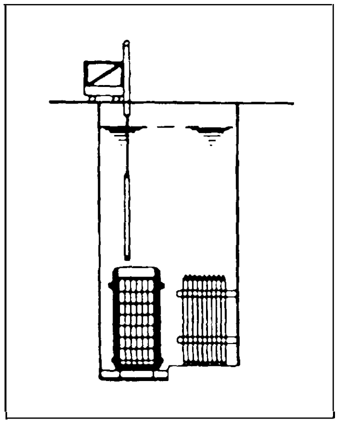
Decommissioning Nuclear Power Plants 4

When a nuclear plant is retired, decommissioning is performed to protect both public health and safety and the environment from accidental releases of remaining radioactivity. As defined by U.S. Nuclear Regulatory Commission (NRC) rules, decommissioning involves removing a reactor safely from service and reducing residual radioactivity to a level that allows a site to be released for unrestricted use, thereby allowing license termination.[1] Under NRC rules, decommissioning activities—such as plant decontamination, reactor dismantlement, and waste removal—can be performed within a few years or extended over many decades. Although current NRC rules favor the completion of decommissioning within 60 years after final plant shut down, the Commission will extend that period if necessary to protect public health and safety.[2] The lack of waste disposal capacity or the presence of other nuclear units on a site are two circumstances that could extend decommissioning periods beyond the current 60-year goal.[3]

Three general decommissioning approaches are recognized by nuclear professionals in the United States: DECON, SAFSTOR, and ENTOMB. The first approach, DECON, involves the immediate dismantlement of radioactively contaminated structures to a level allowing the site to be released for unrestricted use. SAFSTOR involves placing a nuclear plant into safe storage, followed years or decades later by sufficient decontamination and dismantlement to allow site release. The last approach, ENTOMB, involves partial dismantlement followed by the



[1] 10 CFR 30.4, 40.4, 50.2, 70.4, and 72.3.

[2] 10 CFR 50,82 [b)(l)(i). If necessary to protect public health and safety, the U.S. Nuclear Regulatory Commission (NRC) will extend the allowable decommissioning period to about 100 years. 53 *Federal Register 24023* (June *27, 1988).*

[3] 10 CFR 50.82 @)(l) (iii).


SOUTHERN CALIFORNIA EDISON CO

The oldest and smallest of the three units at the San Onofre Nuclear Generating Station (at the far left of the photo) was retired in 1992 after over 24 years of operation. The presence of the two remaining operating units is a factor considered in decommissioning planning for unit one.

encasement of remaining radioactive contaminants in durable materials such as concrete and monitoring a site until sufficient radioactive decay has occurred to allow release for unrestricted use. The best approach will vary by plant and depend upon site-specific conditions, such as the level of radioactive contamination at shutdown, expected land uses, projected labor rates, waste disposal options and costs, and current and anticipated regulatory radioactivity standards.

Rather than technological adequacy, the major uncertainties associated with commercial nuclear power plant decommissioning are the potential impacts of future residual radioactivity standards, limited and dwindling waste disposal options, and cost projections, the reliability of which will improve with the resolution of these other uncertainties. While the technology exists to remove the radiological hazard at individual plant sites, residual radioactivity standards have not been promulgated by the NRC or the U.S. Environmental Protection Agency (EPA). In addition, States may impose nonradiological cleanup requirements at sites (e.g., site restoration) or perhaps additional radiological requirements after NRC license termination. Moreover, the feasibility and costs of long-term radioactive waste storage and disposal remain unclear, both for low-level wastes (LLW) and spent nuclear fuel. These factors create major uncertainties in the anticipated schedules and projected costs of decommissioning commercial nuclear power reactors. With the recent retirement of several large operating reactors, this may be an opportune time to evaluate the national policies, regulatory standards, economics, public concerns, and other uncertainties (particularly waste disposal options) associated with commercial nuclear power plant decommissioning. For example, the 40-year operations period assumed for the collection of decommissioning funds has proven optimistic for several plants and may be optimistic for many others.

Although decommissioning costs are relatively small compared to total plant capital and operations expenses, prematurely retired plants may face significant decommissioning funding shortfalls, because they collected these funds for less time than expected. Although financially healthy utilities will generally be able to cover such shortfalls through increased electricity rates, insurance, credit, and other options, there are potentially serious intergenerational equity issues associated with collecting the bulk of decommissioning funds *after* plant closure. That is, based on current trends, future ratepayers may have to cover most of the costs of commercial nuclear power decommissioning without having received any of the electricity from a retired unit.

RESIDUAL RADIOACTIVITY STANDARDS: HOW CLEAN IS CLEAN ENOUGH?

Residual radioactivity standards define the level of clean up necessary at sites undergoing decommissioning. Depending on their nature and stringency, such standards may have major impacts on decommissioning timing and costs, waste generation, occupational and public health and safety, and the potential future uses of remediated sites.

Under current NRC decommissioning criteria, sites eligible for unrestricted use may contain some radioactivity above natural background levels—no more than 5 additional microrems (10^{-6} rems) of surface contamination per hour.[4] The NRC is currently developing a rule to establish residual radioactivity standards, and their ultimate nature and stringency could differ substantially from the current, less formal guidance, potentially altering the expected scope and costs of decommissioning. Possible residual radioactivity standards discussed during NRC public meetings held in 1993 ranged from doses of 0.03 to 60 millirems (10^{-3} reins) per year, a difference of three orders of magnitude. Based on the best available evidence (see ch. 2), these dose levels translate to lifetime cancer mortality risks ranging from one case per million to two cases per thousand exposed individuals, respectively.[5] Until final standards are promulgated, commercial power licensees and the public will remain uncertain about the residual health risks, cleanup costs, and other impacts of decommissioning nuclear power plants.

The practice of allowing low levels of residual radioactivity after facility closure occurs at many kinds of radiologically contaminated sites, including oil and natural gas drilling operations, nuclear and coal-freed electric power stations, and uranium and thorium mill tailing sites. Similar to other site remediation efforts, including those for containing hazardous chemicals, the potential risk at nuclear sites under current NRC decommissioning criteria is reduced significantly but not eliminated entirely.

Internationally, residual radioactivity criteria are generally developed on a case-by-case basis and are commonly based on safety guidance published by the International Atomic Energy Agency (IAEA).[6] The IAEA guidance is risk-based, similar to existing NRC criteria, and finds that an individual exposure limit of several millirems per year from exempted materials represents a sufficiently small risk. To account for multiple exposure pathways (air, water, soil), the IAEA guidance recommends a limit of 1 millirem per year for each exempted practice. To date, most European nations have applied the principles of this IAEA guidance when setting residual radioactivity criteria for sites, but their major application has been in establishing recycling criteria for radiologically contaminated materials, not in decommissioning.[7]

The negative U.S. public and political reaction to the 1990 "below regulatory concern" (BRC) policy may indicate potential problems with the current NRC residual radioactivity criteria, as the NRC pursues a rulemaking to establish uniform remediation standards for decommissioning (box 4-A). Among other items, the 10 millirem annual exposure limit was a key element of the controversial policy, but current NRC decommissioning criteria of 5 microrem per hour above background would allow an unshielded individual present at the site 6 hours per day to receive roughly the same added annual exposure. In terms of cancer mortality, the best available evidence suggests that an annual exposure of 10 millirems translates

[4] This criterion applies to measurements made at 1 meter from the source, U.S. Nuclear Regulatory Commission, *Termination of Operating Licenses for Nuclear Reactors,* Regulatory Guide 1.86, June 1974, p. 5; and "Radiation Criteria for Release of the Dismantled Stanford Research Reactor to Unrestricted Access,' NRC letters to Stanford University, Mar. 17, 1981 and Apr. 21, 1982. For a discussion of these guidance documents, see U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 (Washington, *DC:* August 1988), p. 2-12.

[5] 58 *Federal Register 33573* (June 18, 1993).

[6] International Atomic Energy Agency, *Principles for the Exemption of Radiation Sources and Practices from Regulatory Control,* Safety Series No. *89* (Vienna, Austria: 1988).

[7] U.S. Nuclear Regulatory Commission "International Decommissioning Activities, " unpublished paper.

Box 4-A-Residual Radioactivity Standards and the NRC Enhanced Participatory Rulemaking

An enhanced participatory rulemaking to develop residual radioactivity standards was first proposed by the U.S. Nuclear Regulatory Commission (NRC) in June 1991. While many rulemaking efforts solicit public input after a standard or guideline has been proposed, the NRC is using this process to solicit comments from affected parties in advance of a rule proposal. To enhance participation, the NRC held seven public meetings between January and May 1993 in different regions of the United States (Chicago, San Francisco, Boston, Dallas, Philadelphia Atlanta, and Washington, DC). The meetings provided a forum to hear public concerns relating to residual radioactivity standards, including their nature and stringency. Under its current schedule, the NRC expects to publish final residual radioactivity standards by May 1995.[1]

The rulemaking on residual radioactivity standards has emerged from failed attempts in the last several years to determine when either licensed materials or sites warranted no further regulatory attention due to sufficiently low levels of radioactivity. The history began with the passage of the Low-Level Radioactive Waste Policy Amendments Act of 1985 (P.L. 99-240; LLRWPAA), which directed the NRC to determine a threshold of radioactivity in waste streams below which regulatory concern was not warranted.[2] In response to that legislation, the NRC published two below regulatory concern (BRC) policy statements (1986 and 1990). The 1986 statement outlined criteria and procedures for the expedited review of BRC petitions to exempt materials from the standard requirements for low-level waste management and disposal.[3] In 1990, the NRC published the second BRC policy statement that proposed individual dose criteria between 1 and 10 millirems (mrem) per year and a collective dose criterion of 1,000 person-rem per year.[4]

In establishing these BRC criteria-about 0.3 to 2.8 percent of current annual U.S. background exposure levels of 360 mrem--the NRC reasoned that the levels were comparable to levels of radiological risk normally accepted by the public (both voluntarily and involuntarily) from other activities (e.g., 5 mrem is a typical exposure for roundtrip flights between the east and west coasts of the United States). The NRC noted that far greater variability than 1 to 10 mrem occurs from natural background exposures in different U.S. regions, such as a difference of over 60 millirems for residents of Denver, Colorado compared to those of Washington, DC.[5]

1 Francis Cameron, Office of the General Counsel, U.S. Nuclear Regulatory Commission, public statement during NRC participatory rulemaking meeting, Arlington, VA, May 6,1993.

2 Public Law 99-240,99 Stat. 1859, Sec. IO(a).

3 51 Federal Register 30839 (Aug. 29,1986).

4 55 *Federal Register* 27522 (July 3, 1990).

5 55 *Federal Register* 27526-27527 (July 3, 1990).

to an incremental annual risk of five cases per million individuals and a lifetime risk (assuming continuous exposure at that level) of about 4 cases per ten thousand.[8] Depending on the site, however, States, local authorities, and the public may have different expectations about acceptable levels of residual radioactivity and health risks. In many cases, the levels of residual radioactivity implied by current NRC guidance maybe acceptable if site access and use are restricted. In other cases, State, local, or public concerns about future land uses at decommissioned sites may overshadow regulatory decisions over the selection of any quantitative radioactivity standards.

8 55 *Federal* Register 27527 (July 3, 1990).

Severe public and congressional reaction to the July 1990 BRC proposal prompted the NRC to place an indefinite moratorium on the policy statement shortly after it was issued. In particular, testimony delivered at congressional hearings held the same month the policy was issued indicated several major concerns about the BRC policy, including the potential to pre-empt State authority to establish more stringent standards, a concern that a great deal of BRC material could be disposed of in ordinary landfills, the lack of clear assurances that the NRC would be able to track and enforce compliance, and the fact that the maximum allowable exposure from releasable materials (10 mrem) was two and one-half times the U.S. Environmental Protection Agency (EPA) drinking water standard (4 mrem).[6] Two years later, the Energy Policy Act of 1992 revoked the NRC's BRC policy statements entirely.[7]

After placing the initial moratorium on the BRC policy statements, the NRC proposed a "BRC consensus process" in 1991 to convene representatives from major groups interested in the development and implications of a BRC policy. That process, however, was canceled several months later when a major environmental group declined to participate.

With regard to decommissioning, three of its most important aspects are affected directly by BRC-type criteria, whether pre-established by formal standards or ad hoc:

1. The residual radioactivity levels that determine when a site can be released for unrestricted use (the current goal of decommissioning);
2. The amount of radioactive waste requiring special disposal; and
3. The extent to which slightly contaminated material maybe reused or recycled in general commerce.

By March 1992, the NRC decided to abandon a generic BRC approach and develop instead specific standards for different licensee activities-such as residual radioactivity standards for decommissioning-in separate rulemakings. Therefore, the moratorium on the BRC policy statements and the termination of the BRC consensus process led to the separate treatment of residual radioactivity standards in the current enhanced participatory rulemaking.

ADDITIONAL SOURCES: 57 *Federal Register* 58727-58730 (Dec. 11, 1992): 10 CFR Part 20, Radiological Criteria for Decommissioning of NRC-Licensed Facilities; Workshops.

U.S. Nuclear Regulatory Commission, Office of the General Counsel, "Proposed Rulemaking To Establish Radiological Criteria For Decommissioning: Issues For Discussion At Workshops," unpublished paper.

U.S. Nuclear Regulatory Commission, "Briefing on Rulemaking Process for Developing Residual Radioactivity Standards for Decommissioning," Mar. 11, 1992, unpublished briefing transcript.

6 See various testimony at hearings before the House Subcommittee on Energy and the Environment, Committee on Interior and Insular Affairs, Hearings on the Nuclear Regulatory Commission's Below Regulatory Concern (BRC) Policy, Juiy 26, 1990, Serial No. 101-29.

7 Public Law 102-466, 106 Stat. 3122, Sec. 2901(b).

Public acceptance of minimal radioactive releases at operating nuclear facilities suggests that low levels of radioactivity are less of a concern if land use is restricted and regulatory oversight is maintained. For example, in the context of commercial nuclear power operations, regulatory criteria specifying acceptable levels of radioactive releases are prescribed and enforced, such as the release of small quantities of tritium to local surface water. Such releases have been made at plant sites for decades,[9] but there has been no major, visible public effort to ban them.

Even with restricted land uses and some maintenance of regulatory oversight, however,

9 Kenneth Carr, Chairman, U.S. Nuclear Regulatory Commission, testimony at hearings before the House Subcommittee on Energy and the Environment, Committee on Interior and Insular Affairs, July 26, 1990, Serial No. 101-29, p. 85.

the public may have concerns about the consistency of residual radioactivity standards for decommissioning with other Federal and State radiological standards. For example, the current EPA standard for residual radioactivity at inactive uranium processing sites (40 CFR 192.12) is four times higher (at 20 microrems per hour above background levels) than current NRC criteria for decommissioned nuclear power plant sites. In addition, many view the regulatory risk goals for limiting cancer risks after radiological cleanups as inconsistent with those for hazardous chemical cleanups.[10] Such discrepancies—perceived or real--could complicate the development and implementation of future residual radioactivity standards and decommissioning plans.

The NRC is pursuing an "enhanced participatory rulemaking" to develop formal residual radioactivity standards for decommissioning.[11] Issues raised during public meetings include the following:

- whether to allow *restricted* land uses at some sites as an alternative to unrestricted release;
- ensuring consistency between proposed standards and existing federal health and safety regulation;
- determining the appropriate level and distribution of radiological and nonradiological risks from decommissioning, LLW disposal, and waste transportation;
- determining the nature of licensee responsibility for residual radioactivity *after* a license is terminated; and
- ensuring the development of clear testing criteria and the existence of adequate technology to measure and verify compliance with any promulgated standards.

By addressing these concerns, the NRC will improve the likelihood that States, local authorities, licensees, and the public will accept future residual radioactivity standards. In addition, the role and legal authority of both the NRC and the EPA, if any, at retired plant sites may require clarification, particularly in case additional cleanup is required after an NRC license has been terminated. Understanding the regulatory roles of both the NRC and the EPA after site release may be critical to participating States, local authorities, licensees, and the public as residual radioactivity standards are developed. In general, if Federal agencies exercise no role or appear to have little or no authority at plant sites after license termination, many parties may expect more stringent cleanup levels than might otherwise be selected.

Under the current regulatory definition, the only expected outcome of decommissioning is license termination and site release for *unrestricted* use (e.g., 10 CFR 50.2). In some cases, however, cleanup to a level suitable for unrestricted use may be neither necessary for public health and safety nor economically desirable, because the expected radiation exposures at a decommissioned power plant site will vary depending on its subsequent use. For example, agricultural activities at released plant sites would introduce different exposure pathways and doses than residential use of the same area.[12] Rather than introduce the added occupational risk and economic cost of remediating a site to permit any activity whatsoever (such as farming), a better option at some sites maybe remediation to a level allowing restricted use for select activities, such as continued power production, provided that future exposures from those activities will com-

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10 See, for example, S.L. Brown, "Harmonizing Chemical and Radiation Risk Management," *Environmental Science and Technology,* vol. 26, No. 12, 1992, pp. 2336-2338.

11 57 *Federal Register 58727-58730* (Dec. 11, 1992).

12 W.E. Kennedy, Jr., D.L. Strenge, Battelle Pacific Northwest Laboratory, *Residual Radioactive Contamination From Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent,* NUREG/CR-5512, vol. 1 (Washington DC: U.S. Nuclear Regulatory Commission, October 1992).

ply with regulatory goals and standards for the protection of public and occupational health and the environment.

Power plant sites are developed industrial facilities, generally located near water, transport, and electrical infrastructure. As a result, some sites may be better-suited for further power production or other industrial activities, rather than other uses such as farming or public recreation. Therefore, remediating a site to allow future uses that are unlikely to occur may be unwarranted from a health protection or economic perspective. At the same time, States, local authorities, and the public may accept or prefer restricted land uses or access at some former nuclear facility sites based on concerns about health and safety from any residual radioactivity on site.

To increase the options to perform site cleanups that protect public health and the environment and that are economically feasible, alternatives to unrestricted use may be worth considering, such as restricted use for other industrial purposes, Thus, more than one decommissioning goal (unrestricted use) and more than one residual radioactivity standard may be appropriate. Given the extended periods allowed for some decommissioning methods (SAFSTOR, ENTOMB), restricted use is already practiced at many sites with retired nuclear plants. That is, current regulations allow an extended period of restricted use before final site release, and the concept may be worth extending beyond license termination.

Residual radioactivity standards have implications for both radiological and nonradiological risks during and after decommissioning. Similar to most hazardous chemical remediation, nuclear decommissioning does not eliminate, but rather isolates and transfers, contaminants from one site (such as a nuclear power plant, a research laboratory, or a medical clinic) to another (the treatment, storage, or disposal sites). Decommissioning crews operate a variety of electrical and mechanical equipment to decontaminate and demolish retired facilities, while waste transport to disposal sites adds risks to haulers and other people living beyond the plant site.

Each unit of radiological contamination removed from a site, therefore, confers both radiological and nonradiological risks on and offsite. As a result, the nature and stringency of residual radioactivity standards will determine how much material will require isolation and transport and will affect the balance of total radiological and nonradiological risks associated with decommissioning. As these comments suggest, decisions about ‘‘how clean is clean enough? are fundamentally decisions about the acceptable levels and distribution of the risks associated with decommissioning.

Other important aspects of residual radioactivity standards are measurability and verification, which become increasingly difficult as standards become more stringent, particularly in the range of a few millirems or less.[13] Background radiation levels on any land area may vary several millirems or more, depending on the exact location sampled, its geology, and the weather. Therefore, measuring and verifying compliance with residual radioactivity standards may be difficult and may affect decommissioning practicability and project costs if their stringency approaches background levels. Such stringent cleanup levels may also compel some licensees to remediate site radioactivity associated with previous, allowed releases.

Finally, residual radioactivity standards may have substantial impacts on final decommissioning costs, because they will determine the amount of material requiring removal and disposal. The current NRC financial assurance rules (discussed below), as well as most cost estimates performed by private contractors, assume final residual radioactivity levels given in the current NRC

[13] William Dornsife, Director, Bureau of Radiation Protection, Pennsylvania Department of Environmental Resources, personal communication, May 6, 1993.

guidance, but those levels may change in the future. At present, estimates of decommissioning costs typically assume residual radioactivity standards no more stringent than about 10 millirems per year,[14] the level specified in the now revoked BRC policy, but the NRC, States, local authorities, or the public may expect more stringent standards in the future.

RADIOACTIVE WASTE DISPOSAL

The essential challenge of decommissioning is to remove and dispose of radioactive waste, while keeping occupational and other exposures as low as possible. There are three major classes of commercial nuclear plant waste, based on the composition and radioactivity of the materials involved: LLW, mixed LLW, and high-level waste (HLW).[15] All three kinds of waste are generated from both operating and decommissioning nuclear power reactors. LLW represents more than 99 percent of the volume of all commercial nuclear waste but less than 0.1 percent of the total radioactivity. Spent nuclear fuel, on the other hand, the only HLW form in the commercial nuclear power industry, represents less than 1 percent of the volume, but more than 99.9 percent of the radioactivity, of commercial nuclear waste.[16] The other major class, mixed waste, is a special subset of LLW composed of both radioactive and hazardous chemical elements, which poses a special problem for Federal regulators (discussed below).

Waste disposal is a major portion of expected decommissioning costs. The estimated cost of shipping and disposing LLW is over one-third of the total estimated cost of DECON (immediate dismantlement) decommissioning for very large (more than 1,100-megawatt (MW)) electric light water reactors.[17] This section reviews the classification of major decommissioning wastes, projections of the amounts generated, and disposal options.

Low-Level Waste

The Low-Level Radioactive Waste Policy Act (Public Law 96-573; LLRWPA) and the Low-Level Radioactive Waste Policy Amendments Act of 1985 (Public Law 99-240; LLRWPAA) defined LLW by what it is not: radioactive waste not classified as HLW, spent nuclear fuel, or

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14 See, for example, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 (Washington, DC: August 1988), pp. 2-12 to 2-13.

15 Two other classes of radioactive waste—uranium mill tailings and transuranic waste—exist but are not associated with commercial nuclear power plant decommissioning and consequently are not discussed in this report. (Uranium mill tailings are generated by uranium ore processing and contain very low radioactivity. Transuranic (TRU) waste also contains very low radioactivity (akin to LLW) and is composed of long-lived radioactive elements heavier than uranium (hence the name); TRU waste is mostly plutonium and derives almost exclusively from nuclear weapons production,) M. Holt and J.E. Mielke, *Civilian Radioactive Waste Management: Technical and Policy Issues, 91-867* ENR (Washington DC: Congressional Research Service, Dec. 10, 1991), pp. 4,27.

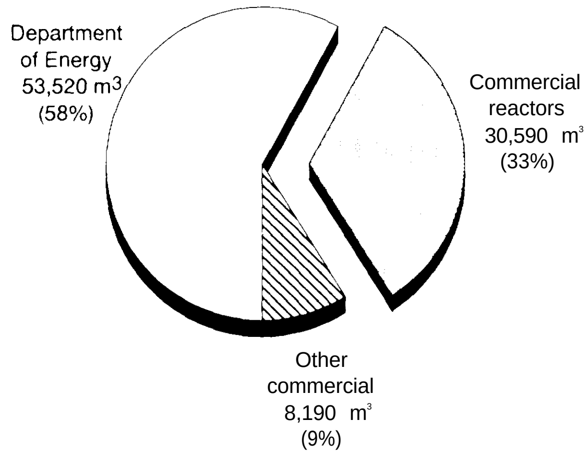
16 At the end of 1991, the sum of commercial LLW disposed of historically in the United States amounted to 1.4 million cubic meters with a total activity of about 5.7 million curies. By comparison, commercial spent fuel volumes totaled about 9,500 cubic meters, with a total activity of 23.2 billion curies. U.S. Department of Energy, *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics,* DOE/RW-0006, Rev. 8 (Washington, DC: October 1992), pp. 9, 14. A curie (Ci) is a common measure of radioactive decay, representing 37 billion disintegrations per second.

17 The estimate varies depending on whether the reactor is a BWR (34 percent) or a PWR (38 percent). G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station: Technical Support for Decommissioning Matters Related to Preparation of the Find Decommissioning Rule,* NUREG/CR-0672, Addendum 3 (Washington, DC: U.S. Nuclear Regulatory Commission, July 1988), p. 3,1; and G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station: Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule,* NUREG/CR-0130, Addendum 4 (Washington, DC: U.S. Nuclear Regulatory Commission, July 1988), p. 3.1. As shorthand, the NRC study reactors are referred to as the "reference reactors" in this report. The cost estimates shown here represent the shipment and disposal of all LLW and the *shipment only* of spent fuel. Delays in developing a national geologic repository for commercial spent fuel, however, may require many licensees to construct interim storage capacity on their sites, an unanticipated and costly enterprise discussed in more detail inch. 3.

uranium or thorium mill tailings and mill wastes is LLW.[18] Roughly 92,000 cubic meters (m^3) (or 3,249,000 cubic feet (ft^3)) of LLW are disposed annually in the United States. Most (about 58 percent) stems from U.S. Department of Energy (DOE) activities, including defense programs, uranium enrichment, naval propulsion, and research and development (R&D) projects (figure 4-l). Commercial nuclear power production—including uranium conversion, fuel fabrication, and power plant operations—accounts for another 33 percent. Other commercial enterprises, such as radiochemical manufacturers, laboratories, hospitals, universities, and medical schools, account for the remaining 9 percent. 19

LLW is produced during nuclear power plant operations, repair and maintenance outages, and decommissioning (box 4-B). In 1990, operating pressurized water reactors (PWRs) in the United States disposed an average 108 m^3 of solid LLW, less than one-fifth of the 1980 average (figure 4-2). The same year, operating boiling water reactors (BWRs) disposed an average 301 m^3 of solid LLW, less than one-third of the 1980 average (figure 4-3).[20] Typical solid LLW includes contaminated worker clothing, gloves, equipment, and tools. Operating plants also generate some wet LLW, which consists of spent ion exchange resins (used to regenerate chemical decontaminants), plant sludges, and evaporator concentrates.[21]

Figure 4-l-Sources of Low-Level Waste in the United States, 1991



SOURCE: U.S. Department of Energy, *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics,* DOE/RW-0006, Rev. 8 (Washington, DC: October 1992), pp. 117, 121.

Rising disposal costs in the 1980s spurred LLW volume reductions, largely from waste compaction and improved management (waste segregation, storage, evaporation, and incineration).[22] Between 1980 and 1991, annual commercial LLW disposal volumes decreased from about 100,000 m^3 (3.5 million ft^3) to 34,000 m^3 (1.2 million ft^3),[23] even with the addition of many new nuclear power plants, the major source of commercial LLW.

The NRC distinguishes four LLW types, ranked by increasing radioactivity: Class A, Class

18 42 U.S.C. 202 l(b).

19 U.S. Department of Energy, *Integrated Data Base for 1992: US. Spent Fuel and Radioactive Waste Inventories, projection, and Characteristics*, DOE/RW-0006, Rev, 8 (Washington, DC: October 1992), pp.117, 121. Cubic meters are converted to cubic feet by dividing the former by 0.0283168.

20 Institute of Nuclear Power Operations, ''1990 Performance Indicators for the U.S. Nuclear Utility Industry' (Atlanta, GA: March 1991). Note: More recent figures for LLW produced by commercial power plants are available from INPO but are no longer given as averages, preventing simple comparisons with earlier data, As a result, the more recent figures are not given here.

21 S.W. Long, *The Incineration of Low-Level Radioactive Waste: A Report for the Advisory Committee on Nuclear Waste*, NUREG-1393 (Washington, DC: U.S. Nuclear Regulatory Commission, June 1990), p. 2.

22 See, for example, U.S. Department of Energy, Office of Environmental Restoration and Waste Management, *1991 Annual Report on Low-Level Radioactive Waste Management Progress, DOE/EM-0091P* (Washington, DC: November 1992), pp. B-3 to B-4.

23 W.R. Hendee, ''Disposal of Low-Level Radioactive Waste: Problems and Implications for Physicians,' Special Communication% *Journal of the American Medical Association*, vol. 269, No. 18, May 12, 1993, p. 2404.

Box 4-B—Low-Level Radioactive Waste and Decommissioning

Three general groups of low-level waste (LLW) stem from decommissioning power reactors. Neutron-activated materials generally contain significant quantities of long-lived radionuclides, particularly nickel-59 (75,000-year half-life), nickel-63 (100-year half-life), and niobium-94 (20,300-year half-life). Materials are activated when neutrons dispersed from the fission reaction collide with trace metals in their structures. A reactor pressure vessel (RPV), its internal components, and the surrounding concrete biological shield are the major plant components that undergo activation.[1]

Even after 40 years of operation, a RPV and its concrete biological shield will generally rank as Class A LLW, though some reactor internals--incore instrumentation, upper and lower guide structures, pressurized water reactor (PWR) control rod assemblies, **boiling water reactor** (BWR) control rod blades-may undergo enough activation to rank as high as greater-than-Class-C (GTCC) waste.[2] In cases where plant operations were short (such as Shoreham) or availability was low (such as Fort St. Vrain), neutron-activation will be less significant, and the existing waste will generally be classified low (e.g., Class A). Alternatively, where operations were far longer (15 to 20 years), total plant radioactivity actually levels off,because of the short half-life (5 years) of cobalt-60,the major contaminant in operating plants.

Contaminated **materials are standard** materials such as steel and concrete that contain or have embedded trace amounts of short-lived radionuclides, all of which are neutron-activated materials. In general, contamination is caused by the settling or adherence of activated products on internal surfaces such as piping. While contaminated materials can be cleaned (i.e., decontaminated), activated materials must be removed by structural disassembly. The most common radionuclides in contaminated materials are cobalt-60 {5-year half-life) and cesium-137 (30-year half-life), although some long-lived radionuclides maybe involved as well. Most of the piping and equipment and much of the concrete in the buildings containing and surrounding the reactor vessel become contaminated from power operations. These structures include the containment, fuel, auxiliary, control and, in the case of BWRs, turbine generator buildings. The average concentrations of the short-lived radionuclides contaminating these structures is generally low enough to rank their materials as Class-A LLW.[3]

The last general group of decommissioning waste, other radioactive waste, is composed of materials that become contaminated when they are used by plant workers, such **as gloves, rags, tools,**plastic sheeting, and chemical decontaminants. Like conventional contaminated waste, other radioactive waste is largely composed of the same short-lived radionuclides (cobalt-60 and cesium-137), with perhaps some small portions of long-lived radioisotopes, The distinction made between contaminated and other radioactive waste is worth noting, however, because the latter is not part of the original physical plant (concrete, piping, reactor vessel, turbines) and needs to be managed differently because of its mobility. Such radioactive waste is generally Class A, although as much as 25 percent by volume may qualify as Class B.[4]

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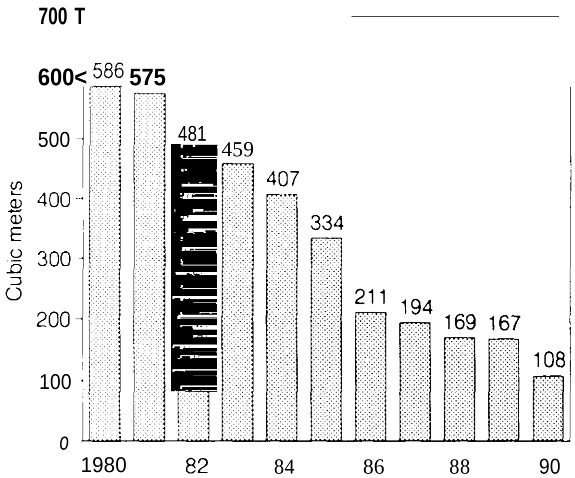
1 E.S. Murphy, *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station: Classification of Decommissioning Wastes,* NUREG/CR-0130, Addendum 3 (Washington, DC: U.S. Nuclear Regulatory Commission, September 1984), p. 2.1. Half-life information Is from U.S. Department of Energy, *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics,* DOE/RW-0006, Rev. 8 (Washington, DC: October 1992), app. B, pp. 255-261.

2 Thomas s. LaGuardia, President, TLG Engineering,letter to the Office of Technology Assessment, Jan. 22, 1993.

3 Ibid.; and E.S. Murphy, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station: Classification of Decommissioning Wastes*, NUREG/CR-0672, Addendum 2 (Washington, DC: U.S. Nuclear Regulatory Commission, September 1984), p. 2.1. Note: The turbine generator building In BWRS becomes contaminated by the direct flow of reactor coolant water to the turbines, a unique aspect of BWR design that allows greater generation efficiency relative to PWRs. Such flow does not occur in PWRs, where steam generators heat water in a secondary Imp that drives the turbines. However, steam generator leaks, often from ruptured or cracked tubes, can lead to PWR turbine contamination.

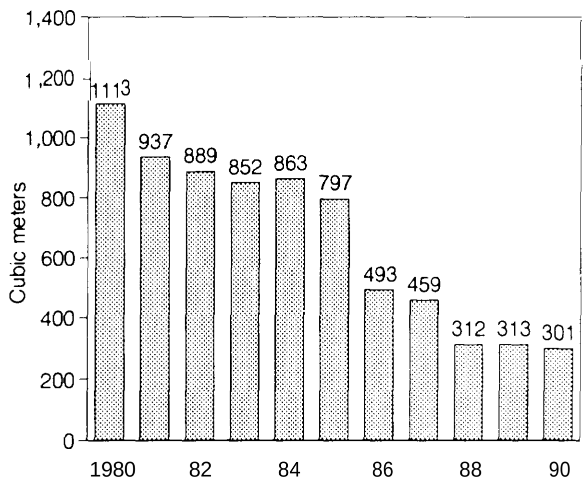
4 Ibid., p. 2.2.

Figure 4-2—Solid Low-Level Waste Volumes From Operating Pressurized Water Reactors in the United States, Annual Averages, 1980-1990



SOURCE: Institute of Nuclear Power Operations, "1 990 Performance Indicators for the U.S. Nuclear Utility Industry" (Atlanta, GA: March 1991).

Figure 4-3-Solid Low-Level Waste Volumes From Operating Boiling Water Reactors in the United States, Annual Averages, 1980-1990



SOURCE: *Institute of* Nuclear Power Operations, "1990 Performance Indicators for the U.S. Nuclear Utility Industry" (Atlanta, GA: March 1991).

B, Class C, and greater-than-Class C (GTCC).[24] Classification depends on the type and concentration of the radionuclides present, which are determined by site-specific conditions, such as the duration of power operations and the amount of activated trace metals (such as nickel and copper) contained in the reactor and steam supply system. Class A waste contains the least radioactivity and represents the lowest risk to public health and the environment. Most of the piping, concrete, and equipment located in a nuclear power plant will qualify as Class A waste, including significant portions of a reactor pressure vessel. Other common Class A wastes include contaminated tools, worker clothing, and protective plastic sheeting.[25]

Class A waste represents about 97 percent of total commercial LLW volumes, emits very little heat and radiation, requires no special shielding to protect workers or the public, and remains harmful for about one century. Classes B and C waste remain harmful for 300 to 500 years, while GTCC waste is harmful for several hundred to several thousand years.[26]

While Class A waste comprises almost the entire volume of commercial LLW disposed annually, its total radioactivity is relatively small. This highlights a general, though not absolute,

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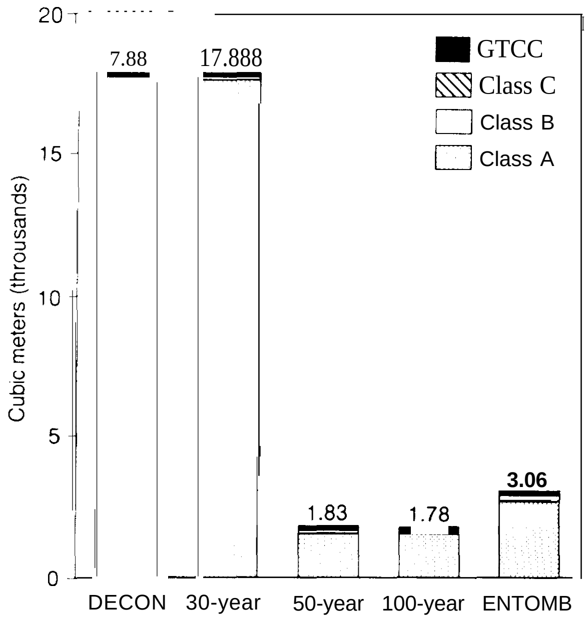
[24] 10 CFR 61.55.

[25] E.S. Murphy, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station: Classification of Decommissioning Wastes,* NUREG/CR-0130, Addendum 3 (Washington DC: U.S. Nuclear Regulatory Commission, September 1984), pp. 2.1-2.2, 6.3-6.9; and E.S. Murphy, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station: Classification of Decommissioning Wastes,* NUREG/CR-0672, Addendum 2 (Washington DC: U.S. Nuclear Regulatory Commission September 1984), pp. 2.1-2.2,6.3-6.9.

[26] U.S. Congress, Office of Technology Assessment *Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste,* OTA-O-426 (Washington, DC: U.S. Government Printing Office, November 1989), p. 81; and U.S. Congress, Office of Technology Assessment, *An Evaluation of Options for Managing Greater-Than-Class-C Low-Level Radioactive Waste,* OTA-BP-O-50 (Washington DC: October 1988), p. 38.

Figure 4-4-Projected Low-Level Waste Volumes From Decommissioning a Reference Pressurized Water Reactor as a Function of Storage Period



SOURCE: E.S. **Murphy, Pacific Northwest Laboratory,** ***Technology, Safety*** and ***Costs*** **of** ***Decommissioning a Reference Pressurized*** *Water Reactor Power Station: Classification of Decommissioning Wastes,* **NUREG/CR-0130, Addendum 3 (Washington, DC: U.S. Nuclear Regulatory Commission, September 1984), p. 2.3, 4.3.**

characteristic of LLW: the greater health and environmental risks are posed by waste classes possessing the lower total volumes, most notably GTCC waste. This is particularly important to appreciate about decommissioning waste, where the great volumes of several LLW classes account for far less radioactivity than the less voluminous but more active GTCC waste and spent nuclear fuel.

LLW DECOMMISSIONING VOLUMES AND DISPOSAL OPTIONS

According to NRC projections, decommissioning 1,1OO-MW light water reactors that have operated their full 40-year licensed lives will generate roughly 18,000 m^3 (636,000 ft^3) of LLW, about 98 percent of which is Class A (figures 4-4 and 4-5). The NRC is currently revising these estimates. ENTOMB produces more LLW than 50- and 100-year SAFSTOR, because the NRC estimate assumes dismantlement of the reactor internals prior to final entombment in order to remove long-lived radionuclides in the vessel that would prevent site release within a reasonable period (e.g., 100 years). An extended storage period prior to any internals dismantlement and final entombment, however, could possibly reduce total ENTOMB LLW volumes, depending on the types, concentration, and distribution of radionuclides remaining after plant shutdown.

Based on current information, decommissioning a large commercial power plant may generate more LLW than generated during its operations. As suggested above, operating commercial nuclear power plants in the United States have steadily decreased their LLW disposal volumes for more than a decade. From 1980 to 1990, U.S. operating PWRs generated average annual LLW volumes of 336 m^3 and operating BWRs 666 m^3, but the actual amounts disposed in recent years have been far lower.[27] If LLW disposal volumes from operating plants in recent years represent the likely annual average over 40 years of operation, DECON decommissioning will generate at least 50 percent more LLW than generated during plant operations. Of course, LLW volume reduction efforts during decommissioning may substantially lower the expected amounts of disposed waste, but the development of residual radioactivity standards more stringent than current regulatory criteria would have the opposite effect.

As figures 4-4 and 4-5 suggest, waiting as much as 50 years to dismantle a reactor is expected to reduce final LLW volumes substantially—90 percent for both PWRs and BWRs. Shorter waiting periods have less of an effect; LLW disposal volumes are virtually unchanged when a 30-year storage period is assumed. For both PWRs and BWRs, 30 years of storage would

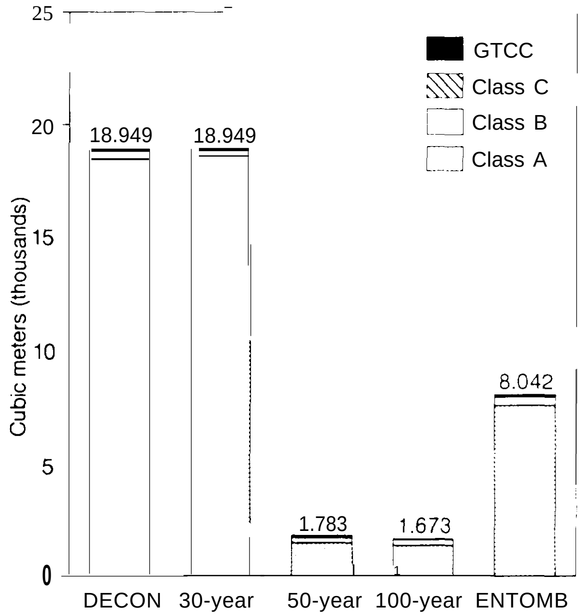
27 Institute of Nuclear Power Operations, ''1990 Performance Indicators for the U.S. Nuclear Utility Industry' (Atlanta, GA: March 1991).

allow a large portion of Class B waste to decay to Class A status, but the volumes of other waste classes (C and GTCC) would remain the same.

Under NRC rules, the frost three LLW classes may be disposed by shallow land burial, although packaging, transport, and disposal requirements are progressively more stringent with each waste class (A to C). Other disposal technologies (reinforced vaults, modular concrete canisters, concrete bunkers) are available but are more expensive and have not yet been implemented.[28] Through arrangements with the NRC, 29 States (known as "Agreement States") regulate these frost three LLW classes, The last class, GTCC, is not suitable for shallow land burial and must be disposed of by the Federal Government in a geologic repository (10 CFR 61), which is not yet available.

The first LLW disposal site opened in Nevada in 1962 (Beatty), and five more were operating by 1971. Three of these sites closed later in the 1970s,[29] and Beatty closed January 1993. As a result, only two sites are in operation today: Barnwell (South Carolina) and Richland (Washington). To encourage the development of more LLW disposal facilities, Congress passed the Low-Level Radioactive Waste Policy Act in 1980 (P.L. 95-573; LLRWPA), This statute directed States to assume responsibility for LLW disposal and encouraged the formation of regional interstate compacts to manage LLW. Compacts were authorized to restrict LLW disposal access to their member States beginning in 1986. At present, the Richland site is restricted to members of the Northwest and Rocky Mountain compacts, and out-of-compact access to the Barnwell site will continue until July 1, 1994. After that, Barnwell access will be restricted to members of the

Figure 4-5-Projected Low-Level Waste Volumes From Decommissioning a Reference Boiling Water Reactor as a Function of Storage Period



SOURCE: E.S. Murphy, Pacific Northwest Laboratory, Technology, *Safety* and *Costs of Decommissioning a Reference Boiling Water Reactor Power Station:* Classification *of Decommissioning Wastes,* NUREG/CR-0672, Addendum 2 (Washington, DC: U.S. Nuclear Regulatory Commission, September 1964), p. 2.3, 4.3.

Southeast compact for 18 more months, at which time the facility is scheduled to close.[30]

In 1985, with no new LLW disposal facilities under development, Congress passed the Low-Level Radioactive Waste Policy Amendments Act (P.L. 99-240; LLRWPAA). This legislation postponed the allowable access restrictions to 1993 and authorized surcharges on LLW disposed by licensees belonging to any compact that was failing to make progress towards opening

28 W.R. Hendee, "Dispos~ of Low-Level Radioactive Waste: Problems and Implications for Physicians, ' Special Communication, *Journal of the American Medical Association,* vol. 269, No. 18, May 12, 1993, p. 2405.

29 These three sites were in West Valley, New York (closed 1975); Maxey Flats, Kentucky (closed 1977); and Sheffield, Illinois (closed 1978), U.S. Department of Energy, *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics,* DOE/RW-0006, Rev. 8 (Washington, DC: October 1992), pp. 132, 136.

30 "Barnwell Wrote Site to Remain Open," *Nuclear Engineering International,* vol. 37, No. 458, September 1992, p. 4.

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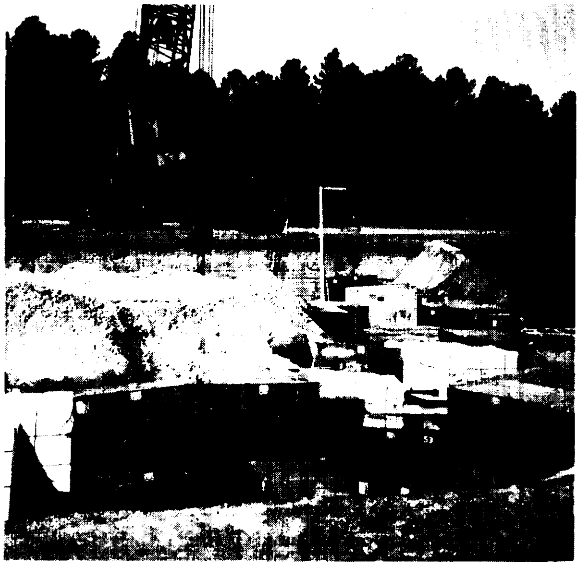

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Barnwell, SC, and Richland, WA, are the two LLW disposal facilities remaining in operation in the United States. Barnwell (above) *is scheduled to close in 1996, and Richland (right) no longer accepts waste generated outside the Rocky Mountain and Pacific Northwest regions.*

new disposal sites.[31] In many cases, these surcharges have become greater than the nominal disposal fee. For example, in 1990, the fees at the three existing LLW disposal sites ranged from \$32 to \$41 per ft^3 for the least active waste. Additional fees could be imposed, depending on the waste phase (solid or liquid), weight, and the surface radioactivity of the containing vessel.[32] The authorized surcharge for noncompact licensees that same year, however, was \$40 per ft^3, which tripled to \$120 per ft^3 in 1992 for LLW generators located within any State or compact region that had failed to apply for a new LLW facility by that time.[33]

The future amounts of both the LLW fees and surcharges (as well as nonmember access to other compact disposal sites) are two important uncertainties with projecting future LLW decommissioning disposal options and costs. Between 1978 and 1986, nominal LLW disposal fees increased ten fold, from \$3 to \$30 per ft^3 (excluding surcharges and other fees).[34] Rates at new dis-

31 A provision of this statute that required States without LLW disposal options in 1996 to take title to waste generated within their borders has been ruled unconstitutional. *New York v, United States, No. 91-543,* June **19, 1992,**

32 U.S. Nuclear Regulatory Commission, *Report on Waste Burial Charges: Escalation of Decommissioning Waste Disposal Costs at Low-Level Waste Burial Facilities,* NUREG-1307, Rev, 2 (Washington, DC: July 1991), pp. A-1 to A-8.

33 Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA), Public Law 99-240, 99 Stat. 1849, Sec. 5(d)(l)(C) and 99 Stat. 1854, Sec. 5(e)(2)(D).

34 R.I. Smith, Battelle Pacific Northwest Laboratory, "Potential Impacts of Extended Operating License Periods on Reactor Decommissioning Costs,' PNL-7574 (Richland, WA: Battle Pacific Northwest Laboratory, March 1991), p. 7.

posal sites are projected at $200 to $300 per ft³,[35] largely because the new facilities will have lower disposal capacities but similar fried capital costs. Currently, the minimum LLW disposal charge at Barnwell for generators outside the Southeast compact is $270 per ft³.[36] Where LLW disposal costs will stabilize remains a matter of speculation.

No new LLW disposal sites have been opened since Barnwell began operating in 1971, more than 20 years ago. Since then, no attempt to license a LLW facility has yet succeeded, due to legal, technical, or political reasons, including efforts in California, Connecticut, Illinois, Michigan, Nebraska, New York, and Texas.[37] In part, the experience at closed LLW disposal sites may affect current public attitudes about new site planning; the largest closed facility, Maxey Flats in Kentucky, leaked enough contaminants within a decade of its closure to qualify as an EPA Superfund site in 1986.[38] LLW disposal management and technologies have improved over the last 20 years, but the level of public confidence in the reliability and safety of candidate sites will continue to affect the prospects of developing them.

As an interim measure, several dozen nuclear power licensees have constructed LLW storage facilities at their plant sites, and more plan to do the same.[39] Beginning in 1996, however, NRC rules discourage the use of onsite LLW storage.[40] In the short term, onsite storage offers cost savings for LLW management by allowing greater radioactive decay of waste before final disposal. In the long-term, though, extended onsite LLW storage may lead to added radioactivity exposures in several ways, including added worker handling, releases from storage containers, additional monitoring requirements during storage, and potential changes to container requirements between storage and final disposal, which could necessitate additional waste handling.[41] In addition, NRC rules governing LLW disposal facility licensing (10 CFR 61.50) may prevent many nuclear power sites from becoming permanent disposal facilities, because power sites are generally located near major bodies of surface water (rivers, bays, coasts), are likely to have high water tables, and could disperse leaked contaminants more readily than other areas more suitable for permanent disposal,

GTCC waste is not suitable for near-surface disposal and requires geologic burial (10 CFR 61.55). As discussed in box 4-B, some reactor vessel internals are expected to undergo sufficient activation over several decades of operation to classify as GTCC waste. As with spent nuclear fuel, the DOE is responsible for accepting and disposing GTCC waste for the commercial power industry, but there is no clear progress in develop-

35 Stephen N. Solomon, Technical Analyst, Office of State Programs, U.S. Nuclear Regulatory Commission, internal NRC memorandum to Carleton Kammerer, Director, Office of State Programs, Nov. 10, 1992.

36 R.R. Zuercher, ''Southeast Compact Commission Bars Central States' Access to Bamwell, ' *Nucleonics Week, vol. 34, No. 16,* Apr. 22, 1993, p. 11.

37 J. Clarke, ' 'Deadlines Loom But No LLW Sites Open Yet, ' *The Energy Daily,* vol. 20, No. 204, Oct. 22, 1992, pp. 1-2; U.S. Congress, General Accounting Office New *York's Adherence to Site Selection Procedures is Unclear,* GAO/RCED-92-172 (Gaithersburg, MD: August 1992); R.R Zuercher, "Nebraska Officials Going Back to Beginning to Slow LLW Site Progress, " *Nucleonics* Week, vol. 33, No. 21, May 21, 1992, pp. 8-9; R.R. Zuercher, ''Proposed California Waste Site Mired in Election-Year Politics,' *Nucleonics Week,* vol. 33, No. 20, May 14, 1992, p. 11; and U.S. Congress, General Accounting Office, *Slow Progress Developing Low-Level Radioactive Waste Disposal Facilities,* GAO/RCED-92-61 (Gaithersburg, MD: January 1992), pp. 4, 18.

38 N. Powell, ''A Concerned Community: Plutonium Had Migrated Hundreds of Feet, " *EPA Journal, vol. 17, No. 3,* July/August 1991, pp. 31-32.

39 L. Oyen and R. Nelson, Sargent & Lundy Engineers, *Interim On-Sire Storage of Low-Level Waste,* vol. *2,* Part 2: Survey of Existing On-Site LLW Storage Facilities, EPRI TR-1OO298 (Palo Alto, CA: Electric Power Research Institute, September 1992), p. 2-1.

40 58 *Federal Register 6735-6736* (Feb. 2, 1993).

41 58 *Federal Register 6731* (Feb. 2, 1993).

ing GTCC packaging, transport, and disposal options.[42] As with spent fuel, therefore, operable GTCC storage or disposal facilities are needed to complete decommissioning work.

Mixed Waste

Also known as "mixed low-level waste," this waste is a combination of radioactive and hazardous chemical substances.[43] Joint guidance established by the NRC and the EPA in 1989 defines mixed waste as any waste containing both LLW (as defined by the LLRWPAA) and hazardous waste, as listed or characterized in 40 CFR Part 261.[44] The major groups of mixed waste generated in commercial nuclear plants (and the activities they are associated with) include organic compounds (laboratory counting tests and solvents used to clean clothes, tools, equipment, and instruments), waste oil (pumps and other equipment used in radioactive areas), metallic lead (contaminated when used for radioactive shielding), cadmium (welds and welding rods), and chromates (corrosion inhibitors, resins) .45

MIXED WASTE DECOMMISSIONING VOLUMES AND DISPOSAL OPTIONS

Mixed waste represents only a few percent of annual LLW generation, and nuclear utilities consider most of their mixed waste treatable. While there are no national estimates of decommissioning mixed waste volumes, their expected amounts are low relative to conventional LLW. In 1990, operating commercial nuclear power plants in the United States produced an estimated 396 m^3 (14,000 ft^3) of mixed waste, about 10 percent of the estimated amount from all sources that year. The same year, nuclear utilities were storing an estimated 623 m^3 (22,000 ft^3) of mixed waste, primarily contaminated chlorofluorocarbons (39 percent), contaminated oil (23 percent), and contaminated lead (20 percent). In the future, material substitutions are expected to decrease final disposal volumes.[46] At present, there are three commercial mixed waste disposal sites (Colorado, Florida, and Utah), but their disposal permits are restricted to select waste groups with low activities.[47]

Part of the challenge with mixed waste management is regulatory: the NRC has authority over the radioactive portion of the material, while the EPA regulates the hazardous chemical portion. Under current EPA rules authorized under the Resource Conservation and Recovery Act (P.L. 94-580; RCRA), land disposal of hazardous waste is restricted, but the only option currently available for LLW disposal is shallow land burial. Compared to problems with both LLW and HLW disposal, mixed waste is a minor waste challenge for operating nuclear plants, but the problem may become more important as more licensees perform decommissioning and pursue license termination in the future. In the future, the DOE may coordinate with States in the development of

42 Richard G, Ferreira, Assistant General Manager, Sacramento Municipal Utility District, letter to the Office of Technology Assessment, Feb. 18, 1993. See also 1. Selin, "The Future for Low-Level Waste Disposal: Where Do We Go From Here?" *Public Utilities Fortnight/y,* vol. *131, No. 6, Mar. 15, 1993, p. 55.*

43 High-level waste can mix with *hazardous* waste *as well,* but the higher levels of radioactivity associated with that waste alone determine its treatment. U.S. Department of Energy, *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics, DOE/RW-0006,* Rev. 8 (Washington DC: October 1992), p. 209.

44 "Results of the National Profile on Commercially Generated Low-Level Radioactive Mixed waste, " unpublished paper presented to the Advisory Committee on Nuclear Waste, U.S. Nuclear Regulatory Coremission, Nov. 20, 1992.

45 U.S. Congress, of ffice of Technology Assessment, *Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste,* OTA-O-426 (Washington DC: U.S. Government Printing Office, November 1989), pp. 85-87.

46 J.A. Klein, J.E. Mrochek, R.L. Jolley, I.W. Osborne-Lee, A.A. Francis, and T. Wright, Oak Ridge National Laboratory, *National Profile on Commercially Generated Low-Level Radioactive Mixed Waste,* NUREG/CR-5938 (Washington DC: U.S. Nuclear Regulatory Commission, December 1992), pp. xiii, 2021,47,50-51.

47 Ibid., pp. 32-35.

additional mixed waste treatment and disposal capacity.[48]

The two facilities currently undergoing active DECON decommissioning (Fort St. Vrain and Shoreham) expect to generate no mixed wastes.[49] These two cases, however, are probably anomalies; most plants retired in the future will contain far more radioactivity from longer operations, increasing the probability that hazardous materials will be contaminated with radiation. Shoreham operated only for the equivalent of two full power days and Fort St. Vrain, although it operated 10 years, achieved only an average 15 percent capacity factor and was of a design (helium gas-cooled) that limits plant contamination. Older, larger light water reactors that operate longer will show far more radioactive contamination, increasing the likelihood of mixed waste generation. In addition, higher levels of radioactivity increase the potential benefits of chemical decontamination, a process that can generate mixed wastes.

High-Level Waste

Irradiated (spent) nuclear reactor fuel is the only HLW generated by commercial nuclear power plants.[50] Spent fuel contains more radioactivity than any other form of commercial radioactive waste. The long-term public health and environmental risks from spent fuel are of far greater concern than LLW, because spent fuel contains greater concentrations of long-lived radionuclides, some with half-lives on the order of tens of thousands of years and longer.[51]

SPENT FUEL WEIGHTS AND DISPOSAL OPTIONS

In recent years, total annual spent fuel discharges (measured in metric tons of initial heavy metal) from operating U.S. reactors have amounted to roughly 2,000 tons. The total amount of discharged spent commercial fuel in the United States (1968-1991) is nearly 24,000 tons.[52] Before decommissioning can be completed at any commercial facility, all spent fuel previously discharged to the storage pool and any fuel still present in the reactor vessel must be removed. As discussed in chapter 3, however, the Federal program to dispose spent fuel, as required under the Nuclear Waste Policy Act of 1982 (P.L. 97-425; NWPA), has lagged. In addition to affecting plant life decisions, the current inability to dispose of spent fuel affects decommissioning planning and implementation. Progress in developing interim HLW storage options (e.g., dry cask installations, a Federal monitored retrievable storage (MRS) facility) and a geologic repository are discussed in chapter 3.

The development of a viable, long-term management and disposal strategy for nuclear waste will resolve not only major uncertainties with decommissioning the first generation of commercial nuclear plants but could influence substantially the future prospects of developing a second generation of nuclear reactors in

48 U.S. Department of Energy, *Department of Energy Strategy for Development of a National Compliance Plan for DOE Mixed Waste*, predecisional draft (Washington DC: November 1992), pp. 4, 20,24.

49 For more details on these current decommissioning projects, see boxes 4-C and 4-D.

50 The regulatory definition of HLW (10 CFR 60.2) also includes the liquid and solid wastes generated by reprocessing spent fuel, but reprocessing no longer occurs in the U.S. commercial power sector and is restricted to cleanup of the nuclear weapons complex. For a review of defense HLW cleanup, see U.S. Congress, Office of Technology Assessment, *Complex Cleanup: The Environmental Legacy of Nuclear Weapons Production, OTA-O-484* (Washington, DC: U.S. Government printing Office, February 1991); and U.S. Congress, Office of Technology Assessment, *Long-Lived Legacy: Managing High-Level and Transuranic Waste at the DOE Nuclear Weapons Complex*, OTA-BP-O-83 (Washington, DC: U.S. Government Printing Office, May 1991).

51 For example, the half-lives of Nickel-59, Niobium-94, and Iodine-129, all constituents of commercial spent fuel, are 75,000; 20,300; and 15,700,000 years, respectively. U.S. Department of Energy, *IntegratedData Basefor 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 8 (Washington, DC: October 1992), pp. 280-289.

52 U.S. Department of Energy, Energy Information Administration, *Spent Nuclear Fuel Discharges From U.S. Reactors 1991*, SR/CNEAF/93-01 (Washington, DC: February 1993), p. 21.

the United States. Unless viable disposal options for both LLW and HLW are developed, utility and financial planners and the public will remain reluctant to invest further in nuclear power.

EXPERIENCE TO DATE

International decommissioning experience is limited thus far to small reactors (250 MW and less), which generally had short lives and relatively little contamination. Larger commercial reactors that are being retired today, on the other hand, typically will have operated longer and have far higher levels of contamination. By 2015, the licenses of over 40 operating plants (all but one of them larger, older, and therefore more contaminated than the early plants) may have expired.[53] And based on current economic trends in the nuclear utility industry, one financial industry estimate suggests that from several to as many as 25 nuclear power plants may retire in the next decade and require decommissioning sooner than expected.[54] Commercial nuclear decommissioning, therefore, is likely to become a more visible and controversial political and economic issue in the next few decades.

Although no large commercial reactors have undergone complete decommissioning yet, decades of experience dismantling small experimental and commercial reactors, combined with experience performing major plant upgrades and repairs at large operating units, suggests that decommissioning large commercial nuclear power plants can be accomplished with existing technologies. The most valuable experience thus far has been dismantling the 72-MW Shippingport PWR, and major plant upgrades, such as removing and replacing steam generators, also suggests that existing technologies are sufficient to decommission large reactors.

Many of the technologies used to decommission nuclear plants are the same ones used to demolish other industrial facilities and buildings, including torches, saws, milling machines, and controlled explosives. Were it not for the considerable residual radiation hazard that remains even after the nuclear fuel is removed, a nuclear power plant could be dismantled and demolished in the same way as any other industrial facility or building. Of course, the benefit of having adequate decommissioning technologies is diminished if waste disposal options are limited or absent.

U.S. Decommissioning Experience

Experience with decommissioning nuclear power plants in the United States is limited,[55] and work is complete at only four small plant sites, the largest being the 72-MW Shippingport PWR (table 4-l). No large (more than 500 MW) reactors have been decommissioned yet, and the few reactor decommissioning performed thus far offer little indication of the potential costs of large reactor dismantlement, because of their low contamination and small size. By comparison, 96 percent of currently operating commercial reactors in the United States (103 of 107 units) are 500

53 This assumes all current reactors operate only for the duration of their existing license terms (see table 1-2) and no units receive license renewals.

54 P.C. Parshley, D.F. Grosser, and D.A. Roulett, Shearson Lehman Brothers, "Should Investors Be Concerned About Rising Nuclear Plant Decommissioning Costs?" *Electric Utilities Commentary, vol. 3, No.* 1, Jan. 6, 1993, p.1.

55 A total of 286 various nuclear reactors (both civilian and military) have been shut down permanently in the United States. Many have been partially or completely decommissioned, but most were generally very small (less than 10 MWe) noncommercial reactors. Thirty-seven percent (106) of these retired units were military, production, and export reactors, while the greater share (180 units, or 63 percent) were civilian reactors, including 105 test, research, and university reactors (most very small general and university research reactors of less than 1 M'We); 50 experimental reactors (most for space applications); and 25 power reactors, two of which had defense applications. Thus, to date, only 23 central station nuclear electric power units have been closed permanently, and decommissioning is complete at only 4 of them. U.S. Department of Energy, Office of Scientific and Technical Information, *Nuclear Reactors Built, Being Built, or Planned: 1991,* DOE/OSTI-8200-R55 (Washington DC: July 1992), pp. xv, 23-27. (Note: The DOE figures are slightly revised here, in part to reflect the recent retirement of the Yankee Rowe, SONGS-1, and Trojan reactors.) This small subset of 23 retired units is listed in table 4-1.

Table 4-l—Retired Commercial Nuclear Power Plants in the United States and Their Decommissioning Status

Plant	Design rating and type	Operating license issued	Shut down date	Decommissioning approach and status
Pathfinder	66-MW BWR	1964	1967	DECON completed 1991.
Shippingport	72-MW PWR	1957	1982	DECON completed 1989.
Sodium Reactor Experiment	10-MW SCGM	1957	1964	DECON completed 1983.
Elk River	22-MW BWR	1962	1968	DECON completed 1974.
Trojan	1,155-MW PWR	1975	1993	Decommissioning plan under development.
San Onofre Unit 1	436-MW PWR	1967[a]	1992	Decommissioning planning in progress.
Yankee Rowe	175-MW PWR	1961[a]	1992	Decommissioning plan under development.
Rancho Seco	918-MW PWR	1974	1989	SAFSTOR until 2008; plan under NRC review.
Shoreham	820-MW BWR	1989	1989	DECON in progress since 1992.
Fort St. Vrain	330-MW HTG	1973	1989	DECON in progress since 1992.
La Crosse	48-MW BWR	1967	1987	SAFSTOR until 2014.
Three Mile Island Unit	926-MW PWR	1978	1979	Monitored storage; plant shut down in 1979 due to reactor accident.
Dresden Unit 1	200-MW BWR	1959	1978	SAFSTOR until 2017.
Humboldt Bay	65-MW BWR	1962	1976	SAFSTOR until 2015.
Indian Point Unit 1	265-MW PWR	1962	1974	SAFSTOR until 2009.
Peach Bottom Unit 1	40-MW HTG	1966	1974	SAFSTOR.
Fermi Unit 1	61-MW SCF	1963	1972	SAFSTOR.
Saxton	3-MW PWR	1962	1972	DECON in progress since 1986.
Bonus	17-MW BWR	1964	1968	ENTOMB.
Carolinas-Virginia Tube Reactor	17-MW PTHW	1962	1967	SAFSTOR.
Piqua	11-MW OCM	1962	1966	ENTOMB.
Hallam	75-MW SCGM	1962	1964	ENTOMB completed 1968.
Vallecitos	5-MW BWR	1957	1963	SAFSTOR.

a Due t. a delay in the issuance of the formal operating licenses, the date of initial commercial operation is given here instead.

KEY: BWR = boiling water reactor; HTG = high-temperature gas-cooled reactor; OCM = organic-cooled and moderated; PTHW = pressure tube, heavy water reactor; PWR = pressurized water reactor; SCF = sodium-cooled, fast reactor; SCGM = sodium-cooled, graphite-moderated reactor.

SOURCES: U.S. Nuclear Regulatory Commission, Office of the Controller, Nuclear *Regulatory Commission Information Digest: 1992 Edition*, NUREG-1350, *vol. 4* (Washington, DC: March 1992), pp. 79-93; U.S. Department of Energy, *Integrated Data Base for 1992: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 8 (Washington, DC: October 1992), pp. 189-206; and the Office of Technology Assessment 1993.

MW or larger.[56] However, historical decommissioning experience is telling from a technical perspective, suggesting that existing technologies are adequate to decommission today's larger units.[57]

The Elk River reactor was shut down in 1968 after 4 years of operation.[58] Dismantlement was completed in 1974, after 3 years, at a cost then of $6.15 million; this was the first commercial site

56 U.S. Nuclear Regulatory Commission, Office of the Controller, *Information Digest,]992 Edition*, NUREG-1350, vol. 4 (Washington DC: March 1992), app. A, pp. 79-91.

57 Organisation for Economic Co-Operation and Development, Nuclear Energy Agency, *Decommissioning of Nuclear Facilities: Feasibility, Needs and Costs* (Paris, France: 1986), pp. 8, 31.

58 D. Borson, *Payment Due: A Reactor-by-Reactor Assessment of the Nuclear Industry's $25+ Billion Decommissionig Bill* (Washington, DC: Public Citizen Critical Mass Energy Project, Oct. 11, 1990), p. 14.

released for unrestricted use by the Federal Government.[59] The Sodium Reactor Experiment operated only from 1957 to 1964, and dismantlement was initiated in 1976.[60] When decommissioning was completed in 1983, costs totaled about $16.6 million.[61] Pathfinder operated from 1965 to 1967, when it shut down due to a condenser tube leak; dismantlement began in 1989 and was completed 2 years later.[62] Although they represent technological watersheds, these three small commercial decommissioning projects convey little if any sense of the scale of large reactor decommissioning work, because all were very small, operated for brief periods, and contained far less contamination than larger, older units that will retire in the future.

Shippingport decommissioning, however, has received the most international attention of any completed nuclear power plant dismantlement project. The reactor operated from December 1957 to October 1982, and the reactor buildings and associated nuclear portions of the facility were completely dismantled in less than 4 years (September 1985 to July 1989) at a total cost of $91.3 million (nominal dollars, by year of expenditure). The turbine generator and remaining secondary systems were not dismantled. From the perspective of project management, the applicability of the Shippingport experience to future large-scale decommissioning projects appears promising-the work was completed with existing technologies on schedule and under budget.[63]

Doubts about the applicability of the Shippingport experience, however, center on project costs. Unlike all of today's large commercial nuclear facilities, which are exclusively owned and operated by utilities and regulated by the NRC, Shippingport was jointly owned by the DOE and the Duquesne Light Company (DLC); the DOE owned the reactor and steam generating portions of the plant, while DLC owned the remaining facilities, such as the generating equipment and the transformer yard. In addition, as a DOE project, Shippingport decommissioning was not regulated by the NRC. The uncommon ownership arrangement between the Federal Government and a private utility was designed both to help demonstrate PWR technology and to generate salable electricity, but it also had the effect of substantially reducing eventual decommissioning costs.

First, as part of its demonstration effort, the DOE replaced the reactor core twice during the plant's Life, each time conducting cleanup work, including a full primary cooling system decontamination before the final core was installed.[64] (Replacing reactor cores is not standard practice for commercial nuclear power reactors.) Because a reactor is the most heavily contaminated portion of a nuclear plant, the Shippingport core replacements reduced plant radioactivity substantially. At final shut down, the last Shippingport reactor core had been in operation only 5 years (August 1977 to October 1982), and the radioactivity in the reactor pressure vessel (RPV) was about

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59 U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 (Washington, DC: August 1988), p. 1-5,

60 D. Borson, *Payment Due: A Reactor-by-Reactor Assessment of the Nuclear Industry's $25+ Billion Decommissioning Bill* (Washington, DC: Public Citizen Critical Mass Energy Project, Oct. 11, 1990), p. 15.

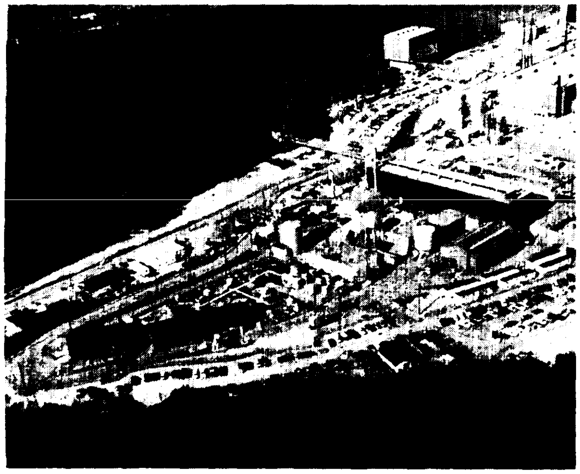
61 J.T.A. Roberts, R. Shaw, and K. Stahlkopf, "Decommissioning of Commercial Nuclear Power Plan@, " *Annual Review of Energy* (Palo Alto, CA: Annual Reviews, Inc., 1985), vol. 10, p. 257.

62 Michael Weber, U.S. Nuclear Regulatory Commission, personal communication, May 6, 1993.

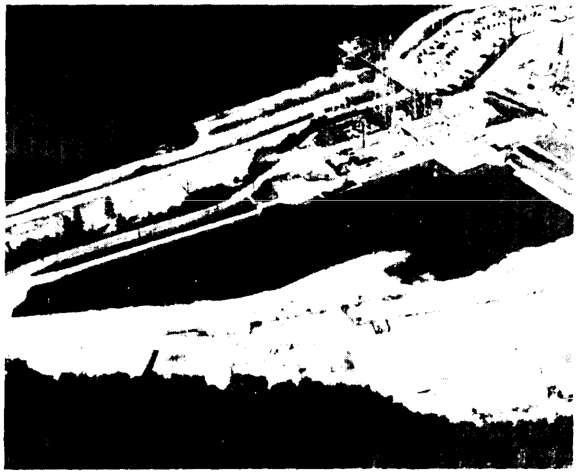
63 U.S. Congress, General Accounting Office, *Shippingport Decommissioning—How Applicable Are the Lessons Learned?* GAO/RCED-90-208 (Gaithersburg, MD: September 1990).

64 W. Murphie, 'Greenfield Decommissioning at Shippingport: Cost Management and Experience, *"NuclearDecommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal, Special* Issue, vol. 12, 1991, p. 121.

RMCI CORP.



RMCI CORP.



Decommissioning of the relatively small Shippingport reactor, completed in 1989, was managed by the U.S. Department of Energy. Although done at Shippingport, radiological decommissioning at other sites may ***not*** *require removal of buildings and other structures.*

30,000 curies (Ci), which had decayed to 16,000 Ci when decommissioning began 3 years later.[65] For comparison, the projected radioactivity levels in the RPV of an 1,175-MW PWR at shut down (assuming 30 years of effective full power operation) have been estimated at 4.8 million Ci,[66] about 300 times the amount at Shippingport when decommissioning began there.

Second, the small size and low contamination of the Shippingport RPV allowed one-piece disposal. Though relatively large for its low power capacity, the Shippingport RPV was far smaller than typical commercial units, with a height of 25 feet, width of 10 feet, and weight of about 153 tons. Standard-sized vessels in large reactors, however, are 45 to 70 feet high and can weigh as much as 1,000 tons.[67] Because of their size and expected contamination, the larger vessels at most commercial facilities are likely to require segmentation, which will increase project costs and radiation exposures.

As a third cost saving advantage, Shippingport waste was delivered to Federal facilities, an option not available to typical commercial licensees. Because the DOE managed the project, the highly radioactive spent nuclear fuel was transported to the Idaho National Engineering Laboratory (INEL), and all LLW, including the intact RPV, was buried at the Hanford facility in Washington state. According to the DOE manager of the Shippingport decommissioning project, there has been no effort to determine the cost

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65 U.S. Congress, General *Accounting Office, Shippingport Decommissioning—How Applicable Are the Lessons Learned?* GAO/RCED-90-208 (Gaithersburg, MD: September 1990), p. 16.

66 R.I. Smith, G.J. Konzek, and W.E. Kennedy, Jr., Battelle Pacific Northwest Laboratory, *Technology,* Safety and Costs *of Decommissioning a Reference Pressurized Water Reactor Power Stan"on,* NUREG/CR-O130, vol. 2 (Washington, DC: U.S. Nuclear Regulatory Commission June 1978), pp. C-10, C-12. The reference PWR used in this study is the Trojan Nuclear Plant, a recently retired commercial nuclear power plant in Prescott, Oregon. The figure is a projection only, not an actual measured quantity at the plant.

67 U.S. Congress, General *Accounting C) free, Shippingport Decommissioning—How Applicable Are the Lessons Learned?* GAO/RCED-90-208 (Gaithersburg, MD: September 1990), pp. 4-5. These figures reflect RPV weights prior to preparation for disposal. At Shippingport, falling the RPV with concrete and including lifting fixtures increased the package weight to 1,100 tons. Thomas S. LaGuardia, President, TLG Engineering, letter to the Office of Technology Assessment, Jan. 22, 1993.

savings from the unique circumstances at the Shippingport decommissioning.[68]

The reduced LLW costs, however, provide one indication of the reduced costs experienced at Shippingport. If Shippingport was decommissioned today and the LLW disposed at Barnwell, the only facility available to a Pennsylvania licensee, total project costs would be almost $56 million more, an increase of over 60 percent.[69]

CURRENT AND FUTURE DECOMMISSIONING EXPERIENCE

Two recently retired plants-the 819-MW Shoreham BWR and the 330-MW Fort St. Vrain high-temperature gas-cooled reactor (HTGCR)--are currently undergoing DECON decommissioning and, given their size, may provide better indications than Shippingport of the costs, occupational exposures, and waste disposal requirements of standard-sized commercial reactors (boxes 4-C and 4-D). More than a dozen other U.S. civilian nuclear power units are currently planning or undergoing decommissioning as well. An overview of decommissioning plans for recently retired reactors is given in box 4-E.

Additional and potentially important experience with decontamination, decommissioning, waste minimization, and radiation protection will be gained from existing Federal nuclear remediation programs, many associated with weapons facilities. The DOE Environmental Restoration and Waste Management (ERWM) program covering nuclear weapons complex cleanup, the DOE Formally Utilized Sites Remedial Action Project (FUSRAP) covering former nuclear processing facilities, and the NRC Site Decommissioning Management Plan (SDMP) program for select nuclear material sites will together provide lessons and technological improvements that the industry may find useful as it decommissions commercial power reactors in the future.[70]

The largest of these efforts, the ERWM program, is a multibillion dollar federal effort to remediate and dispose HLW from weapons production, but the nature of this effort is different than commercial nuclear decommissioning in several critical respects. First, unlike commercial nuclear waste, much defense HLW is the liquid byproduct of reprocessing. As a result, a major challenge in defense cleanup has been neutralizing these wastes into more stable forms, such as salt cake, to prepare them for vitrification and final disposal. In the commercial sector, on the other hand, there are no plans to reprocess, neutralize, vitrify, or otherwise transform the solid spent fuel, the only HLW form in the nuclear power industry, because of its existing stability.

Second, a major challenge with defense HLW has been storing and securing the liquid material, where tank leaks threaten local groundwater sources and the risk of fire or explosion in some cases is serious, in part from the accumulation of gases generated by chemical treatment. In addition, the past mixing and treatment of defense HLWs has raised questions about the exact composition of many storage tanks, and sampling

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68 W. Murphie, 'Greenfield Deeornmissioning at Shippingport: Cost Management and Experience, ' *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal,* Special Issue, vol. 12, 1991, p. 121.

69 This estimate is based on current (1993) Barnwell costs for out-of-region LLW generators of $270 per cubic foot. Shippingport LLW totaled 214,000 cubic feet (ft^3) and cost the DOE $2.2 million (year-of-expenditure dollars) for disposal at Hanford, representing just over $10 per ft^3. Westinghouse Hanford Co., *Final Project Report: Shippingport Station Decommissioning Project,* DOE/SSDP-0081 (Richland, WA: U.S. Department of Energy, Richland Operations Office, Dec. 22, 1989), pp. ix, 10. Including only the current out-of-compact disposal surcharge of $120 per ft^3, Shippingport decommissioning today just 4 years later would cost about $26 million more, a total increase to the original nominal cost of about 28 percent. Applying the current Barnwell costs, however, raises the total more than 60 percent.

70 For example, the DOE Environmental Restoration and Waste Management program recently selected 19 R&D projects to assist with the decontamination and decommissioning of closed nuclear weapons facilities, including projects designed to recycle concrete and scrap metal. "DOE Negotiating Contracts for 19 D&D Projects Valued at $40 Million," *Weapons Complex Monitor,* vol. 4, Nos. 20 & 21, Mar. 29, 1993, pp. 7-8.

Box 4-C-The Fort St. Vrain Decommissioning Project

The Fort St. Vrain (FSV) Nuclear Generating Station was a 330-MW high-temperature, gas-cooled reactor owned by the Public Service Co. of Colorado (PSCO). This unique reactor operated commercially from 1979 to 1989,[1] but experienced several serious difficulties, which led to low capacity and high costs. In 1986, a settlement agreement between PSCO, the Colorado Public Utilities Commission (CPUC), the Office of the Consumer Counsel (OCC), and other parties led to the removal of FSV from the rate base. PSCO's subsequent decision to retire the reactor was based on several concerns: problems with the control rod drive assemblies and the steam generator ring headers, low plant availability (about 15 percent), and prohibitive fuel Costs.* The reactor was shut down permanently in August 1989, and PSCO became the first commercial nuclear utility to receive a possession-only license from the NRC since the Commission adopted decommissioning rules in 1988.

In April 1991, the Westinghouse Electric Corp. won a $100-million, fixed-price contract to perform DECON decommissioning at FSV. Project completion is expected by April 1995, including 18 months for project planning (previously initiated) and 39 months for decontamination and dismantlement. As of October 1992, the total estimated decommissioning cost was $157,472,700, based on the anticipated year of project expenditures and including escalation and utility management costs.[3] Although the FSV nuclear decommissioning trust totaled only $28 million in October 1992, the CPUC had approved a Supplemental Settlement Agreement in December 1991 allowing PSCO to recover $124.4 million, plus a 9 percent carrying cost to cover inflation, from rate payers for t he remainder of the decommissioning work. Earlier, the CPUC had limited the rate payer liability for FSV decommissioning to $17.5 million.

Under a Preliminary Decommissioning Plan submitted to the NRC on June 30,1989, PSCO proposed the SAFSTOR approach. The final plan, however, was submitted November 5, 1990, and proposed the DECON approach. In the interim, PSCO decided to convert the plant to a natural gas-fired generating station and wanted the site available sooner. Moreover, PSCO determined that the economic advantages of SAFSTOR were less impressive when examined in detail. For example, significant LLW volume reductions, and hence cost savings, were not expected for 120 years. Also, PSCO did not want to remain vulnerable to Price-Anderson liability, which is imposed on all licensed commercial nuclear reactors for accidents that occur at any U.S. facility.[4] All nuclear power licensees are subject to a potential maximum liability of $63 million in case of *any* major nuclear power industry accident.[5]

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1 The FSV operating license was issued Dec. 21,1973, and the plant was permanently closed Aug. 18,1989. The effective operating period, however, was shorter. U.S. Nuclear Regulatory Commission, Office of the Controller, *Information Digest, 1992 Edition,* NUREG-1350, vol. 4 (Washington, DC: March 1992), p. 92.

2 FSV fuel costs increased substantially, to nearly 60 percent of the total allowed production costs of 4.8 cents per kilowatt hour (kWh) for the unit. Fuel for the next cycle would have cost the utility $80 million, or approximately 2.8 cents per kWh. At the same time, coal-fired power cost PSCO 2.7 cents per kWh and purchased power only 2.2 cents per kWh. Site Manager, Fort St. Vrain Nuclear Statlon, Public Service Co. of Colorado, personal communication, Sept. 23, 1992.

3 Don Warembourg, Public Service Co. of Colorado, "Defueling & Decommissioning Considerations at Fort St. Vrain Nuclear Generating Station," presented at TLG Services, Inc., Decommissioning Conference, Captiva Island, Florida, October 1992. From Thomas S. LaGuardia, President, TLG Engineering, letter to the Office of Technology Assessment, Jan. 22, 1993.

4 Decommissioning Project Engineer, Fort St. Vrain Nuclear Station, Public Service CO. Of Colorado, personal communication, Sept. 23, 1992.

5 42 U.S.C. 2210(b)(l).

(Continued on next page)

Box 4-C-The Fort St. Vrain Decommissioning Project--(Continued)

The FSV DECON project is divided into three major tasks:

1. Decontamination and dismantlement of the prestressed concrete reactor vessel (PCRV)--the major task.
2. Decontamination and dismantlement of the contaminated balance of plant (BOP) systems.
3. Site cleanup and the final radiation survey.

The total estimated occupational radiation exposure for the project is *433* person-rem: 388 person-rem for PCRV decontamination and dismantlement, 2 person-rem for BOP decontamination and dismantlement, and 65 person-rem for waste preparation, packaging, shipping, and disposal. (For companion, the average occupational radiation exposure at operating PWRs in the United States is 288 person-rem and at operating BWRs is 435 person-rem.[6])

Excluding spent fuel, activation analysis suggests that the total radiation for fixed components is 594,185 curies (Ci) and 199,878 Ci for removable components for a total of 794,083 Ci. Low plant availability and the unique HTGCR design restricted total activation and contamination (For comparison, the total radiation estimated for the reactor vessel in the 1,175 MWe NRC reference PWR reactor after 30 years of operation is 4.8 million Ci.[7]) PSCO estimates that the project will generate 100,072 ft^3 of low-level waste (LLW), which will derive almost entirely (99 percent) from the PCRV with some contribution (about 1 percent) from the BOP. Most of the LLW is expected to be Class A (70,788 ft^3 or 71 percent) and the remainder Class B (28,293 ft^3, or 28 percent) and Class C (101 1 ft^3, or 1 percent).[8] The project is expected to generate no mixed wastes, and there are none onsite.

As an effort to maintain regular contact with the NRC during decommissioning, PSCO asked the agency to retain an onsite inspector for the duration of the DECON project, as is done for operating plants.[9] According to officials working with the licensee, however, the NRC denied the request. At present, NRC decommissioning project managers are located offsite.

Under a 1985 contract with the DOE, the Idaho National Engineering Laboratory (INEL) agreed to receive FSV spent fuel. INEL previously accepted three of nine spent fuel segments after refueling outages, but the State of Idaho challenged the legality of shipping additional spent fuel to INEL. In the interim, PSCO spent approximately $2.5 million per month to maintain the unit in its partially defueled condition in accordance with the possession-only license. The company also hired Foster-Wheeler Energy Corp. to build a modular vault dry storage system for the spent fuel onsite at a cost of about $23 million.

The FSV spent fuel storage facility has a 40-year design life and houses all the remaining fuel segments, although the liners in the original shipping casks will eventually require changes to gain NRC approval for transport. At present, these casks are certified to store, but not transport, spent fuel. In June 1992, the last of the remaining fuel segments was placed in the modular vault dry storage facility, and the NRC approved the PSCO decommissioning plan on November 23,1992. Active decommissioning began in January 1993.

6 These figures reflect measured doses in 1989. C.T. Raddatz and D. Hagemeyer, *Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities: 1989,* Twenty Second Annual Report, NUREG-0713, vol. 11 (Washington, DC: US Nuclear Regulatory Commission, April 1992), p. B-3.

7 R. I. Smith, G.J. Konzek, and W.E. Kennedy, Jr., Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station,* NUREG/CR-0130, *vol.* 1 (Washington, DC: U.S. Nuclear Regulatory Commission, June 1978), p. 7-19.

8 Analytical uncertainties suggest that as much as 400 ft^3 of the Class C LLW may require reclassification as greater-than-Class C (GTCC) waste. GTCC waste Is the only form of LLWthat is forbidden from near surface burial and requires disposal in a geologic repository. 10 CFR 61 .55(a)(2) (iv).

9 Manager, Fort St. Vrain Radiation Protection, Scientific Ecology Group, Inc., personal communication, Sept. 23, 1992.

ADDITIONAL SOURCES: A. Barrett, "The Big Turnoff," *Financial World,* vol. 160, No. 15, July 23,1991, pp. 30-32.

"Fort St. Vrain Decommissioning Ready as Nuclear Fuel Removal is completed," *Electric Utility Week,* June 22, 1992, p. 11.

Public Service Company of Colorado, "Notes to consolidated Financial Statements," 1991 Annual Report.

Public Service Company of Colorado, *Proposed Decommissioning Plan for the Fort St. Vrain Nuclear Generating Station, Nov. 5, 1990.*

R.R. Zuercher, "Defueled Fort St. Vrain is Ready for Decommissioning to Begin," *Nucleonics Week,* vol. 33, No. 26, June 25, 1992, pp. 14-15.

R.R. Zuercher, "PSC [PSCO] Gets Go Ahead to Dismantle Fort St. Vrain Gas-Cooled Reactor," *Nucleonics Week,* vol. 33, No. 49, Dec. 3, 1992, pp. 6-7.

U.S. Nuclear Regulatory Commission, "PublicService Co. of Colorado; Issuance of Materials License SNM-2504, Fort St. Vrain Independent Spent Fuel Storage; Installation at the Fort St. Vrain Nuclear Generating Station," 56 *Federal Register* 57539 *(Nov.* 12, 1991).

and characterizing waste in some storage tanks will be necessary before vitrification and disposal. These are not problems with commercial spent fuel, which is not in liquid form and is not treated or mixed with other wastes. Third, due to HLW liquid releases (both planned and not), an important component of the ERWM program involves soil remediation, which is not expected for commercial decommissioning, except perhaps to remove very low levels of radioactivity, but none of it HLW.[71]

Thus, there are several major differences between commercial nuclear power decommissioning and defense HLW remediation, but Federal cleanup programs are likely to offer some valuable lessons about material decontamination, worker radiation protection, waste packaging, and other related efforts for the commercial nuclear power sector. These lessons are likely to be imparted to private decommissioning contractors and nuclear utilities through the usual means, including published papers and reports, conferences and meetings, and information clearinghouses, including those managed by the Federal Government.

International Decommissioning Experience

Similar to the United States, international decommissioning experience is limited to very small reactors. Comparing the technical and economic performance of decommissioning between the United States and other nations is complicated by differing regulatory requirements and waste disposal practices, as well as differences in labor costs and international exchange rates. As a result, direct comparisons are difficult, if not impossible.

Based on reactor generating capacity, the largest foreign nuclear power decommissioning projects are Gentilly-1 in Canada (250 MW), Chinon A2 in France (250 MW), Garigliano in Italy (160 MW), and Kernkraftwerk Niederaichbach (KKN) in Germany (100 MW). Table 4-2 lists major foreign decommissioning projects, their status, and estimated costs. For the two current dismantlement projects for which estimates were available (JPDR and KKN), expected costs are greater than Shippingport--between $120 million and $140 million (both in 1990 U.S.

71 For more information about defense HLW cleanup, see U.S. Congress, Off Ice of Technology Assessment, *Long-Lived Legacy: Managing High-Level and Transuranic Waste at the DOE Nuclear Weapons Complex, OTA-BP-O-83* (Washington, DC: U.S. Government Printing Office, May 1991).

Box 4-D--The Shoreham Decommissioning Project

On April 21,1989, the NRC issued the Long Island Lighting Co. (LILCO) a license under 10 CFR Part 50 to operate the 819-MW Shoreham BWR. Two months earlier, on February 28, LILCO and the State of New York had agreed to transfer Shoreham's assets to the State for decommissioning. The utility pursued the full-power license to demonstrate that the reactor was operable. The decision was costly because, by increasing plant radioactivity, the scope and costs of decommissioning increased accordingly. LILCO estimated decommissioning costs of $186,292,000 (1991 dollars), assuming LLW disposal costs of $240 per cubic foot. The NRC finds the estimate conservative and acceptable.[1]

Shoreham operated intermittently, at low power, between July 1985 and June 1987. The plant was shut down permanently on June 28, 1989, and the average fuel burnup was calculated to approximate 2 days of full-power operation. Fuel removal was completed in August 1989, and the license was amended to possession-only on July 19, 1991.

The NRC issued the Shoreham decommissioning order June 11,1992. The order allows LIPA to perform DECON work under the following conditions:

1. Fuel will be completely removed from the site within 6 years (all 560 fuel assemblies are currently in the Spent Fuel Storage Pool in the Reactor Building. As of June 1990, LILCO estimated that the fuel represents roughly 176,000 Curies).
2. Onsite LLW storage will not exceed 5 years.
3. The NRC must approve the installation of a temporary liquid radwaste system referenced in the licensee decommissioning plan.

The total activated inventory at Shoreham is calculated to be a mere 602 Curies. iron-55 and cobalt-60 account for over 97 percent of the activity. The core shroud, top guide plate, and other RPV internals contain over 96 percent of the activated nuclide inventory. Estimated RPV dose rates for shielded workers are between 0.5 and 20 millirems per hour (mrem/hr).

LILCO estimates the entire decommissioning project will produce a total occupational exposure of about 190 person-rem. By comparison, the total occupational exposure for the Shippingport DECON decommissioning project, a 72-MW PWR, was 155 person-rem.[2] Segmenting and removing the Shoreham RPV is estimated to account for 158 person-rem, or 83 percent of the total exposure. By comparison, the average annual exposure at operating BWRs in the United States in 1990 was 436 person-rem.[3] Even though the projected occupational exposures at Shoreham are lower than the average annual exposures at operating BWRs, they are remarkably high relative to Shippingport, where 16,000 curies (more than 25 times the amount of activity at Shoreham) led to less occupational exposure. Unlike Shippingport, however, the Shoreham RPV requires segmentation prior to disposal.

On November 22, 1991, the NRC granted LILCO an exemption from the decommissioning financial assurance provisions under 10 CFR Part 50.75. The short life of the plant prevented the LILCO's existing nuclear decommissioning trust from becoming a viable funding vehicle. The exemption was granted under the following conditions:

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1 U.S. Nuclear Regulatory Commission, *Safety Evaluation by the Office of Nuclear Material Safety and Safeguards Related to the Order Approving the Decommissioning Plan and Authorizing Facility Decommissioning Long Island Power Authority (LIPA) Shoreham Nuclear Power Station, Unit 1,* Docket No. 50-322, June 11, 1992, p. 21. ,

2 Westinghouse Hanford Company, *Final Project Report: Shippingport Station Decommissioning Project,* DOE/SSDP-0081 (Richland, WA: U.S. Department of Energy, Richland Operations Office, Dee. 22, 1989), p. 13.

3 Institute of Nuclear Power Operations, "1990 Performance indicators for the U.S. Nuclear Utility Industry" (Atlanta, GA: March 1991).

1. LILCO will provide funds to an external account that would cover 3 months of the projected decommissioning costs.
2. LILCO will maintain a $10 million external fund to ensure the facility is placed in safe storage if decommissioning is delayed for any reason.
3. NRC will be notified at least 90 days in advance if the LILCO $300 million line of credit is cancelled or altered.
4. LILCO will maintain an unused line of credit to cover any remaining decommissioning costs at all times.

Shoreham decommissioning will generate an estimated 79,300 cubic feet of solid radioactive waste; the licensee has determined that the entire quantity of this waste could be stored, if necessary, in the on-site Radwaste Building. All radioactive waste is expected to be Class A waste. No mixed waste is expected from Shoreham decommissioning. Under current plans, the virtually unused fuel at Shoreham will be transferred to the Philadelphia Electric Company's Limerick nuclear power plant by February 1994. The Long Island Power Authority (LIPA), the new operator of the plant, has agreed to pay Philadelphia Electric $45 million to receive the fuel. LIPA is currently studying options to convert Shoreham to a fossil-fired power station.

ADDITIONAL SOURCES: Long Island Power Authority, *Shoreham Nuclear Power Station Decommissioning Plan*, December 1990.

U.S. Nuclear Regulatory Commission, *Safety Evaluation by the Office of Nuclear Material Safety and Safeguards Related to the Order Approving the Decommissioning Plan and Authorizing Facility Decommissioning Long Island Power Authority (LIPA) Shoreham Nuclear Power Station, Unit f,* Docket No. 50-322, June 11, 1992.

M. Wald, "Shoreham A-Plant Has Found a Taker For its Spent Fuel," *The New York Times*, Feb. 26, 1993, pp. Al, B4.

R.R. Zuercher, "LiPA to Sign Cogema Contract for Shoreham Fuel Reprocessing," *Nucleonics Week, vol.* 33, No. 49, Dec. 3, 1992, p. 4,

dollars). As with the United States, however, this early experience may indicate little about the future costs and other challenges of decommissioning larger units, particularly as residual radioactivity standards, occupational exposure limits, and waste disposal options may change in the future, both here and abroad.

Decontamination and Decommissioning (D&D) Technologies

A variety of technologies and approaches to mitigate radiological contamination and to remove activation products from nuclear facilities have been developed. The most important of these are reviewed briefly in this section.

Decontamination Technologies

The contamination from the partial reactor core melt accident at Three Mile Island Unit 2 in 1979, along with an increasing interest in reducing worker radiation exposures at operating plants in the 1980s, account for much of the development of nuclear plant decontamination methods in the last decade.[72] Decontamination can lower occupational radiation exposures at nuclear plants, lower the chances of unplanned environmental releases, and reduce the final waste disposal requirements when a plant is decommissioned.

Decontamination performance is expressed by a number known as the decontamination factor (DF), which is simply the ratio of the measured radiation field before decontamination to that

72 J.F. Remark, Applied Radiological Control, Inc., *A Review of Plant Decontamination Methods: 1988 Update*, EPRI NP-6169 (Palo Alto, CA: Electric Power Research Institute, January 1989), p. 1-2.

Box 4-E-Financing Decommissioning for Early Reactor Retirements

Several commercial nuclear power reactors have retired prior to their license expiration dates. In all cases, the accumulated decommissioning funds have been insufficient to complete the work. However, the mere existence of decommissioning funding shortfalls in cases of early reactor retirement should not cause alarm. Utilities with reactors retired early have already developed plans to cover the remaining funds. A brief synopsis of these plans is given below. Two other recent early retirements (Shoreham and Fort St. Vrain) are the subjects of other boxes in this chapter.

Three Mile Island. Three Mile Island Unit 2, a 906-MW pressurized water reactor (PWR), was issued an operating license February 8, 1978, but shutdown due to a partial core melt accident on March 28, 1979. The plant had operated only 1 year. General Public Utilities (GPU) Nuclear Corp. retains its full power operating license but has applied to amend the license to reflect "post defueling monitored storage" (PDMS). GPU intends to maintain Unit 2 this way until Unit 1 is retired and plans to decommission both units as one project. To address Unit 2's post-accident condition, GPU is funding its decommissioning trust at twice the required rate. GPU intends to collect decommissioning funds during the remainder of Unit 2's operating license.

Rancho Seco. This 873-MW PWR operated by the Sacramento Municipal Utility District (SMUD) was issued an operating license August 16, 1974, and was shutdown June 7, 1989, by a local voter referendum. The plant had operated almost 15 years. A proposed decommissioning plan is under NRC review and indicates the SAFSTOR approach, partly because the DOE is not scheduled to accept the spent fuel until after 2008. Under current plans, the spent fuel will be moved into dry storage casks, and active decommissioning will begin in 2008. SMUD estimates decommissioning costs of $281 million (1992 dollars), excluding about $72 million in spent fuel storage costs and $12 million in site restoration and other costs—both of which are excluded from NRC financial assurance rules. To fund decommissioning, SMUD will pay $12 million annually to an external sinking fund. According to the utility, this will provide adequate decommissioning funds by the end of the original license term.

Yankee Rowe. This 185-MW PWR was issued an operating license July 1, 1961, and shutdown officially February 26, 1992, 8 years before the expiration of its operating license. (Due to technical concerns, the reactor had been off line since October 1991.) Decommissioning costs are estimated at $178 million (1992 dollars), excluding $57 million in spent fuel storage costs and $13 million in site restoration costs. The estimate, however, includes about $33 million needed for SAFSTOR preparations. The NRC decommissioning rule requires funding based on a minimum cost of $138 million (1992 dollars) for Yankee Rowe. Therefore, the current licensee estimate ($178 million) is 29 percent greater than the NRC financial assurance rules require for the plant. Moreover, this recent utility estimate is about 80 percent greater than a previous estimate ($98 million) made several years earlier.[1] In 1992, the Yankee Rowe decommissioning trust fund contained approximately $72 million, and the total shortfall ($247 million less $72 million) will be met by contributions from the region's stockholder utilities, earnings on those contributions, and approximately $32 million in tax refunds. Yankee Atomic Electric Company (YAEC), the plant operator, intends to submit a decommissioning plan to the NRC in late 1993.[2]

San Onofre. San Onofre Unit 1 (SONGS-1), a 410-MW PWR operated by Southern California Edison (SCE) Co., began commercial operation January 1, 1968. Pursuant to an agreement with the California Public Utilities Commission (CPUC), SCE retired the plant November 30, 1992, 12 years prior to its license expiration. SCE has tentatively planned SAFSTOR decommissioning, but this is being reevaluated along with a DECON option. A 1990 study estimated decommissioning costs of $211 million (1990 dollars), but this estimate will be updated as part of the ongoing planning.

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1 "FERC Sets Hearing on Yankee Rowe Shut Down, Decommissioning Costs," *Electric Utility Week*, Aug. 10, 1992, p. 7.

2 Donald Edwards, Yankee Atomic Electric Corporation, written comments to the Office of Technology Assessment, Jan. 25, 1993.

Trojan. The 1,175-MW PWR operated from November 21, 1975, to January 4, 1993—about 17 years. The plant had been off line since November 1992 due to tube leaks in one of its steam generators. The licensee, Portland General Electric (PGE), had earlier decided to close the plant in 1996 rather than pay the estimated $200 million needed to replace its steam generators. As the major plant owner (67.5 percent), PGE expects to pay $488 million in 2011 to decommission the unit.[3] A decommissioning plan, with an up-to-date cost estimate, is required within 2 years of final closure under 10 CFR 50.82(a). In particular, the cost revisions eventually submitted by PGE should make an interesting comparison with the one performed by NRC (originally planned for revision this year), because the earlier NRC estimate of Trojan decommissioning was used to develop decommissioning financial assurance requirements for all other PWRs in the United States.

ADDITIONAL SOURCES: ABZ, Inc., "Case Studies of Nine Operating Nuclear Power Plants: Life Attainment, License Renewal and Decommissioning," prepared for the Office of Technology Assessment, February 1993.

P.C. Parshley, D.F. Grosser, and D.A. Roulett, Shearson Lehman Brothers, "Should Investors Be Concerned About Rising Nuclear Plant Decommissioning Costs?" *Electric Utilities Commentary*, vol. 3, No. 1, Jan. 6, 1993, pp. 7-9.

Southern California Edison Company, *Preliminary Decommissioning Plan for the San Onofre Nuclear Generating Station Unit 1*, November 1992, app. B, p. 31; and the Office of Technology Assessment 1993.

U.S. Nuclear Regulatory Commission, Office of the Controller, *Information Digest, 1992 Edition*, NUREG-1350, vol. 4 (Washington, DC: March 1992), pp. 79-93.

3 "PGE Needs to Buy Supplies to Replace 67% Share of 1,100-MW Trojan Plant," *Electric Utility Week*, Jan. 11, 1993, pp. 12-13; and F. Rose, "Oregon Utility Plans to Close Nuclear Facility," *The Wall Street Journal*, Jan. 5, 1993, p. A4.

after decontamination; a DF of 5, for example, indicates that only one-fifth (20 percent) of the radiation remains on the given plant equipment, surface, or system and that decontamination removed 80 percent. The ultimate level of decontamination will depend on the process used, how and how often it is applied, and where in the facility it is applied. Major decontamination technologies and techniques used in the United States are listed in table 4-3.

Chemical decontamination techniques represent increasingly common methods to reduce occupational radiation exposures at operating commercial nuclear power plants[73] (see ch. 3, box 3-A), and may help reduce plant radiation levels and occupational exposures during decommissioning. Electropolishing (or electrochemical decontamination) is generally applied to excised or segmented piping and equipment, but it can also be used to decontaminate intact systems. The technique works on a variety of metals and metal alloys, allows material reuse, is relatively quick, and produces a smooth surface (thus inhibiting recontamination from the electrolytic solution).[74]

Physical decontamination is performed with a variety of technologies and techniques, many of them fairly simple. For example, loose, low-level contamination on floors, walls, and other surfaces can be literally vacuumed or swept, while manual scrubbing with simple cleansing compounds can

73 Ibid., p. 2-9.

74 H.D. Oak, G.M. Holter, W.E. Kennedy, Jr., and G.J. Konzek, Battelle pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station*, NUREG/CR-0672, vol.2 (Washington DC: U.S. Nuclear Regulatory Commission, June 1980), pp. G-1, G-3 to G-4.

Table 4-2—Major International Nuclear Power Plant Decommissioning Projects

Plant	Design rating and type	Operational lifetime	Decommissioning approach, schedule, and estimated cost
Chinon A2 (France)	250-MW, gas-cooled, graphite-moderated reator	1964-85	Stage 1 (1986 to 1992) estimated at $39.9 million (1990 U.S. dollars). Dormancy of at least 50 years prior to Stage 3 (dismantlement).
Garigliano (Italy)	160-MW, dual-cycle BWR	1964-78	Stage 1 (1985 to 1995) for main containment estimated at $54.8 million (1990 U.S. dollars). Dormancy of at least 30 years prior to Stage 3.
Gentilly-1 (Canada)	250-MW, heavy-water moderated, boiling light-water cooled prototype reactor	1970-79	Variant of Stage 1 (1984 to 1986) estimated
Japan Power Demonstration Reactor (JPDR)	45-MW BWR	1963-76	Stage 3(1 986 to 1993) estimated at $143 million (1990 U.S. dollars). Estimate includes site restoration.
Kernkraftwerk Niederaichbach (KKN) (Germany)	100-MW, heavy-water moderated, gas-cooled reactor	1972-74	Stage 3 (1987 to 1994) estimated at $121.4 million (1990 U.S. dollars).
Windscale Advanced Gas Cooled Reactor (WAGR) (United Kingdom)	33-MW, gas-cooled reactor	1962-81	Stage 3 (1983-1998). No current cost estimate available.

NOTE: The international decommissioning staging numbers are descriptive, and there may be some overlap between stages. In general, Stage 1 involves placing a unit into extended storage for later dismantlement, and activities include plant and equipment sealing and extended routine surveillance; Stage 2 involves partial decontamination and dismantlement, allowing re-use of non-radioactive plant areas; Stage 3 is final dismantlement, where all materials and areas with radiation above regulatory levels are decontaminated or removed.

SOURCES: Organisation for Economic Co-Operation and Development, Nuclear Energy Agency, *International Co-Operation on Decommissioning: Achievements of the NEA Co-operative Programme, 1985-1990* (Paris, France: 1992); Organisation for Economic Co-Operation and Development, Nuclear Energy Agency, *Decommissioning of Nuclear Facilities: An Analysis of the Variability of Decommissioning Cost Estimates* (Paris, France: 1991); and S. Yanagihara and M. Tanaka, "Estimating the Costs for Japan's JPDR Project," *The Energy Journal*, vol. 12, Special Issue, 1991, p. 146.

also remove superficial contamination.[75] Other methods, including mechanical devices, are available to remove more tenacious contamination, including high-pressure sprays (water, freon), grit blasters, steam cleaners, strippable coatings, and ultrasonic cleaners. Furthermore, specialized robots can be used to perform work in high radiation or otherwise inaccessible areas.

DISMANTLEMENT TECHNOLOGIES

With the exception of specialized robots used to perform tasks in high radiation fields or other difficult plant areas, the technologies used to decommission nuclear plants are generally applied in innovative ways rather than being innovative themselves. In general, the same technologies used to dismantle other structures, such as build-

[75] Ibid., p. G-5.

Table 4-3-Major Decontamination Technologies and Techniques in the United States

Chemical decontamination		
Technology	**Decontamination factors (DFs)[a]**	**Comments**
CITROX (citric and oxalic acid)	4 to 15	Recirculating, regenerative method. Contains oxalic acid, which may corrode some system components. Used in about 20 percent of reactor decontamination at operating U.S. units (PWRs and BWRs).
CAN-DEREM (citric acid with ethylenediamine-tetraacetic acid, EDTA)	5 to 16	Recirculating, regenerative method. Lacks oxalic acid and thus safe for system components under normal conditions. Original mixture included oxalic acid (CAN-DECON), which is still in regular use. Generally applied to operating BWRs.
LOMI (low oxidation state metal ion)	2 to 61	Recirculating or single-loop, non-regenerative method. Safe to reactor components. Used in BWRs more often than PWRs. The most widely used chemical decontamination technique since 1985.
Electrochemical polishing (electropolishing)	—	As with conventional methods, electropolishing may decontaminate systems in situ, eliminating the need for cutting (if desired). Generates hydrogen, an explosive gas that must be ventilated.
Strippable coatings	5 to 20	Best with less adherent contamination. May also be used to coat surfaces prior to work. All associated waste is solid and resulting volumes are low. Most applications require manual removal.
Water jets (high and ultra-high pressure)	3 to 20 (high--pressure water jet)	High pressure water jets (up to 10,000 pounds per square inch) work only with loose contamination; ultra-high jets (20,000 to 60,000 psi) work well with tenacious contamination. Abrasive grits added to better the DFs. Useful for decontaminating inaccessible areas. High volumes of waste may be generated and contamination may be spread if removed material is not captured.
Robots and robotic devices	Variable	This is a broad category of technologies. Workable in greatly confined work spaces, high radiation areas, and may supplement other technologies. Includes rotating water jet nozzles, mobile concrete spallers, and other often unfunctional devices.

a Decontamination factors (DFs) will vary greatly, depending on the type and level of contamination, how the chemicals are applied (concentration, temperature, duration, and number of flushes) and, especially, the systems or components treated (e.g., reactor water cleanup system, reactor coolant pumps, steam generators, spent fuel pool).

SOURCES: H.D. Oak, G.M. Helter, W.E. Kennedy, Jr., and G.J. Konzek, Batelle Pacific Northwest Laboratory, Technology, *Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station,* NUREG/CR-0672, *vol. 2* (Washington, DC: U.S. Nuclear Regulatory Commission, June 1980), pp. G-3 to G-5; C.J. Wood and C.N. Spalaris, *Sourcebook for Chemical Decontamination of Nuclear Power Plants,* EPRI NP-6433 (Palo Alto, CA: Electric Power Research Institute, August 1989), pp. 1-1 to 2-1 O; J.F. Remark, Applied Radiological Control, Inc., *A Review of Plant Decontamination Methods.' 1988* Update, EPRINP-6169 (Palo Alto, CA: Electric Power Research Institute, January 1989); and H. Ocken and C.J. Wood, *Radiation-Field Control Manual—1991 Revision, EPRITR-1OO265* (Palo Alto, CA: Electric Power Research Institute, 1992), pp. 6-1 to 6-26.

ings, bridges, and fossil-fried power plants, are being used for maintenance and repairs at operating reactors and may be used to dismantle them as well: plasma arc and acetylene torches, electric saws, controlled explosives, remote cutting devices, jackhammers, and specialized robots. Major decommissioning technologies and their functions are listed in table 4-4.

ESTIMATING COSTS AND RADIATION EXPOSURES

Decommissioning cost estimates and radiation exposure projections developed well in advance of reactor retirements are subject to several major uncertainties, including the nature and extent of plant and site radioactivity at final closure, local labor rates, waste disposal costs, and applicable radiation standards during dismantlement. As a result, cost estimates vary depending on a site and its conditions, but their reliability will tend to improve the closer a plant *is* to actual decommissioning. The same is true with projections of radiation exposures. Over the last several years, the technical ability to estimate the costs and radiation exposures from decommissioning has improved considerably; although a few methodological uncertainties remain, estimates should improve with experience,

If viewed as a one time expense, decommissioning costs of several hundred million dollars may appear large but are far less significant compared to the life cycle costs of an operating plant. Current estimates suggest that decommissioning costs will represent only about 1 percent of the total generating costs over a plant's life.[76] Moreover, a doubling or tripling of current estimates would have a minimal effect on generating costs, raising them between one and three mills per kilowatthour.[77]

News stories and other reports about decommissioning projects often fail to distinguish nominal (undiscounted) costs from real (discounted) costs, particularly those claiming decommissioning costs will exceed $1 billion per reactor.[78] In real terms, current decommissioning cost projections are in the range of several hundred million dollars-not $1 billion or more. As decommissioning will generally occur at least 40 to 60 years after plant construction, the future nominal costs may appear much larger, but the major reason is generally inflation calculated over time. For example, real decommissioning costs for the 1,150-MW Seabrook PWR in New Hampshire are estimated at $324 million (1991 dollars), but the nominal costs when dismantlement is expected to begin in 35 years are estimated at $1.6 billion (2026 dollars), which accounts for inflation and trust fund earnings.[79] Any effort, therefore, to compare costs for power plant projects over time should consider the discounted value of resources to reduce the potential for confusion.

Definitions of decommissioning that differ from those in NRC rules, which focus only on remediating radioactive portions of a plant, may lead to differing expectations among State and local governments and the public about what the task involves and its cost. For instance, complete plant dismantlement and site restoration may intuitively seem like basic elements in ''decommissioning' any nuclear or non-nuclear

76 Organisation fo, Economic Co-Operation and Development Nuclear Energy Agency, Decommissioning *of Nuclear Facilities: An Analysis of the Variability of Decommissioning Cost Estimates* (Paris, France: 1991), pp. 7, 10.

77 A mill is a unit commonly used to express electricity production costs and represents one-tenth of one cent. The estimate here assumes an original decommissioning estimate of $200 million and a 1,000 MWe reactor operating 25 years at a 70 percent capacity factor. Under these circumstances, decommissioning cost increases to $400 million (doubling) or $600 million (tripling) would raise the costs of each kilowatthour generated over the period roughly 1.3 and 2.6 mills, respectively, assuming constant dollars.

78 See, for example, R. Johnson and A. De Rouffignac, ''Closing Costs: Nuclear Utilities Face Immense Expenses In Dismantling Plants, *The Wall Street Journal*, Jan. 25, 1993, pp. Al, A9.

79 R.R. Zuercher, 'Seabrook Decommissioning Fund Case Goes To New Hampshire High Court," *Nucleonics Week*, vol. *33, No. 22,* May 28, 1992, pp. 2-3.

Table 4-4—Major Decommissioning Technologies and Their Functions

Technology	Application	Comments (pros/cons)
Arc saw	Segment activated metal; segment piping, tanks, and other metal.	Workable on all metals; usable in air or underwater; remote operations/needs adequate space for blade; significant smoke generation.
Plasma arc torch	Segment activated metal; segment piping, tanks, and other metal.	Workable on all metals; usable in air or underwater; remote or portable operations/lower thickness than arc saw; need contamination control and standoff space behind tool.
Oxygen burner	Segment activated metal; segment piping, tanks, and other metal.	Usable in air or underwater; remote or portable operations/limited to carbon steel; generates radioactive fumes.
Thermic lance	Segment activated metal; segment piping, tanks, and other metal; cuts all types of concrete.	Workable on all metals; usable in air or underwater; portable operations; well-suited for irregular surfaces/remote operations difficult; needs ventilation; requires molten metal removal; use underwater produces bubbles, which obscures visibility.
Controlled explosives	Segment activated metal; segment piping, tanks, and other metal; cuts all types of concrete.	Workable on all metals and reinforced concrete; usable in air or underwater; remote or portable operations/limited cutting thickness; explosion may affect mechanical integrity and may scatter radioactive material and dust.
Mechanical nibbler and shear; hydraulic shear	Segment activated metal; segment piping, tanks, and other metal.	Workable on all metals; usable in air or underwater; remote or portable operations/ usable only for thin metal pieces and pipes.
Hacksaws, guillotine saws, mechanical saws, circular cutters, and abrasive cutters	Segment piping, tanks, and other nonactivated metals.	Workable on all metals; varying degrees or portable and remote uses/slow cutting; small to medium-thickness; space, contamination, smoke, and other problems may apply.
Diamond wire saw	Non or minimally reinforced concrete (walls, floors).	Use not limited by concrete thickness/wire requires water cooling; generates contaminated dust and water.
Concrete spaller	Surface concrete removal (spalling).	Thin- to medium-section spalling; allows large structures to remain intact; no explosions needed; minimal dust generation/difficult with irregular surfaces and limited space.
Abrasive water jet	Nonreinforced concrete (walls, floors).	Thin-section spalling/voluminous generation of contaminated water.

SOURCES: Organisation for Economic Co-Operation and Development, Nuclear Energy Agency, International Co-Operation on Decommissioning: Achievements of the NEA Co-operative Programme, 1985-1990, (Paris, France: 1992), pp. 116-1 19; and H.D. Oak, G.M. Helter, W.E. Kennedy, Jr., and G.J. Konzek, Batelle Pacific Northwest Laboratory, Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station, NUREG/CR-0672, vol. 2 (Washington, DC: U.S. Nuclear Regulatory Commission, June 1980), pp. G-1 to G-22.

facility, but these tasks are not generally necessary to eliminate the radiological hazard at a nuclear power site. NRC rules also exclude spent fuel removal, storage, and disposal from decommissioning funding requirements, although radiological decommissioning cannot be completed until all fuel is removed.[80] Moreover, some States may require nonradiological dismantlement, including site restoration, suggesting that the narrow definition of decommissioning in NRC rules excludes other potential expenses licensees may incur or the public may expect when nuclear plant sites are remediated.

Methods for Estimating Decommissioning costs

To illustrate the relative financial magnitude of decommissioning, some observers have compared these costs with plant construction costs.[81] However, comparing decommissioning costs with plant construction costs may be misleading. Each set of costs is partially related to reactor size, but factors more important than size have determined the costs for each. Key determinants of decommissioning costs are operational history, occupational and residual radiation standards, and waste generation and disposal requirements—not construction costs or much related to them. With regard to construction costs, interest payments on loans and project delays (not reactor size) have historically led to substantial differences; more than 60 percent of Shoreham construction costs, for example, stemmed from interest on construction loans.[82] As a result, the costs either to construct or decommission two similar reactors may each vary greatly, depending upon historical financial and operating circumstances. In many cases, therefore, comparing construction and decommissioning costs is inappropriate.

The history of construction cost estimation, however, provides a cautionary lesson to decommissioning planners to avoid sanguine expectations that dismantling increasingly large reactors will provide major economies of scale and economies of learning, two assumptions that failed to bear out with construction experience.[83]

COSTING METHODS

There are several basic approaches used to estimate decommissioning costs. The least rigorous approach assumes a direct proportional relationship between decommissioning cost and unit size for all reactors. With this approach, the ratio of decommissioning cost to plant size (measured by power output) for a completed project is applied to another plant of known size to estimate its decommissioning cost. For example, the 58-MWt (22.5-MW) Elk River BWR was DECON decommissioned in 1974 at a cost then of $6.15 million. Applying its cost-to-size ratio (roughly $106,000 per MWt) to a standard-sized 3,300-MWt (1,100-MW) reactor planning DECON suggests that the larger reactor would cost $350

80 Within 5 years of license expiration+ NRC rules require commercial nuclear power licensees to submit preliminary decommissioning plans, which must indicate licensee plans to fired spent fuel management until the DOE accepts the fuel for final disposal. 10 CFR 50.54(bb). Until the 5-year mark, however, assuming the licensee is able to plan shut down that far in advance, there are no financial assurance requirements to address spent fuel management storage, or disposal. The only decommissioning financial plarming required during the entire license term, therefore, is for reactor dismantlement, not spent fuel costs.

81 See, for example, G.R.H. Fry, ''The Cost of Decommissioning U.S. Reactors: Estimates and Experience,' *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal,* vol. 12, Special Issue, 1991, pp. 93, 97; and D. Borson, Public Citizen Critical Mass Energy Project, *Payment Due: A Reactor-by-Reactor Assessment of the Nuclear Industry's $25+ Billion Decommissioning Bill* (Washington, DC: Public Citizen, Oct. 11, 1992), p. 79.

82 Thomas S. LaGuardia, President, TLG Engineering, letter to the Office of Technology Assessment, Jan. 22, 1993.

83 R. Cantor, "Applying Construction Lessons to Decommissioning Estimates," *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal*, vol. 12, Special Issue, 1991, pp. 105-117,

million (1974 $) to decommission.[84] Though conservative and unreliable, the proportional approach provides a quick, crude estimate of the potential cost to decommission a given plant.

To improve the crude estimates generated from simple proportional calculations, the unit cost factor approach was developed under the auspices of the Atomic Industrial Forum in the 1970s to provide a more systematic examination of likely decommissioning costs to help set appropriate utility rates. The approach determines unit costs for the range of tasks (e.g., cutting and packaging pipe of a given size) necessary to decommission plant systems, and the unit costs are adjusted according to assumptions about work difficulty (expressed as quantitative "difficulty factors") and performance times. Total cost is the product of the number of unit operations multiplied by their associated unit costs. The same method is used to determine cumulative radiation doses.

The challenge with the unit cost approach is determining reasonable difficulty factors, which some contend may currently be too conservative (i.e., large) and require refinement.[85] Experience with decommissioning one or more large commercial reactors should provide critical information about the appropriateness of current difficulty factors used in unit cost estimates. The unit cost approach is commonly used in the private sector, particularly by one firm (TLG Engineering, Inc.) that has provided site-specific estimates for more than 90 U.S. commercial nuclear power reactors .86

Another basic approach used to estimate decommissioning costs is the **detailed engineering** method. This approach is based on in-depth reviews of specific existing operating plants to determine labor requirements, radiation doses, efficient work schedules, and costs. This approach was used by Battelle Pacific Northwest Laboratory (PNL) in developing estimates for the NRC reference reactors, which are the basis of the Federal decommissioning financial assurance figures.[87] Both methods (unit cost factor and detailed engineering) are used extensively today. There is no current consensus on the more reliable approach, but both methods are likely to improve with actual decommissioning experience at a few large reactors, including Shoreham and Fort St. Vrain.

There is no reliable method to project labor costs many years in advance, because work difficulty, worker productivity, and project scheduling will vary with time and changing conditions. Variables such as local labor rates, available labor pools, training costs, radiation exposure and monitoring requirements, technological performance, and plant contamination levels are generally more speculative the further a licensee is from the commencement of decommissioning work. With time, any of these variables could increase or decrease final decommissioning costs.

Current database programs, which are used in both unit cost factor and detailed engineering analyses, provide detailed records of plant inventories and contaminated equipment and materials; these programs determine unit cost factors fairly easily for simple, repetitive tasks. The challenge, however, arises with more complicated tasks, particularly the dismantlement of steam generators and reactor pressure vessels, The reliability of

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84 R.I. Smith, ' 'Generic Approaches to Estimating U.S. Decommissioning Costs, " ***Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,*** M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal, vol. 12,* Special Issue, 1991, p. 150. Note: This paper uses the phrase "linear extrapolation' to describe the proportional method of calculating decommissioning costs.

85 Ibid., pp. 1s0-152.

86 Thomas LaGuardia, president, TLG Engineering, Inc., comments delivered during NRC public meeting in Arlington, VA, May 6, 1993.

87 R.I. Smith, "Generic Approaches to Estimating U.S. Decommissioning Costs," *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal, vol. 12, 1991,* Special Issue, pp. 152-153.

cost estimation for this more complex work will improve with more decommissioning experience.

Several other key uncertainties hamper current costing models. First, scheduling and other time-dependent assumptions in current models were developed from experience with smaller dismantlement projects and may be inappropriate for larger plants. Second, the macroeconomic supply and demand impacts on costs are not addressed in current models. For example, utility planners generally assume stable unit costs for dismantlement work, disregarding the potential market impacts of other decommissioning projects commencing in the same period.[88] Third, current models cannot reliably predict whether major economies of scale or other benefits of experience may occur when larger reactors are dismantled.[89]

In sum, future experience decommissioning large reactors should improve cost estimation considerably, but current uncertainties in determining the actual costs to dismantle large (more than 50 MW) commercial reactors will probably remain so for at least another decade, if not longer, because no large reactors with operational lives more than a few years have been dismantled yet nor are likely to be soon. Some current uncertainties with decommissioning cost estimation reflect unresolved Federal policies and standards, including final standards for residual radioactivity. Lingering questions about both HLW and LLW disposal siting, capacity, and costs also prevent plant operators from making reliable final estimates of total decommissioning costs. Labor and project scheduling assumptions used in current cost models may also change with more experience dismantling larger plants, including their large components such as reactor pressure vessels. The ultimate impact of such potential changes on total costs remains speculative.

Decommissioning Cost Estimates

A 1991 national survey of decommissioning cost estimates for large operating reactors determined an average of $211 per kilowatt (kW), with a standard deviation of $96 per kW (both in 1989 dollars). The average estimate for the 47 PWRs surveyed was $191 per kW (standard deviation of $65 per kW), and $248 per kW (standard deviation of $126 per kW) for the 26 BWRs surveyed.[90] These figures suggest that decommissioning a 1,000-MW plant would cost about $211 million (1989 dollars), based on existing estimates, although the standard deviation is substantial ($96 million).

These aggregate cost figures have two major limitations. First, as discussed above, comparing estimated costs with plant size can be misleading, because plant size is neither the single, nor best, measure of potential decommissioning costs. Second, the relatively narrow range of these estimates may reflect an artificial uniformity, because most were derived from TLG and PNL models.[91] However, the results provide simple averages of current decommissioning cost estimates.

88 R. Cantor, "Applying Construction Lessons to Decommissioning Estimates," ***Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,*** M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal, vol. 12,* Special Issue, 1991, p. 108.

89 See G.R.H. Fry, "The Cost of Decommissioning U.S. Reactors: Estimates and Experience," *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal,* vol. 12, Special Issue, 1991, pp. 87-104. Examining the limited U.S. decommissioning experience to date, Fry argues that there appear to be few or no economies of scale. However, the analysis includes two reactors (Fermi Unit 1 and Three Mile Island Unit 2) that experienced partial core meltdowns, thus obscuring what may be a trend of decreasing cost with size for reactors without such major accidents. Fry concludes that more experience will be necessary to confirm whether or not scale economies will develop for large decommissioning projects.

90 P.M. Strauss and J. Kelsey, "State Regulation of Decommissioning Costs, " *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal, vol. 12, Special* Issue, 1991, pp. 56-64.

91 Ibid., pp. 60-63.

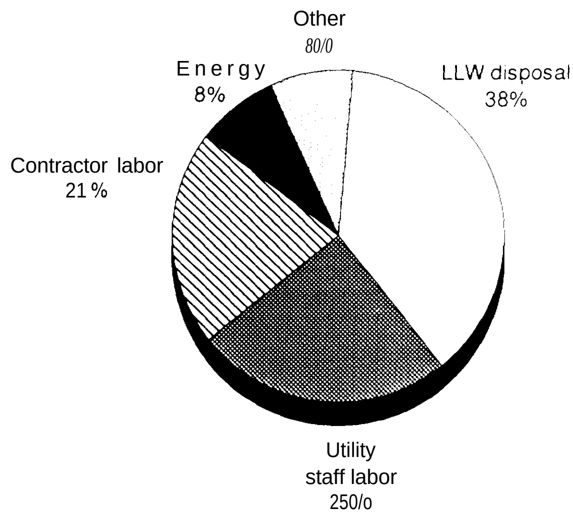
A series of NRC studies, using the PNL model, has examined the potential costs to decommission U.S. commercial reactors by examining two units in detail. These studies are detailed engineering analyses of the 1,175-MW Trojan Unit 1 PWR (Prescott, Oregon) and the 1,155-MW Washington Nuclear Project (WNP) Unit 2 (Richland, Washington) (the "reference reactors"). The estimates vary depending on the reactor type (PWR or BWR) and decommissioning approach. In brief, DECON decommissioning using an external contractor for labor and management assistance was projected to cost $103.5 million for the reference PWR and $131.8 million for the reference BWR (both in 1986 dollars, assuming a 25 percent contingency).[92]

The major elements of the reference PWR and BWR cost estimates are waste shipment and disposal, labor, and energy (figures 4-6 and 4-7).[93] For both estimates, supplies, equipment, and other items account for the remainder of costs. Both estimates exclude spent fuel disposal, nonradiological decommissioning, and site restoration costs, because these activities are excluded from the NRC definition of decommissioning.

The lack of demonstrable progress in developing a national MRS facility or a geologic repository, however, suggests that more commercial nuclear power licensees will need to build and operate interim spent fuel storage facilities. This will add waste management costs of at least $20 million to $30 million per plant, representing about 10 to 20 percent of expected dismantlement costs. In some cases, interim spent fuel storage will cost far more. Moreover, LLW volume projections from decommissioning will remain somewhat speculative until either the NRC or the EPA promulgates residual radioactivity standards. In addition to NRC requirements, licensee plans or State requirements may introduce additional nonradiological decommissioning costs, perhaps including site restoration.

The key differences between current decommissioning cost estimates generally center on the two major cost elements—labor and waste disposal. In general, the NRC reference studies project lower labor requirements, lower LLW

Figure 4-6--Major Costs From Decommissioning a Reference Pressurized Water Reactor

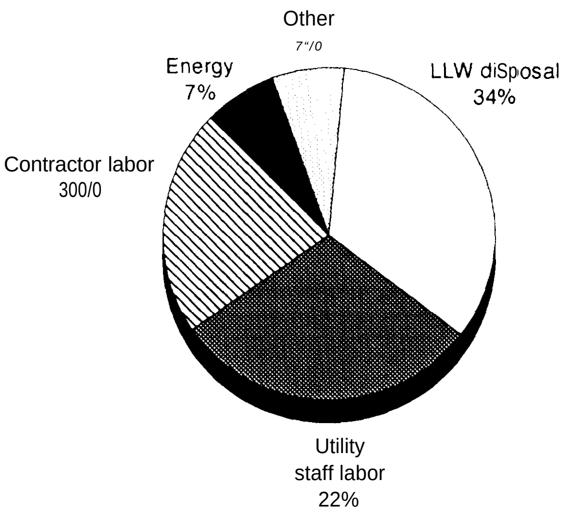


SOURCE: G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning* a *Reference Pressurized Wafer Reactor Power* Station: *Technical Support for Decommissioning* Matters Related to Preparation *of the* Final *Decommissioning Rule*, NUREG/CR-0130, Addendum 4 (Washington, DC: U.S. Nuclear Regulatory Commission, July 1988), p. 3.1.

92 The DECON approach is assumed for financial planning, because it is considered the most expensive option. As noted earlier, however, the use of DECON (immediate dismantlement) may not be viable for many (if not most) light water reactors due to spent nuclear fuel cooling requirements, which currently prevent fuel removal from storage pools for at least 5 years. As a result, plant-specific analyses will be necessary to determine the minimum period of safe storage prior to decommissioning. George J. Konzek, Sr., Senior Research Engineer, Pacific Northwest Laboratories, letter to the Office of Technology Assessment, Jan. 8, 1993.

93 G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station: Technical Support for Decommissioning Matters Related* to *Preparation of the Final Decommissioning* Rule, NUREG/CR-0130, Addendum 4 (Washington DC: U.S. Nuclear Regulatory Commission, July 1988), p. 3.1; and G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and* Costs *of Decommissioning a Reference Boiling Water Reactor Power Station: Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule,* NUREG/CR-0672, Addendum 3 (Washington DC: U.S. Nuclear Regulatory Commission, July 1988), p. 3.1.

Figure 4-7—Major Costs From Decommissioning a Reference Boiling Water Reactor



SOURCE: G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station: Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule*, NUREG/CR-0672, Addendum 3 (Washington, DC: U.S. Nuclear Regulatory Commission, July 1988), p. 3.1.

volumes, and hence lower costs than most site-specific industry estimates.[94] For example, an independent industry analysis of the NRC reference BWR estimates that DECON decommissioning (using the NRC definition) will cost $201.5 million (1987 dollars), about 46 percent more than the $138 million (1987 dollars) projected in the PNL study. While the industry analysis estimated LLW generation of 24,489 m^3, a 29 percent increase over the NRC figure, this difference accounted for a minor portion of the cost difference. Instead, the most significant difference between the estimates, about $40 million, was labor costs.[95] Field experience from future dismantlement projects will eventually help test the reliability of the methods underlying these estimates.

Under contract with the NRC, PNL is revising both reference reactor cost estimates. Although no report has been finalized, the revised PWR cost estimate is currently $124.6 million (1993 dollars), about $5 million less when adjusted to the original (1986) dollars. The report authors attribute the cost decrease to LLW volume reductions but also acknowledge many of the excluded costs (e.g., spent fuel management) and other uncertainties (e.g., absence of residual radioactivity standards, LLW disposal costs). This estimate could more than double when the excluded costs and the other uncertainties are considered.[96]

The Impacts of Life Extension on Decommissioning Costs

The impacts of license renewal on decommissioning are a likely deferral of dismantlement work, a slight increase in final plant radioactivity levels, and the disposal of any major equipment replaced during the renewal term (e.g., PWR steam generators, BWR turbine blades). A 1991 PNL study estimated the impacts on decommissioning costs of extending operations of the reference reactors by 20 years and assumed that some major equipment (RPV and internals) would need replacement.[97] Even under this unlikely scenario of RPV replacement, the estimates

94 P.M. Strauss and J. Kelsey, "State Regulation of Decommissioning Costs," *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal,* vol. 12, Special Issue, 1991, pp. 60-63.

95 G.J. Konzek and R.I. Smith, Battelle Pacific Northwest Laboratory, *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station: Comparison of Two Decommissioning Cost Estimates Developed for the Same Commercial Nuclear Reactor Power Station,* NUREG/CR-0672, Addendum 4 (Washington, DC: U.S. Nuclear Regulatory Commission, December 1990), pp. 2.5, 2.10.

96 E. Lane, "pNL Study Cuts Cost Estimate For Nuclear Decommissioning," *The Energy Daily,* vol. 21, No. 123, June 29, 1993, p. 3.

97 R.I. Smith, Battelle Pacific Northwest Laboratory, "Potential Impacts of Extended Operating License Periods on Reactor Decommissioning Costs, PNL-7574 (Richland, WA: Battelle Pacific Northwest Laboratory, March 1991). All material in this section is from the PNL report.

indicated that extended operations would minimally affect final decommissioning costs, adding about $2 million (1986 dollars) to dismantle each reactor. However, the analysis was limited to GTCC disposal costs and assumed that replacing the RPV and internals during the extended license term would account for the major increase in decommissioning costs (aside from PWR steam generator replacement). The study estimated that most of the estimated cost increase could be eliminated by high-density packaging of the GTCC waste, a procedure not considered in the original PNL reference reactor analyses.

In the original reference PWR and BWR analyses, LLW disposal represented the largest single cost. On the basis of uncertainty, however, the life extension study did not estimate future LLW disposal costs but indicated that new compact sites could charge as much as $100 to $200 per cubic foot (excluding surcharges) by the year 2000. A key determinant of potential future costs, therefore, was excluded. The impacts of other uncertainties (e.g., labor cost escalation and future residual radioactivity standards) were not examined.

Estimating Radiation Exposures for Decommissioning

The human health and environmental challenge during decommissioning is to hold radiation exposures as low as possible. This section reviews the results of modelling estimates of collective radiation doses from decommissioning. In addition, the section summarizes predicted or measured doses from several actual steam generator replacement and reactor decommissioning projects. Radiation standards during decommissioning (10 CFR Part 20) are the same that apply during plant operations (see ch. 2). Although the NRC does not set collective dose standards, the measurement is used to compare the aggregate exposures for different tasks (e.g., decommissioning) conducted at nuclear facilities.[98]

COLLECTIVE DECOMMISSIONING DOSE: PROJECTIONS BASED ON THE NRC REFERENCE REACTORS

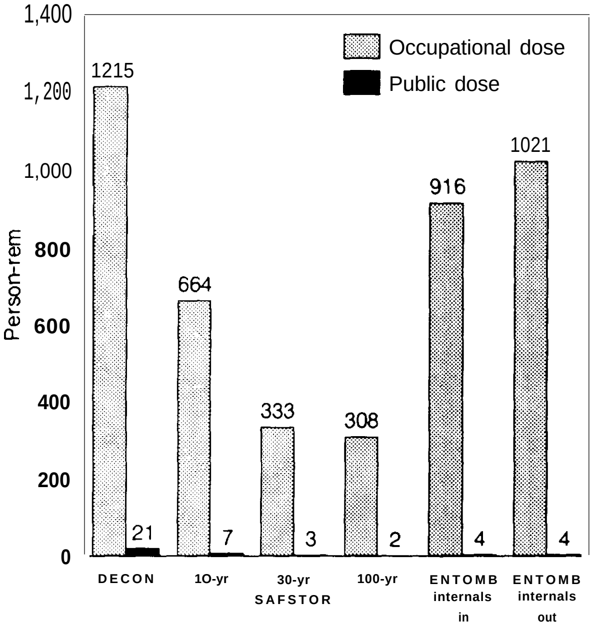
The collective doses projected for decommissioning the two NRC reference reactors are given in figures 4-8 and 4-9. The values differ significantly, depending on the reactor type (greater collective dose for BWRs generally), decommissioning approach (greatest collective dose for DECON), and the length of time work is deferred (lowest collective dose for 100-year SAFSTOR).

In brief, BWRs are single-loop systems that channel reactor cooling water in the form of steam directly to the turbines, leading to greater contaminant dispersion and thus explaining the higher projected doses for decommissioning. For the same reason, BWRs also produce greater collective doses than PWRs during normal operations. In addition, more plant radioactivity decays the longer decommissioning is deferred, explaining why 100-year SAFSTOR produces the lowest collective doses and DECON the highest. (This study projected that ENTOMB yielded greater collective doses than SAFSTOR, because the former method was assumed to involve more decontamination and some partial dismantlement earlier than the SAFSTOR scenarios.)

The NRC projections suggest that the annual collective occupational doses associated with decommissioning are very similar to those experienced while plants are in operation, even in the worst dose scenario (four-year DECON). The DECON estimates represent an annual average PWR dose of about 279 person-remand an annual average BWR dose of about 440 person-rem. By comparison, the average annual occupational

98 The major limitation with collective exposure numbers is that they are averages; the variation in individual exposures, no matter how significant, is not indicated by this number, and individual or collective radiation risks cannot be determined by this number either. It is merely a gross measure of the average individual exposure in an affected group,

Figure 4-8-Collective Radiation Doses From Decommissioning a Reference Pressurized Water Reactor



SOURCE: U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 (Washington, DC: August 1988), pp. 4-8.

dose at operating PWRs in the United States in 1990 was 294 person-rem and 436 person-rem at operating BWRs.[99]

Collective public dose from decommissioning is minimal compared to collective occupational dose. Under all scenarios, for both PWRs and BWRs, collective public dose derives almost entirely from the truck shipments of radioactive waste to the disposal facilities. Projections of collective occupational doses, on the other hand, for DECON and 10-year SAFSTOR are principally from decontamination activities, while most occupational doses for 30- and 100-year SAFSTOR stem from activities associated with storage preparations.[100]

COLLECTIVE DOSE: OTHER PROJECTIONS AND RELATED EXPERIENCE

Limited but useful information from actual decommissioning and nuclear plant maintenance projects suggests the relative radiological impacts expected from future decommissioning work. The Shippingport decommissioning project, for example, disposed of 16,000 Ci and resulted in a collective occupational exposure of 155 person-rem, only 15 percent of the 1,007 person-rem projected during decommissioning planning. Shippingport decommissioning project management attributes the lower occupational dose to ALARA (as low as reasonably achievable) planning and coordination. However, by not segmenting the RPV, which contained over 99 percent of the disposed curies, project planners unquestionably eliminated much of the expected occupational dose at Shippingport.[101]

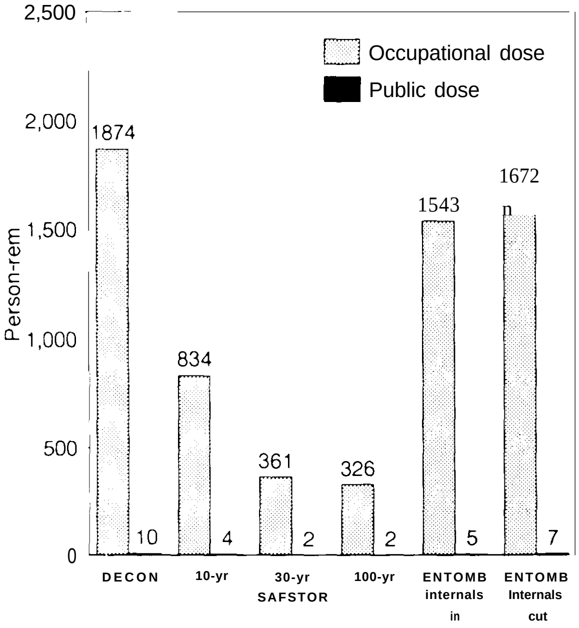
Unless other technologies or techniques such as metal melting are applied in the future, RPV segmentation is likely to be the norm for most commercial nuclear power plant decommissioning work, and this will increase decommissioning exposures considerably relative to Shippingport. At both Fort St. Vrain (box 4-C) and Shoreham (box 4-D), RPV dismantlement is expected to account for most of the occupational exposures but, like Shippingport, the radiation at these units was almost entirely present in their RPVs; this will not be the case with larger units that operate longer.

99 Institute of Nuclear Power Operations, "1990 Performance Indicators for the U.S. Nuclear Utility Industry' (Atlanta, GA: March 1991).

100 U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 *(Washington DC:* August 1988), pp. 4-8,5-8.

101 RPV segmentation was part of the original Shippingport decommissioning plan. Westinghouse Hanford Company, *FinalProjectReport: Shippingport Station Decommissioning Project,* DOE/SSDP-0081 (Richland, WA: U.S. Department of Energy, Richland Operations Office, Dec. 22, 1989), pp. 13,48.

Figure 4-9—Collective Radiation Doses From Decommissioning a Reference Boiling Water Reactor



SOURCE: U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 (Washington, DC: August 1988), pp. 5-8.

Table 4-5-Occupational Radiation Exposures From Recent Steam Generator Replacements

Unit (year of replacement)	Net capacity (MWe)	Total exposure (person-rem)
H.B. Robinson 2 (1984)..	739	1,207
Cook 2 (1988)	1,133	561
Indian Point 3 (1989).	1,013	540
Palisades (1990).	805	487
Millstone 2 (1993)....	889	650
North Anna 1 (1993)....	947	240

SOURCES: North Anna data from R.R. Zuercher, "Virginia Power Sets World Record For Steam Generator Replacement," *Nucleonics Week, vol. 34, No.* 15, Apr. 15, 1993, pp. 1, 11; Millstone data from R.R. Zuercher, "NU Restarts Millstone-2 Following Extended Steam Generator Outage," *Nucleonics Week, vol.* 34, No. 3, Jan. 21, 1993, pp. 6-7; all other data from H. Hennicke, "The Steam Generator Replacement Comes of Age," *Nuclear Engineering International, vol.* 36, No. 444, July 1991, p. 23.

Collective occupational radiation exposures measured from recent steam generator replacements at U.S. operating plants have been as high or higher than the NRC projections of average annual DECON exposures (table 4-5). As these figures suggest, exposures from major maintenance activities at operating commercial plants are comparable to expected decommissioning exposures and therefore represent common, generally accepted levels of risk.

REACTOR RETIREMENT AND FINANCIAL REQUIREMENTS

Beyond estimating decommissioning costs, a challenge remains to collect reasonable decommissioning funds while a unit is still operating, rather than later when electricity production has ceased. In cases of early reactor retirement, decommissioning funding shortfalls may be significant (box 4-E), although the costs of unrecovered plant capital will often match or exceed the remaining decommissioning liability (see ch. 3) and thus introduce larger impacts on consumer electricity rates than decommissioning shortfalls. This section reviews the major regulatory issues relating to decommissioning and its financing, including relevant NRC requirements, funding options, and the performance of existing funds. Although the NRC has established minimum funding levels to plan for decommissioning, State utility commissions have the major role in determining the actual timing, amounts, and other conditions of decommissioning financing.

None of the three general decommissioning approaches (DECON, SAFSTOR, or ENTOMB) is the obvious choice for most decommissioning work, and NRC rules do not dictate which option to use. The approach chosen by licensees will depend on site-specific conditions, including the availability and costs of LLW disposal facilities, the economic potential and regulatory requirements for later site use, and the particular need or urgency (if any) to eliminate the potential environmental and financial liability that a contaminated site represents. For purposes of financial planning, most commercial nuclear power licensees assume they will DECON decommission,[102] but recent data suggest that DECON may not be viable for many light water reactors.[103] And although numerous small research reactors have undergone ENTOMB decommissioning, the NRC considers its technical viability for large commercial plants limited.[104] As a result, under current regulations and technical specifications, most U.S. commercial power reactors are likely to complete decommissioning within a period ranging from 5 to 60 years after they retire.

Terminating an Operating License

Under NRC rules, commercial nuclear power licensees must apply for the termination of their operating licenses within 2 years after permanent shutdown and in no case later than 1 year before license expiration, If not submitted earlier, a proposed decommissioning plan must accompany an application for license termination. Proposed plans must describe the decommissioning approach, procedures to protect occupational and public health and safety, and an updated cost estimate.[105] A license may not be terminated until the site is remediated and a final radiation survey performed.

A variety of safety requirements that apply to operating reactors become unnecessary once operations cease permanently. In recognition of that, NRC Regulatory Guide 1.86 allows plant operators to apply for an amended operating license that allows plant possession only. A ‘‘possession-only license” (POL) exempts plant operators from a variety of costly operating requirements, including requirements applied to emergency core cooling systems (10 CFR 50.46), in-service inspection (10 CFR 50.55a(g)), and reactor fracture toughness against pressurized thermal shock (10 CFR 60.61).[106]

With an approved POL, licensees may forego NRC annual operating fees, which amount to roughly $3 million per unit.[107] The saved resources may be used for other work, such as decommissioning planning and execution, but there are no current standards and guidelines that specify the format of POL applications. As a result, such applications are developed on a case-by-case basis.[108] By issuing standards and guidance clarifying the role of and application process for POL status, the NRC would help ensure that post-closure licensee activities and costs are reasonably minimized and that final

102 P.M. Strauss and J. Kelsey, “State Regulation of Decommissioning Costs, ” *Nuclear Decommissioning Economics: Estimates, Regulation, Experience and Uncertainties,* M.J. Pasqualetti and G.S. Rothwell (eds.), *The Energy Journal,* vol. 12, Special Issue, 1991, pp. 56-65. Of course, deferring plant dismantlement (the SAFSTOR approach) would reduce significantly the amount of LLW necessary for disposal, but there are other costs (license fees, security, taxes, insurance) and uncertainties (potential changes to waste disposal capacity, disposat costs, or regulatory release criteria) associated with deferring dismantlement.

103 The use of DECON (immediate dismantlement) may not be viable for many (if not most) light water reactors due to spent nuclear fuel cooling requirements, which currently prevent fuel removal from storage pools for at least 5 years. As a result, plant-specific analyses will be necessary to determine the minimum period of safe storage prior to decommissioning. George J. Konzek, Sr., Senior Research Engineer, Pacific Northwest Laboratories, letter to the Office of Technology Assessment Jan. 8, 1993.

104 U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities,* NUREG-0586 (Washington, DC: August 1988), pp. 2-6 to 2-12. For large reactors with long operational lives, the ENTOMB approach is not likely to ensure sufficient decay of long-lived radioisotopes within reasonable periods (e.g., 100 years) to allow site release.

105 10 CFR 50.82.

106 Nuclear Management and Resources Council, Inc., *Regulatory process for Decommissioning Prematurely Shutdown ?'[ants, NUMARC 92-02* (Washington, DC: November 1992), p. 4-4.

107 10 CFR 171.15.

108 Nuclear Management and Resources Council, Inc., *Regulatory Process for Decommissioning Prematurely Shutdown Plants,* NUMARC 92-02 (Washington, DC: November 1992), p. 4-1.

decommissioning planning and execution could begin as expeditiously and safely as possible.

NRC Financial Assurance Requirements

NRC financial assurance rules are designed to ensure that sufficient funds are available to decommission nuclear plants even if the licensee defaults.[109] Although the default of an electric utility is rare, decommissioning financial assurance is considered necessary, because electric utilities are typically private, investor-owned firms that are vulnerable, as any other firm, to insolvency. In addition, if the salvage value of a power plant exceeded its expected cleanup costs, the need for financial assurance requirements would be less compelling, but potential salvaging revenues for nuclear plants are limited (perhaps a few tens of millions of dollars at best) relative to decommissioning costs (a few to many hundreds of millions of dollars).

Under NRC rules, the *minimum* financial assurance that licensees must provide to decommission each of their reactors is determined by a sliding scale that considers primarily the type and size (as measured in MWt) of a reactor.[110] In 1986 dollars, the minimum financial assurance for decommissioning a PWR ranges from roughly $86 million for the smallest reactors to $105 million for the largest, and the minimum financial assurance for a BWR ranges from roughly $115 million to $135 million.[111] These regulations contain additional requirements to adjust annually the escalations in labor, energy, and LLW burial costs[112] (the most significant components of decommissioning expenses). Utilities are required to perform but not report these adjustments.

Adequacy of NRC Financial Assurance Requirements

The NRC maintains that the amounts in the financial assurance rule are not decommissioning cost estimates but rather provide a reasonable approximation of the *minimum* costs of decommissioning. In the Supplementary Information to its 1988 decommissioning rule, the NRC suggested that the financial assurance provisions should provide the *bulk* (not necessarily all) of the funds needed to decommission commercial nuclear plants in the United States.[113] In that respect, though, the amounts represent an actual (though perhaps minimum) estimate.

The NRC financial assurance rules establish finding levels for commercial power plants in each reactor class (PWR or BWR) by adjusting primarily for size. While these rules are based on detailed engineering studies of two reference reactors, the generic approach may not be satisfactory for providing reliable financial assurance for the entire industry given the significant differences in individual reactor designs, operating histories, eventual plant contamination, and other factors that will be more important than size in determining final decommissioning costs at many (if not most) commercial nuclear power plants in the United States.

A simple understanding of plant size may not be sufficient to predict *or* plan financially for total project costs, if plant design, final contamination, and other site conditions have more important impacts on decommissioning costs than reactor size. Compared to site-specific decommissioning estimates performed for several recently retired reactors (box 4-E), the NRC requirements are consistently and substantially low.

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109 53 *Federal Register* 24018-24056 (June 27, 1988).

110 The capacity of an electrical generating plant can be expressed in MWe (electrical capacity) or MWt (thermal capacity). The NRC decommissioning financial assurance requirements are based on MWt, which is considered a better indication of physical plant size. MWe, on the other hand, is a measure of the efficiency of power conversion which can change over time without any changes to plant size.

111 10 CFR 50,75(C)(1).

112 10 CFR 50.75(c)(2).

113 53 *Federal Register* 24030 (June 27, 1988).

Furthermore, the current regulatory definition of decommissioning and the related NRC financial assurance rules under 10 CFR 50.75 exclude spent fuel disposal, its associated costs, and other potential nonradiological expenses (e.g., site restoration) that States may require. As plant decommissioning cannot be completed before all spent fuel is removed, the current regulatory distinction between spent fuel waste disposal and other decommissioning activities is arbitrary and masks the range of activities and costs needed to complete "decommissioning," even as defined by NRC rules. As previously discussed, the costs of providing any needed interim storage for spent fuel can be substantial, about $20 million to $30 million per plant, which is in the range of 10 to 20 percent of the current estimates of radiological decommissioning.

Post-closure costs such as plant maintenance and inspection, security, property taxes, insurance, and remaining license fees may be significant as well but are also excluded from NRC decommissioning financial assurance requirements, which focus on removing site radiological contamination. As a result, radiological decommissioning is only one part (although perhaps the most important) of post-closure expenses at commercial nuclear power plants, but future changes to NRC financial assurance rules could include some of these other costs, such as spent fuel management, plant maintenance and monitoring, insurance, and site security.

There appears to be widespread agreement among utilities, State public utility commissions (PUCs), and even the NRC that the reference reactor decommissioning cost estimates underlying the NRC financial assurance rules are low. The NRC is currently updating its studies of the reference reactors, one of which (Trojan) retired this January. In the meantime, utilities and PUCs have relied increasingly on site-specific cost estimates to prepare for eventual decommissioning; most licensees, in fact, now use site-specific estimates. Thus, the future benefit of revising the generic NRC financial assurance formulae may be negligible. Encouraging licensees to develop and update regularly their own site-specific decommissioning cost estimates may have more value in assuring adequate financing than actually revising the regulatory figures in 10 CFR 50.75.

NRC rules require licensees to submit a preliminary decommissioning plan and cost estimate about 5 years prior to expected plant retirement.[114] However, the licensees of all seven reactors that retired early in the last 14 years had far less than five years to plan for their respective reactor retirements, suggesting that this generic requirement may also have little practical value in assuring adequate decommissioning financing.

EARLY REACTOR RETIREMENT

The recent trend of early nuclear power plant retirements undermines the basic NRC objective that licensees have available sufficient decommissioning funds at final shutdown, an objective expressed as part of the 1988 rule.[115] With early retirement, the operating period assumed for the collection of decommissioning funds is reduced, often substantially. Collections for decommissioning trusts are calculated assuming a unit operates its full licensed life. The average life, however, of the seven retired reactors was less than 15 years. Excluding arguable anomalies such as Three Mile Island and Shoreham, both of which shut down after a year or less of operations, the average life of the remaining five plants was only 20 years, half the time assumed in standard license periods. These early retirements highlight

114 10 CFR 50.75(f). This rule does not specifically require a site-specific estimate.

115 53 *Federal Register* 24031 (June 27, 1988).

the need to re-examine the NRC financial assurance requirements to ensure that adequate decommissioning resources are available (or assured) whenever a plant closes. Also, as discussed in chapter 3, the allocation of decommissioning costs among current and future consumers and utility shareholders is an issue for which there is limited precedence.

FUNDING REQUIREMENTS FOR EARLY REACTOR RETIREMENT

In 1992, the NRC promulgated a rule to address decommissioning funding for reactors retired prior to their license expiration. Recognizing that licensees generally have access to significant financial capital, the NRC decided to determine the need for accelerated fired accumulation based on case-by-case determinations of licensee financial conditions.[116]

These requirements are based on two basic principles stated in the preamble to the rule. One, all decommissioning funds should be collected before the original operating license term expires. Two, licensees may collect funds during any storage period, but only until the license expiration date and only if they maintain a bond rating of at least "A" or equivalent by Moody's Investment Services, Standards and Poors, or another national rating agency. If licensee bond ratings fall below the "A" screening criterion more than once in a 5-year period, the balance of decommissioning funds may have to be collected and deposited into an external account within 1 year of the downrating, unless other criteria that reasonably assure financial solvency are met.[117]

There are several potential problems with the decommissioning financial assurance rules as applied in cases of early retirement. First, linking bond rating to fund accumulation may effectively eliminate SAFSTOR as a financially attractive decommissioning alternative by potentially limiting the period in which funds may be collected. Second, the rule may create a disincentive to close uneconomic plants out of concern to collect sufficient decommissioning funds during operations. Third, requiring licensees to collect the remainder of any funding shortfall precisely when their bond ratings drop may aggravate further their financial position, without substantially improving the prospects of collecting all decommissioning finds. Finally, these rules may assure adequate funding for eventual decommissioning, but they do not prevent future ratepayers from paying the bulk of decommissioning costs.

POST-ACCIDENT PREMATURE DECOMMISSIONING INSURANCE

In 1991, insurance became available to cover the costs of premature decommissioning from severe accidents that cause property claims to exceed $500 million. Both of the two nuclear excess property insurers provide coverage. Nuclear Electric Insurance Limited (NEIL), an industry-sponsored organization, will cover the difference between the amount in the decommissioning trust fund and final target up to the pre-selected sublimit. (The current maximum is $200 million, which is expected to increase to $250 million.) American Nuclear Insurers and Mutual Atomic Energy Liability Underwriters (ANI/MAELU), pools of commercial insurers, will indemnify decommissioning coststoa''greenfield" condition, once other decommissioning funds are exhausted, up to $100 million.[118]

FUNDING REQUIREMENTS IN OTHER NATIONS

Official decommissioning funding requirements in other nations vary considerably, and many are

116 57 Federal Register 30383-30387 (July 9, 1992). See 10 CFR 50.82(a).

117 These other criteria include an evaluation of the licensee's financial history, local and State regulatory conditions, the number of its Other nuclear and non-nuclear generating plants, and other factors deemed relevant by the NRC. 57 *Federal Register 30385* (July 9, 1992).

118 ABZ, Inc., "Case Studies of Nine Operating NuclearPower Plants: Life Attainm ent, License Renewal and Decommissioning, contractor report prepared for the Office of Technology Assessment February 1993, p. 52.

far less rigorous than NRC requirements. The governments of Germany, Italy, and the United Kingdom have not imposed decommissioning funding requirements, although German plant operators make voluntary financing arrangements. The Canadian government requires nuclear operators to arrange decommissioning financing but does not specify actual amounts or funding methods. Finland, Spain, and Sweden have decommissioning funding requirements but, unlike the United States, monies are collected from operators by their respective governments and managed in separate national finds. In France, the government-owned utility adjusts its accounts monthly to help finance future decommissioning based on the product of reactor capacity (size) multiplied by 15 percent of the construction costs of a reference 1,300-MW PWR. In Japan, where 85 percent of collected fund monies are tax-free, utilities determine decommissioning funds based on the estimated weight of dismantled plant wastes.[119]

Funding Options

By July 1990, NRC licensees were required to submit reports indicating their plans to provide reasonable financial assurance for decommissioning.[120] These reports had to specify the type and amount of financial assurance provided, using either site-specific cost estimates or the NRC regulatory minimum given in 10 CFR 50.75(c). Three general types of financial assurance are eligible: prepayment; an external sinking fund; or a surety method, insurance, or other guarantee.

Prepayment, as the word suggests, involves depositing sufficient cash or other liquid assets prior to facility operations into an account maintained separately from licensee assets to fund decommissioning. Prepayment may be in the form of a trust, escrow account, government fund, certificate of deposit, or deposit of government securities.[121] An external sinking fund is also maintained separately from licensee assets, but payments are made at least annually during operations rather than in advance. External fund investments may be the same as those for prepayment.[122] The last decommissioning option—a surety method, insurance, or other guarantee method-may be in the form of a surety bond, a letter of credit, or a line of credit, but any surety method used must remain effective until the NRC terminates the license.[123] Most licensees use an external fund to finance decommissioning.[124] The choice is understandable: prepayment is expensive, requiring a licensee to collect all decommissioning monies in advance and, until recently, no decommissioning surety options were available on the market.

QUALIFIED AND NONQUALIFIED EXTERNAL FUNDS

Before 1984, any funds collected for decommissioning were federally taxed. By 1986, statutory changes allowed Federal tax deductions for

119 Organisation for Economic Co-Operation and Development, Nuclear Energy Agency, *Decommissioning of* Nuclear Facilities: *An Analysis of the Variability of Decommissioning Cost Estimates* (Paris, France: 1991), pp. 104-108.

120 10 CFR 50.33(k),

121 10 CFR 50.75(e)(l)(i).

122 10 CFR 50.75 (e)(l) (ii), (c)(3)(@.

in 10 CFR 50 75(e) (1)(iii), (e)(l) (hi)(C) Until 1990, many licensees maintained internal decommissioning accounts to control better their financial management, but concerns about the loss of these funds in cases of utility insolvency led the NRC to eliminate this option. 53 *Federal Register 24033* (June 27, 1988).

124 "Outlook On Decommissioning Costs," *Nucleonics Week,* Sept. *27, 1990,* Special Report, p. 5. This review examined documents filed for 68 nuclear plants.

any decommissioning funds placed in qualified investments (public debt securities and bank deposits). Decommissioning funds may be invested in other securities, but they are ineligible (nonqualified) for corporate tax deductions and, until recently, faced the full corporate tax rate of 34 percent. Nonqualified funds, such as mutual funds, are higher risk investments that generally earn more than qualified funds-even accounting for their greater tax burden. Nonetheless, most decommissioning monies are invested in qualified funds.[125]

In recent years, many investment managers and utility analysts have argued that earnings from many qualified investments, though relatively safe financially, have not performed well, some barely (if at all) earning more than inflation.[126] Although monies placed in qualified funds have been tax deductible, their earnings were taxed at the full corporate rate of 34 percent. Moreover, disbursements from qualified funds were taxed at the full corporate rate, reducing substantially the benefits of their qualified status. At the same time, even though nonqualified fund monies were taxed, their disbursements were not, increasing substantially their stature as an investment option. Concerns about trust fund earnings recently prompted Congress to repeal the investment restrictions on qualified external funds and reduce their applicable tax rates to 22 percent in 1994 and 20 percent starting in 1996.[127] At present, nuclear decommissioning trusts (NDTs) total an estimated $5 billion to $7 billion, with an estimated 80 percent invested in municipal bonds. The recent congressional changes, however, are likely to shift many investments to other, higher yielding securities.[128]

B Performance of Existing Funds

In 1990, the Critical Mass Energy Project of the nongovernmental group Public Citizen surveyed the status of existing NDTs. Their findings suggest that commercial nuclear power licensees are not collecting decommissioning funds quickly enough. The group determined that less than 14 percent of the total sum of all projected U.S. nuclear power plant decommissioning costs had been collected, even though more than 33 percent of their expected operational lives had passed (assuming neither life extension nor premature retirement).[129] However, with compounded interest earnings, net NDT growth will accelerate in later years. In addition, the NRC financial assurance rules were not effective until 1990, but the Public Citizen findings are a reminder that many licensees had operated their plants 10 years or longer before the NRC rule became effective, and many licensees will have to accelerate their collection schedules. The report also found that about one-third (34 percent) of decommissioning funds remained in internal funds in 1990.[130]

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125 H. Hiller, ''Investment Strategies for Nuclear Decommissioning and Pension Funds: Highlighting the Differences, ' Salomon Brothers, Inc., Bond Portfolio Analysis: Nuclear Decommissioning, Apr. 14, 1989, p. 5,

126 See, for example, P.C. Stimes and R.T. Flaherty, "Investment Management for Nuclear Decommissioning Trusts, " *Public Utilities Fortnightly*, vol. 126, No. 11, Nov. 2, 1990, pp. 32-33; and M.D. Weinblatt, S. D'Elia, and T.A. Haven, ''Choosing Investment Strategy for Qualified Nuclear Plant Decommissioning Trusts," *Public Utilities Fortnight[y,* vol. 122, No. 10, Nov. 10, 1988, pp. 33-36.

127 Energy Policy Act of 1992, Public Law 102486, 106 Stat. 3024-3025, Sec. 19 17.

128 J. Pryde, ' 'Nuclear Decommissioning Funds Are Unlikely To Fully Eliminate Municipal, Analysts Say,' *The Bond Buyer, vol. 302, No.* 29021, Nov. 3, 1992, p. 1.

129 D Borson Public Citizen Critical Mass Energy Project, *Payment Due: A Reactor-by -ReactorAssessment of the Nuclear Industry's $25+ Billion Decommissioning Bill* (Washington, DC: Public Citizen, Oct. 11, 1992), p. 2.

I[N] Ibid., p. 3.