on it.[312] This formula appears to be workable and might serve as a minimum standard for dealing with the issue of intergenerational equity.

IV. Developing a Responsible Radioactive Waste Management Program

Developing a management program for high-level radioactive waste will involve both technical and policy issues. Accordingly, the decisionmaking process must be structured to ensure that both sorts of questions are properly considered. This process will require the participation of Congress, the President, various governmental agencies and the general public. Generally speaking, federal agencies such as the NRC, EPA and DOE seem best equipped to deal with technical matters. Perhaps an interagency group such as the IRG could be assigned the task of outlining the various waste management options and evaluating them from the perspective of technical and economic feasibility.

High-level waste management, however, also involves important issues of public policy. Therefore, Congress and the Presi-

311. *See generally* J. Rawls, A Theory of Justice 284-93 (1971).

312. EPA, Criteria for Radioactive Waste, 43 Fed. Reg. 53,262 (1978).

dent should decide whether the risks associated with a particular program are acceptable. Difficult questions of geographical and generational risk distribution must also be addressed. We believe that the legislative process, with its provisions for open debate and public participation, provides the best structure for the resolution of these sorts of policy issues.

In this section, we will examine some of the waste management options that might be considered. We shall also briefly outline a proposed program. Finally, we shall discuss the problem of securing public acceptance for a nuclear waste management program and the problem of implementing such a program.

At the present time, there are two major types of high-level radioactive waste in the United States. The first is reprocessing waste from nuclear weapons programs. Most of this military waste is in liquid form, but some of it has now been converted into salt-cake or calcine material. The second type of high-level waste is spent fuel from commercial nuclear power plants. There are two methods of dealing with this spent fuel: one is to dispose of it in its present form. This is known as the "once-through" or "throwaway" option. The other method is to reprocess the spent fuel in order to recover plutonium and uranium for reuse. This second alternative would generate reprocessing waste similar to that produced by the military. A responsible high-level radioactive waste management program must provide for the safe storage and disposal of both military and civilian radwaste.

A. Military Reprocessing Waste

Since World War II military reprocessing plants have reprocessed spent fuel from plutonium production reactors at various federal facilities now managed by the DOE. The federal government is presently converting liquid reprocessing waste into salt-cake and calcine respectively at its Washington and Idaho facilities. This is a prudent step because, under present circumstances, high-level radioactive wastes are not suitable for either long-term storage or permanent disposal in liquid form.

However, there is more that can be done about high-level military waste. Neither salt-cake nor calcine are the most desirable forms for long-term storage or disposal. Instead, military waste, if possible, should be converted to either glass or ceramic form. This has been done experimentally, but no effort has been made to treat military wastes in this manner on a large-scale basis. It is recommended that DOE give serious consideration to such a program.

The federal government should also continue with its present efforts to identify a safe and effective method of permanent disposal for high-level military waste. At this point, deep burial in bedded salt formations seems to be the most attractive choice. Currently, DOE is planning to construct a waste depository near Carlsbad, New Mexico. This facility, known as WIPP (waste isolation pilot plant), is intended to operate as a demonstration plant for transuranic waste technology, but it could also be used as a test for the disposal of solidified reprocessing waste or possibly spent fuel.[313] If this approach proves successful, DOE should proceed with the construction of additional prototype disposal facilities. The final step, of course, would be the completion of one or more full-scale disposal facilities. Once these facilities are completed, if DOE can develop a technology for large-scale conversion of liquid reprocessing waste to glass or ceramic material, there is no reason why military waste cannot be safely disposed of within 10 years after it is produced.

B. High-Level Waste from Commercial Nuclear Power Plants

Formulating a program for the management of high-level waste from commercial nuclear power plants is complicated by the continuing uncertainty over fuel cycle alternatives. The throwaway approach would involve the storage and disposal of spent fuel, still housed in its original cladding, without any substantial physical or chemical alteration. Fuel recycling, on the other hand, would involve reprocessing waste somewhat similar to that produced by military programs. Each of these fuel cycle alternatives has advantages and disadvantages.

The throwaway approach avoids most of the risks associated with the transportation and use of plutonium. However, the transport, storage and disposal of spent fuel involves its own hazards. Under the throwaway option, there is the risk of escape of krypton and other gaseous substances if the fuel elements are ruptured. In addition, since each metric ton of spent fuel contains up to 10 kilograms of plutonium and other transuranics, disposal techniques that will assure isolation from the environment for 250,000 years or more are required.

Fuel recycling is the second alternative for commercial nuclear power plants. Viewed solely from the waste management perspective, fuel recycling has clear advantages over the throwaway approach. Specifically, it permits each form of radioactive

313. 21 NUCL. NEWS 18 (Apr. 1978).

waste to be dealt with separately. Thus, volatile substances such as iodine-129, krypton and tritium are separated from the remainder of the waste at the reprocessing plant. They can then be collected and immobilized. Fuel cladding waste can also be treated, and finally, plutonium and uranium can be removed for reuse as fuel. The remaining waste would be composed primarily of fission products, although some transuranic elements would also be present. With the development of partitioning techniques, it may soon be possible to remove all transuranics from the waste stream, thus greatly simplifying the process of nuclear waste management.

However, there are other aspects to recycling which lie beyond the scope of nuclear waste management concerns. Proponents of recycling note that the recovery of plutonium and uranium from spent fuel would extend the life of America's existing uranium reserves,[314] but opponents have questioned the economics of recycling.[315] Opponents of recycling have also warned that some countries might use plutonium recovered from spent fuel to produce nuclear weapons.[316] There is also concern about the possible theft of plutonium by foreign and domestic terrorists,[317] as

314. Reprocessing would reduce the amount of uranium required by one-third and would lessen the demand on enrichment facilities by 26%. Taylor, *Peaceful Uses of Nuclear Energy: Environmental, Security and Safety Considerations, in* INTERNATIONAL SAFEGUARDS AND NUCLEAR INDUSTRY 424, 437 (M. Willrich ed. 1973).

315. ISSUES AND CHOICES, *supra* note 72, at 322-30; Speth, Tamplin & Cochran, *Plutonium Recycle: The Fateful Step*, 30 BULL. OF THE ATOM. SCIENTISTS 15 (Nov. 1974). *But see Oversight Hearings on Nuclear Energy Before the Subcommittee on Energy and the Environment of the House Committee on Interior and Insular Affairs*, 94th Cong., 1st Sess., pt. 1, at 857-67 (1975); GESMO, *supra* note 169, at X1-1 to X1-83.

316. At least ten countries now have the technological capability to reprocess spent fuel. Joskow, *The International Nuclear Industry Today*, 54 FOREIGN AFF. 788, 796-97 (1976). In addition, Argentina, Brazil, Pakistan, Spain, Yugoslavia and other countries are interested in acquiring reprocessing equipment and technology from other more developed countries. Feiveson & Taylor, *Security Implications of Alternative Fission Futures*, 32 BULL. OF THE ATOM. SCIENTISTS 14, 15 (Dec. 1976). Under commercial operating conditions, a 1000-megawatt reactor could produce 200 kilograms of plutonium a year. Willrich, *Worldwide Nuclear Industry, in* INTERNATIONAL SAFEGUARDS AND NUCLEAR INDUSTRY 45, 54 (M. Willrich ed. 1973). A 20-kiloton nuclear weapon would require only 5 to 10 kilograms of plutonium. Note, *Recent U.S. Efforts to Control Nuclear Proliferation*, 10 VAND. J. TRANSNAT'L L. 271, 273 (1977). Signatories to the Nuclear Non-Proliferation Treaty are prohibited from diverting plutonium from spent fuel to nuclear weapons production. The International Atomic Energy Agency monitors compliance with the Treaty's provisions, but its inspection program is weak. *See generally* Vaughn, *Nuclear Diversion: An International Problem in Need of International Solution*, 17 ATOM. ENERGY L.J. 179 (1975); Note, *Nuclear Proliferation: Dim Prospects for Control*, 3 BROOKLYN J. INT'L L. 57 (1976).

317. D. ROSENBAUM, J. GOOGIN, R. JEFFERSON, D. KLEITMAN & W. SULLIVAN, SPECIAL SAFEGUARDS STUDY, ATOMIC ENERGY COMMISSION, *reprinted at* 120 CONG. REC. 12,353 (1974). If a terrorist group were able to get possession of 5-10 kilograms of plutonium metal or oxide it might be able to construct a crude nuclear weapon. T. TAYLOR & M. WILLRICH, NUCLEAR THEFT: RISKS AND SAFEGUARDS 14-21 (1974). Terrorists might also release pluton-

well as the possible threat to civil liberties that anti-terrorism measures might involve.[318] Finally, there is the risk of exposure to radiation resulting from accidents during the transportation of pure plutonium.[319]

For these reasons, it seems likely that the throwaway option will be chosen over the recycling alternative. Nevertheless, it would be imprudent to formulate a final program for waste disposal until a decision on fuel cycle alternatives is actually made —a prospect which may be years away. Consequently, America's present policy for commercially produced radioactive waste should emphasize storage rather than disposal.

The most urgent problem is spent fuel storage. Many nuclear power plants are running out of on-site storage space for their spent fuel. The use of compaction techniques has provided some respite, but it is obvious that additional storage facilities must be constructed. DOE is proposing to accept spent fuel from private utilities for storage, but at the moment has no away-from-reactor (AFR) facility capable of storing such material. Therefore, it is recommended that DOE proceed with the construction of several AFR facilities.[320] Water-cooled basins should be used in these first AFR facilities since the technology of water cooling methods has already been developed. If additional AFR storage is subsequently required, newer facilities might use a passive air-cooled system such as the system suggested in ERDA's SURFF proposal.[321]

Once the problem of spent fuel storage is resolved, the next step is to formulate a plan for disposing of radwaste permanently. Only tenative proposals can be made as long as the fuel recycling

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ium into the atmosphere using conventional explosions or simply relying on the wind. *See* Deinken, *Malevolent Acts and Nuclear Power: Additional Protection Under NEPA and the Energy Reorganization Act of 1974,* 16 ARIZ. L. REV. 920, 928 (1974).

318. *See* Comment, *Policing Plutonium: The Civil Liberties Fallout,* 10 HARV. C.R.-C.L. L. REV. 369 (1975).

319. With recycling, plutonium oxide would be shipped from the reprocessing plant to the fuel fabrication plant. Plutonium in mixed-oxide fuel assemblies would also be shipped from the fuel fabrication plant to the various nuclear power plants. The NRC estimates that there will be more than 100,000 plutonium shipments annually by the year 2020, mostly by truck. *See* Comment, *The Plutonium Society: Deterrence and Inducement Factors,* 41 ALB. L. REV. 251, 260-61 (1977) (Citing *Oversight Hearings on Nuclear Energy Before the Subcomm. on Energy and the Environment of the House Comm. on Interior and Insular Affairs,* 94th Cong., 1st. Sess., pt. 1, at 797-98 (1975). For a discussion of the probability and consequences of transportation accidents, see GESMO, *supra* note 169, at II-45 to II-48.

320. The NRC concluded in its draft environmental impact statement on spent fuel storage that six pools of 7000 metric ton capacity would be sufficient to handle spent fuel storage until tbe year 2000. 21 NUCL. NEWS 21A (mid-Apr. 1978).

321. *See* text accompanying notes 241-42 *supra.*

issue remained unresolved. Under a throwaway approach, disposal of the spent fuel itself is necessary while under a recycling approach, disposal of reprocessing waste is needed. If recycling is desired, reprocessing waste will need to be converted into glass or ceramic form. Some preliminary planning is possible under this option because spent fuel and solidified reprocessing waste have many characteristics in common. In both cases, fission products such as strontium-90 and cesium-137 are the primary sources of radioactivity and heat. In both cases most of the waste material would be incorporated in a stable glass or ceramic substance. There are, of course, some significant differences. For example, volatile fission products such as radioactive iodine and krypton are removed from reprocessing waste, but remain present in spent fuel. In addition, most of the plutonium is removed from reprocessing waste, although other transuranic elements would still be present. In contrast, all of the transuranics, including plutonium, are present in spent fuel.

Despite the differences between spent fuel and solidified reprocessing waste, deep burial in underground geologic formations appears to be suitable as a method of permanent disposal for either form of high-level waste.[322] Accordingly, preliminary planning should be directed toward this approach. Preliminary measures would include site selection and perhaps the construction of prototypes or intermediate scale facilities (ISF's). Some of this initial work could probably be combined with military waste disposal programs. It has been suggested, for example, that the WIPP facility at New Mexico be designed to handle both military and civilian radwaste, including spent fuel.

The actual construction of full-scale disposal facilities for commercial radwaste should still be postponed until the final decision on fuel recycling has been made. This means that spent fuel must continue to be stored either in near surface (SURFF) facilities or in retrievable deep underground sites. This clearly involves some risk, but it permits the United States to defer a decision on fuel recycling until the end of the century, and also allows more time to develop better waste disposal technology and to learn about the behavior of radioactive waste in various geologic environments. This is an acceptable trade-off in light of the present unsettled state of the energy situation.

This article proposes a program that will deal with the various waste management problems in an orderly sequence. In the first stage, military waste will be solidified and AFR facilities

322. *See* note 263 *supra*.

will be constructed for the storage of spent fuel from commercial reactors. Next, facilities for the permanent disposal of military waste would be constructed in bedded salt and possibly other geologic formations. Finally, once a decision on fuel recycling is made by the federal government, work can commence on facilities for the permanent disposal of high-level waste from civilian nuclear power plants, whether it be in the form of spent fuel or solidified reprocessing waste. It is believed that a systematic approach such as this will avoid both precipitate action and unconscionable delay in the development and implementation of a comprehensive high-level waste management program.

C. *Remaining Problems in Radioactive Waste Management*

The program described above is only one of the possible approaches which might be chosen to manage high-level radwaste. However, regardless of which alternative is selected, there are additional problems which must be overcome. The first is securing a reasonable degree of public acceptance for whatever program is adopted; the second is developing sufficient managerial capability to ensure that the program will be carried out effectively.

1. PUBLIC ACCEPTANCE OF THE PROGRAM

Once a waste management program is formulated, it must achieve a reasonable degree of public acceptance if it is to be implemented successfully. However, for various reasons, the government may find it difficult to generate much popular support for any specific nuclear waste management program. Nuclear energy has become a target of the anti-technology movement,[323] and increasingly is unpopular in both political and nonpolitical circles. Therefore, any waste management proposals which seem to make further use of nuclear power more realizable are likely to be viewed negatively by a certain segment of the public. Other members of the public are concerned about the risk distribution aspects of nuclear waste management. This is a serious problem because the unavoidable risks of nuclear waste management almost certainly will not be shared equally by members of the public. Many of these risks will be borne by those who derive little or no benefit from nuclear power.[324]

323. Rowe, *Governmental Regulation of Societal Risks*, 45 GEO. WASH. L. REV. 944, 947 (1977).

324. *See* text accompanying notes 304-08 *supra*.

Another factor inhibiting public acceptance of radioactive waste management is popular suspicion of governmental decisionmaking procedures. Regulatory agencies such as the NRC rely heavily on cost-benefit and risk assessment calculations in their decisionmaking. However, these techniques are not reliable when inadequate data are relied on or when faulty methodologies are utilized.[325] Moreover, even when these techniques are used properly, they sometimes cause the agency to obscure or minimize significant policy issues.

In addition, the procedures employed sometimes unduly limit public participation. In particular, the NRC has tended to resolve radioactive waste management issues by utilizing rulemaking procedures which prohibit discovery or cross-examination.[326] Unfortunately, this weakens public confidence in the integrity of the decisionmaking process, particularly in the minds of anti-nuclear groups. Consequently, the federal agencies involved in nuclear waste management should give full and frank consideration to criticisms and opposing views or they will almost certainly have a problem with public acceptance of the program.

2. IMPLEMENTATION OF THE PROGRAM

Developing a program is one thing, putting it into successful operation is quite another. The present involvement of so many federal agencies in the nuclear waste management process[327] raises serious questions about the ability to administer even a well-designed program. The current regulatory framework, with its overlapping areas of jurisdiction, invites competition rather than cooperation among the agencies. Congress will have to simplify these agency relationships if the program is to function smoothly and efficiently. One solution would be to vest the sole authority over all phases of high-level radioactive waste management in a single federal agency. Perhaps a new agency or government corporation could undertake this responsibility.

In addition to the organizational issue, there is the question

325. *See generally* Lovins, *Cost-Risk Benefit Assessments in Energy Policy*, 45 GEO. WASH. L. REV. 911 (1977).

326. *See* Natural Resources Defense Council v. Nuclear Regulatory Comm'n, 547 F.2d 633 (D.C. Cir. 1976), *rev'd sub nom.*, Vermont Yankee Nuclear Power Corp. v. Natural Resources Defense Council, 435 U.S. 519 (1978). For comments on the NRC's rulemaking procedures and the *Vermont Yankee* Decision, see Breyer, *Vermont Yankee and the Courts' Role in the Nuclear Energy Controversy*, 91 HARV. L. REV. 1833 (1978); Byse, *Vermont Yankee and the Evolution of Administrative Procedure: A Somewhat Different View*, 91 HARV. L. REV. 1823 (1978); Stewart, *Vermont Yankee and the Evolution of Administrative Procedure*, 91 HARV. L. REV. 1805 (1978).

327. *See* text accompanying notes 175-89 *supra*.

of managerial capability. Almost all of the past incidents involving nuclear waste have resulted from inadequate management rather than from technological failure. The operational problems of the fuel reprocessing plant at West Valley, New York, the contamination of ground water at Maxey Flats, Kentucky, and the theft of radioactive articles at Beatty, Nevada are all examples of inadequate regulation or supervision.[328] The leaks of radioactive wastes at Hanford, Washington resulted from poor planning and inspection practices, while the poor site selection choice, at Lyons, Kansas and the use of radioactive fill at Grand Junction, Colorado were caused by failure to obtain adequate information before proceeding with an activity.[329] Though corrective action was eventually taken in each of these instances, they nevertheless suggest a disturbing pattern of short-sightedness, sloppiness, and incompetence. Examples of managerial weakness in the nuclear power area are not limited to radioactive waste management. The incident at the Three Mile Island nuclear power plant near Harrisburg, Pennsylvania raises additional questions about man's ability to manage something as complex and dangerous as nuclear power.

This lack of managerial capacity is one of the most distrubing aspects of nuclear power. Of course, to some extent this is a problem with using any complex technology. However, nuclear power is a particularly "unforgiving" technology. There are few other areas of human endeavor where small errors can produce such long-lived and disasterous consequences.

V. CONCLUSION

Nuclear power not only presents a challenge to our technological ability, but also to our social and political institutions.[330] In the words of one commentator:

> We nuclear people have made a Faustian bargain with society. On one hand, we offer . . . an inexhaustible source of energy. . . . But the price that we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to.[331]

Nuclear waste management, therefore, presents our society with a challenge. Technology cannot prudently continue to be

328. *See* text accompanying notes 131-34 *supra*.

329. *See* text accompanying notes 280-82 *supra*.

330. *See generally* Mishan, *On Making the Future Safe for Mankind*, 24 THE PUB. INTEREST 33 (1971); Tribe, *Technology Assessment and the Fourth Discontinuity: The Limits of Instrumental Rationality*, 46 S. CAL. L. REV. 617 (1973).

331. Weinberg, *Social Institutions and Nuclear Energy*, 177 SCI. 27, 33 (1972).

used when its adverse effects on present and future generations remain uncontrollable. Our ability to manage radioactive waste is thus a test of our capacity to live with nuclear power.[332]

The next few years will be critical. If the United States can formulate a radioactive waste management program and begin the construction of waste storage and disposal facilities, it will have made considerable progress toward resolving its nuclear dilemma. On the other hand, continued failure to solve the problem of radioactive waste disposal casts doubt on our ability to manage nuclear power technology in a responsible manner.

332. Of course, nuclear weapons programs also produce high-level radioactive waste and, therefore, raise the same moral issue. However, while it might be argued that our continued survival ás a nation requires the possession of nuclear weapons, the case for nuclear power is not nearly as strong.