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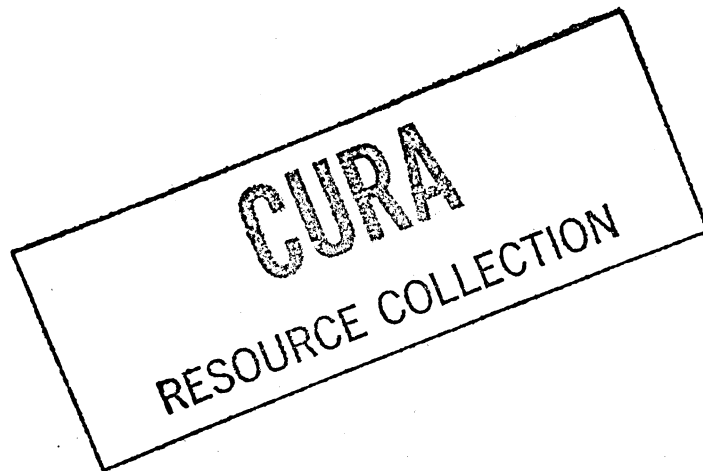


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by

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Decommissioning Commercial Nuclear Power Plants

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PREFACE

The decommissioning of nuclear power plants is an exceedingly complex subject. One can quickly become immersed (and lost) in the myriad technical details. In this paper we approach decommissioning not as a strictly technological problem but as a policy issue. We deal with technical aspects of decommissioning to the extent necessary to present the basic technological options and to highlight important policy questions. Our goal is to provide a useful orientation to decommissioning for those who wish to understand and deal with these questions.*

The authors wrote the summary and Part IV together. Dave Aquilina wrote Part I with some assistance from Jane Anderson, who wrote Part II. David Rodbourne wrote Part III and updated the paper for publication. While we acknowledge our individual efforts we wish to emphasize that we conceive of the paper as a single work and take joint responsibility for it. The paper was prepared initially in 1979 and has been updated for this publication. However, the issue continues to unfold in various governmental, research, and private settings.

We owe our thanks to many people. Professors at the University of Minnesota, officials at Northern States Power, and staff of various federal and state agencies across the country graciously answered our questions and supplied us with information. We acknowledge their assistance with gratitude. In particular, we wish to thank Dean Abrahamson and Judith Weir.

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David Rodbourne

*Please note that a glossary of technical terms is supplied at the end of this paper.

PART I

DECOMMISSIONING AND ITS POLICY CONTEXT

INTRODUCTION

Decommissioning Defined

What is decommissioning? The American National Standards Institute has formulated a comprehensive definition:

Decommissioning: the planned and orderly execution of a program devised by a nuclear facility licensee to achieve a substantial and permanent improvement in the status of a shut-down facility. The program includes: 1) decontamination of the structures and equipment, 2) removal of sources of radioactivity, 3) return of the site to a condition wherein it may safely be returned to unrestricted surface use, and 4) maintenance under the minimum surveillance required for the protection of public health and safety for a specified time if it is shown to be technically or economically infeasible to decontaminate the site to levels acceptable for unrestricted use.¹

The Nuclear Regulatory Commission (NRC) limits the operating license of a nuclear power plant to 40 years, including construction time. The operating lifetime of a nuclear plant is determined, as is the case for all industrial facilities, by the engineering specifications of its structural components, the actual circumstances of its operation, safety requirements, and, importantly, economic considerations.²

A nuclear power plant must be carefully decommissioned at the end of its operating life because of the radioactivity accumulated in its structural components.³ During operation, some of the neutrons produced by nuclear fission in the reactor core pass into the steel structures which support the nuclear fuel, into the coolant water which flows between the fuel rods, and into the steel vessel which contains both the fuel rods and the coolant water. This neutron bombardment makes the steel highly radioactive and causes embrittlement which affects the strength of the steel reactor vessel. In addition to materials made radioactive by neutron bombardment (induced radiation), other parts of the plant not in direct contact with the fission reaction, such as pumps and piping systems, are contaminated with radioactive material. When a nuclear plant is shut down, the total build-up of radioactivity, particularly

from induced radiation but including contamination, constitutes a significant environmental and public health hazard for thousands of years.⁴

According to the Nuclear Regulatory Commission, 67 commercial nuclear power reactors are currently licensed for operation in the United States.⁵ In addition, one reactor is licensed for low power testing; 72 reactors are under construction; 15 permits for additional reactors have been issued; and 11 construction permit applications are under review. As of February 1980, the total licensed commercial reactor capacity was 155,229 MWt (megawatts thermal), capable of generating approximately 50,000 MWe (megawatts of electricity). Nuclear power generates approximately 11.5 percent of the electricity produced in this country, accounting for 3.6 percent of total U.S. energy consumption.⁶

Decommissioning of Other Nuclear Facilities

Nuclear power plants are not the only nuclear facilities which must be decommissioned. Although this paper focuses on commercial power reactors, for the sake of completeness it is important to mention some of the other facilities which require decommissioning--other reactors and the principal components of the nuclear fuel cycle.⁷

Reactors are generally considered to present the major decommissioning problems because of the large number of reactors and their vast amounts of induced radioactivity. In addition to the 67 commercial power reactors in this country there are currently about 325 other reactors. Of these, 150 are non-power reactors, used primarily in research, and are much smaller than the power reactors used by utility companies to generate electricity. The federal government owns about 80 nonpower reactors, and private industry and universities have the remainder. The military has about 175 reactors. Most of these are used by the Navy to power nuclear submarines and aircraft carriers.

The nuclear fuel cycle begins with the mining of uranium ore. Twenty uranium mills are now licensed to refine and process mined uranium ore. In the milling process, the ore is crushed and wet ground into a slurry. After the uranium is extracted from the slurry, the waste slurry, containing a large volume of finely ground solids, is transferred to a tailings pond. There the solids, called mill tailings, settle into a pile. The milling process in the United States annually generates 10 to 15 million tons of tailings.⁸

The radioactivity of mill tailings is lower than that produced at other stages of the nuclear fuel cycle. The level of radioactivity is equal to the

relatively low level natural radioactivity present in uranium ore. However, the tailings' long-lived radioisotopes and their physical form combine to create a potential public health hazard. It takes about 80,000 years for the thorium-230 in mill tailings, from which radon gas and radium are derived, to decay to one-half of its original concentration level. Natural processes and human activities can disperse the finely ground tailings into the environment. Radon gas easily escapes into the atmosphere from unstabilized tailings, and radium may be released into surface water through leaching by rain and surface runoff. In the past, tailings have been used in the construction of houses and other buildings.⁹

To decommission uranium mills, steps must be taken to minimize the re-release of radon and radium from the tailings. Two methods are feasible: 1) covering the tailings with certain materials to stabilize them and prevent erosion and radon release; and 2) burying the tailings in uranium mines or pits below ground level.¹⁰ Due to the long half-life of the tailings' radioactivity, these methods must be designed and implemented to minimize need for continued surveillance and to prevent natural processes or human activities from dispersing the tailings in the distant future.

As of 1977, 21 commercial fuel fabrication plants were operating in the United States. These facilities convert natural and enriched uranium from refined ores into uranium oxide. The uranium oxide is packed into tubular fuel rods for use in nuclear reactors.

Normal production operations result in surface contamination of components in fuel fabrication plants. The low levels of radiation associated with surface contamination require less complex and less expensive decommissioning procedures than those required for commercial power reactors. The Nuclear Regulatory Commission (NRC) regulates the chemical decontamination and disposal of equipment from these plants.¹¹

Fuel reprocessing plants recover uranium and plutonium from spent nuclear fuel in order to produce more fuel or nuclear weapons material. The Carter Administration imposed a moratorium on commercial reprocessing because of its implications for nuclear weapons proliferation.¹² Of the three commercial reprocessing plants in the United States, the one owned by Nuclear Fuels Service (NFS), Inc., located in West Valley, New York, is the only one that ever operated. NFS ceased operations in 1972 and in 1976 closed the plant for economic reasons. The federal government operates four reprocessing plants,

used in weapons production. An additional five federal reprocessing facilities were shut down in the 1950s and 1960s and have not yet been decommissioned.

During plant operations, large quantities of both induced radiation and surface contamination accumulate in reprocessing plants. Thus, unlike other facilities in the nuclear fuel cycle, reprocessing plants present decommissioning problems as large and complex as commercial power reactors.

The Battelle Pacific Northwest Laboratory estimates that after shut-down but prior to decontamination, a reprocessing plant would contain radiation levels in excess of 30 million curies and radiation exposure rates from a few thousand to 200,000 milliroentgen per hour in various parts of the plant.¹³ Even after chemical decontamination, the plant would contain more than 22,000 curies of radiation, and the radiation dose to workers involved in immediate dismantlement of the plant would be more than 530 man-rems. Reprocessing plant decommissioning would create large quantities of radioactive wastes. One estimated cost for completely dismantling a fuel reprocessing plant is \$58 million (in constant 1975 dollars).

In sum, commercial nuclear power plants constitute only part of the total number of reactors which must be decommissioned. In terms of reactor decommissioning, commercial power reactors are the most difficult because of their large size and long operating lifetimes. Reactors, in turn, are part of the range of facilities in the nuclear fuel cycle which require decommissioning. These different facilities pose different decommissioning problems.

Decommissioning: Framing the Issue

Until the mid-1970s decommissioning commercial nuclear plants was not a priority policy issue for the utilities, the federal government, or the states. From the standpoint of the nuclear industry, decommissioning presented no intractable technological problems, and decommissioning costs were expected to be low in comparison with nuclear power plant construction costs.

What then is the issue? To understand the importance of decommissioning as a policy issue, it must be examined within the context of the unresolved questions on nuclear waste storage and the economics of nuclear power. It is in relation to these questions that decommissioning derives much of its significance as a public policy issue.

DECOMMISSIONING AND NUCLEAR WASTE STORAGE

Background Information

Decommissioning can generate large quantities of radioactive waste.¹⁴ In order to decommission nuclear power plants, waste repositories capable of handling these wastes must be available. Thus, decommissioning represents one aspect of the nuclear waste storage issue. And the development of public policy on waste storage may significantly affect decommissioning.

The relationship between decommissioning and broader waste storage questions is complex. The principal sources of decommissioning wastes include: the internal structures of the reactor core, pressure vessel, control rods, pipe systems, and the thermal and biological shields. The exact amount of waste and its radioactivity depend upon the type of reactor, its operating history and condition at shut-down, and the decommissioning method employed.

It is estimated that the decommissioning of a 1144 MWe commercial nuclear plant will generate between 65 and 13,000 cubic yards of radioactive solid wastes and from 3,600 to 159,000 gallons of aqueous radioactive wastes.¹⁵ In addition to these wastes, which vary in concentrations of radioactivity, decommissioning requires the removal of the tons of highly radioactive spent fuel from the plant's storage pool. This consists of 120 to 150 metric tons of heavy metal (that is, uranium and plutonium) plus tons of radioactive cladding and other structural materials from the fuel bundles and assemblies.

Radioactive wastes, including those from decommissioning, consist of a great many materials in a variety of physical and chemical forms. The amounts and sources of radioactivity vary. Each kind of nuclear waste presents distinct handling and storage problems. The different kinds of wastes may be classified in three basic ways:

1. Wastes may be classified according to their origin. The nuclear facility or process generating the waste determines its radiological composition and concentration level.¹⁶
2. They may be classified by physical and chemical form. Nuclear wastes occur as solids, liquids, and gases. Since different forms require different processing and storage methods, this classification can be helpful for decommissioning studies.

3. The radiological profile approach may be used. It details the radiological composition and concentration of various wastes and then classifies them as high-, medium, or low-level waste. These distinctions are arbitrary and specific definitions of concentration levels vary.

The federal Interagency Review Group on Nuclear Waste Management (IRG), established in March 1978 by President Carter to formulate nuclear waste policy recommendations, has defined major categories of nuclear waste which combine the three basic classification schemes. The IRG's five waste categories are: 1) high-level, 2) low-level, 3) transuranic, 4) uranium mill tailings, and 5) gaseous effluents.¹⁷ In relation to nuclear power plant decommissioning, high- and low-level are the significant categories and merit detailed discussion.

High Level Waste (HLW)¹⁸

The definition of HLW remains an open question. The Energy Reorganization Act of 1974 refers to but does not define high-level radioactive waste in assigning the Nuclear Regulatory Commission (NRC) authority over storage facilities for such wastes. NRC regulations related to spent fuel reprocessing plants define "high-level liquid radioactive waste" as the "aqueous wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes resulting from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels."¹⁹ However, the Marine Protection, Research, and Sanctuaries Act of 1972 in prohibiting ocean dumping of "high-level radioactive wastes" defines them to include "irradiated reactor fuel from nuclear power reactors" (spent fuel) as well as reprocessing wastes. Additionally, on at least one occasion, the NRC used a definition of HLW that included not only reprocessing wastes but also spent fuel rods and transuranic contaminated wastes, and the IRG report treats spent fuel as HLW.

Designation and treatment of waste as high-level reflects several factors: high, penetrating radiation; long duration; and biological toxicity. In essence, high-level wastes require special management and precautions because they present serious biological hazards over extremely long periods of time (measured in thousands or hundreds-of-thousands of years).

Reprocessing wastes are highly radioactive, generate high levels of heat, and are of extremely long duration. They contain nonvolatile fission products and some transuranics (about one percent by weight).²⁰ Radiation levels of reprocessing wastes are measured in thousands of curies (up to 10,000 curies per gallon), and permanent isolation from the biosphere is essential. Traditionally, reprocessing wastes have been thought of as the primary HLW problem because of the expectation that spent fuel would be reprocessed to recover uranium and plutonium.

Spent fuel, in the absence of reprocessing, is also considered to be HLW and a major waste management problem. It contains all of the fission products and transuranics found in reprocessing waste plus the unused uranium and plutonium that would have been recovered during reprocessing. Spent fuel emits high levels of radiation, generates high levels of heat, and is a very long-lived source of radiation. Because it presents hazards comparable to reprocessing waste, it requires comparable handling and storage.

Cladding hulls from spent fuel, transuranic contaminated wastes from fuel reprocessing and recycling, and some decommissioning wastes can also be considered HLW. Cladding hulls and transuranic contaminated wastes, although not intensely radioactive like spent fuel and reprocessing wastes, contain very long-lived radionuclides which require effective isolation from the biosphere for extremely long periods.

Decommissioning a nuclear power plant by prompt dismantlement, one of the options discussed in Part II of this paper, requires removal of all radioactive components (and spent fuel) from the plant site. In particular, the irradiated reactor internals, control rods, and pressure vessel contain various radionuclides that present radiological hazards. The amount of contaminated and activated steel in a commercial reactor (1,000 to 1,200 megawatts electric) could total as much as 800 metric tons. At shut-down after a normal operational lifetime, the activated reactor components could contain nearly five million curies of radiation.²¹

For several decades after shut-down, cobalt-60 in the irradiated steel of the reactor presents the predominant radiological hazard.²² Although it is a source of intense radiation, cobalt-60 has a half-life of only 5.2 years and decays relatively quickly. Nevertheless, while this source of radiation is present, special handling and storage measures are required. Immediate dismantlement of a plant must confront this problem. Deferred dismantlement,

another decommissioning option, tackles the problem by waiting for cobalt-60 to decay to less hazardous levels.

Regardless of the decommissioning method chosen, very long-lived radionuclides remain in the reactor steel and present a long term management problem. Nickel-59 (half-life 80,000 years) and niobium-94 (half-life 20,000 years), although not sources of intense radiation like cobalt-60, persist for periods of time comparable to HLW. About 80 years after shut-down, the extremely slow decaying niobium-94 predominates in determining any reduction in the radiation dose rate. Even after thousands of years, therefore, the radiation hazard from the reactor vessel will still be substantially above release levels.²³

Decommissioning studies have generally assumed that, with the exception of spent fuel, radioactive wastes in the form of activated and contaminated materials would be permanently disposed of by shallow land burial at low-level waste sites. However, although no policy decision has been made on the subject, one study estimated that, other than spent fuel, approximately 74 metric tons of activated reactor components might warrant deep geological storage like HLW.²⁴ Deferring dismantlement for several decades would not solve the problem due to the presence of extremely long-lived radionuclides in the material.

As of 1977 there were about 9.5 million cubic feet of reprocessing wastes, roughly equivalent to 70.6 million gallons.²⁵ Federal military and research programs generated almost all of it. The federal reprocessing HLW totaled 9.4 million cubic feet (about 70 million gallons). It is stored at three Department of Energy sites. Liquids constitute 40 percent of the federal HLW inventory; most of the remaining wastes have been processed into sludge and salt cakes.

This HLW in liquid and sludge form is currently stored in underground tanks. At the Hanford Reserve in Washington more than 500,000 gallons have leaked from 20 different tanks. In 1973, some 115,000 gallons seeped into the ground from a single leak in one tank.²⁶ The federal government is exhuming some of the tanks and placing the wastes into new ones. The remaining reprocessing waste, about 82,000 cubic feet (0.6 million gallons), is now stored in one tank at the Nuclear Fuels Service plant in New York. Even if accidental leaks are prevented, the tanks cannot contain HLW indefinitely. The volume and danger of the reprocessing waste and the questionable adequacy of temporary storage methods underscore the importance of resolving the problem of permanent waste storage.

Spent fuel from commercial reactors now totals about 6,000-7,000 metric tons of heavy metal. By 1985 this amount could increase up to 16,800 metric tons; by the year 2000, the inventory of commercial spent fuel could reach as high as 97,800 metric tons depending on the rate of growth of nuclear power. (See Appendix B.)

Presently there are no facilities for the permanent storage of HLW. However, several technological approaches to the HLW problem have been considered. They include placing HLW underground in deep, stable geological formations, burial beneath the ocean floor or in Antarctic ice sheets, and ejection into space.²⁷ The federal government, nuclear industry, and university researchers have focused their efforts on underground storage, apparently the most feasible method.

To prepare reprocessing waste for storage, the liquid and sludge waste would first be concentrated and immobilized in glass, ceramic or a composite material. The solidified waste would then be placed in stainless steel canisters. Spent fuel would also be stored in canisters. The canisters would be placed in a vault or mine in a dry, stable geological formation of salt, granite or shale.

Since the National Academy of Sciences first recommended underground storage in 1957, many researchers have argued that salt would be the best medium, primarily because salt formations are stable and isolated from groundwater. The Department of Energy is experimenting with storage in a salt formation near Carlsbad, New Mexico. The Waste Isolation Pilot Project (WIPP) is scheduled to commence operations in 1985, the original target date for the first permanent HLW repository.

Many serious questions have been raised on the use of salt formations for HLW storage.²⁸ Fundamentally, the nature of geology as a science is the key technological problem; it is principally a descriptive not a predictive science. Moreover, "local political attitudes now loom as large as geological criteria,"²⁹ in the search for an HLW storage site. An increasing number of states are taking action to prohibit or restrict the location of nuclear waste repositories within their borders.

According to the Interagency Review Group (IRG), if salt is the chosen medium and a site is selected by 1982, a permanent HLW facility could be ready sometime between 1988 and 1992. But, if site selection is based on an assess-

ment of a broader range of geological formations, permanent HLW storage could be delayed until 1995.³⁰ A recent Department of Energy estimate calls for opening permanent storage facilities between 1997 and 2006.³¹ Due to the unresolved technical questions and the political volatility of siting waste storage facilities, the availability of permanent HLW storage by the year 2000 is certainly open to question.

The IRG estimates that five commercial nuclear power plants will be decommissioned by the year 2000.³² To do so, a combined total of 600 to 750 metric tons (heavy metal) of spent fuel must be removed from the plants' storage pools. If the IRG timetable for permanent HLW storage facilities is not met, plant decommissioning could be undertaken only to a limited extent unless adequate offsite interim storage is available.

Although the utilities are primarily responsible for temporary storage of spent fuel, the federal government plans to establish interim spent fuel storage at away-from-reactor sites (AFRs).³³ However, decommissioning is not the central problem creating the need for these facilities. In the course of normal operations, about one-third of a commercial reactor's fuel is replaced every 12 to 18 months. The spent fuel is stored temporarily in pools adjoining the reactor. The moratorium on commercial reprocessing and the lack of permanent waste repositories are causing many of these pools to become filled.

The Nuclear Assurance Corporation has estimated that by 1987 about 14 operating commercial nuclear plants will run out of on-site spent fuel storage capacity. (See Appendix D.) Even though by the end of 1979 the NRC had issued 47 licenses allowing utilities to store additional spent fuel assemblies in their on-site pools beyond original design capacity. AFRs and additional storage capacity will still be necessary.

AFRs would be large storage pools with an average capacity of 5,000 metric tons each. The IRG believes that the NRC could issue licenses for AFRs sometime between 1982 and 1984, if sites for these facilities could be found. If the deadlines for permanent HLW storage are met, three AFRs would be required. "The AFR requirement roughly doubles for a three-year delay and triples for a delay of five years."³⁴ If these storage pools are built, they could handle the spent fuel from decommissioned reactors and operating plants with full on-site storage capacity.

Still another short term alternative is continuing spent fuel storage at the reactor site beyond the expiration date of the operating license. In late 1979, the NRC commenced an assessment of the permanent safe storage problem as it bears on reactor licensing. Among the issues included is whether spent fuel storage at the reactor site can be continued safely even after the facility's operating license expires. The Department of Energy (DOE), designated the lead agency in federal waste management research, has stated that such on-site spent fuel storage would be safe at least until permanent storage becomes available-- estimated by DOE to be between 1997 and 2006.³⁵ However, one DOE official has testified that opening a permanent storage facility would not necessarily mean that a utility could immediately ship out its spent fuel.³⁶

When placed in the context of the total volume of spent nuclear fuel and reprocessing waste, the spent fuel which must be removed from plants being decommissioned represents a small part of the waste storage problem. Nonetheless, it is important to understand that utility companies cannot fully decommission nuclear power plants unless they can remove the spent fuel from reactor sites. Further, other radioactive decommissioning wastes--whether those associated with the relatively short-term but intense hazard presented by cobalt-60 or those associated with the extremely long-lived nickel-59 and niobium-94 -- may require storage measures comparable to the techniques used for other HLW. Thus the availability of permanent HLW storage sites and facilities has important implications for the decommissioning of nuclear plants.

Low Level Waste (LLW)³⁷

Low level wastes have concentration levels of around one micro-curie per cubic foot versus the thousands of curies per cubic foot (or gallon) of HLW. LLW is generated at every stage of the nuclear fuel cycle and in medical and research uses of radioactive isotopes. It consists of a great variety of contaminated materials such as pipe systems in reactors, laboratory instruments and equipment, chemical solvents used to clean surface contamination, and miscellaneous trash (paper, rags, plastic items). LLW remains radioactive for several hundred years, considerably less time than HLW. It is disposed of by shallow land burial.

While LLW is much less dangerous than HLW, the problems of LLW management are considerable. As the IRG stated in its report to former President Carter:

The heterogeneity of the wastes, the extreme range of their physical and chemical properties, and their interaction with the ground...after disposal are, at present, sufficiently complex as to make it difficult to confidently predict their long term behavior and their potential hazard.³⁸

By the year 2000, depending on assumptions about nuclear capacity growth rates and waste technology, the volume of LLW from federal programs (research and military) could total between 38 and 190 million cubic feet. Commercial LLW could total 83-260 million cubic feet by that time. Commercial decommissioning wastes, as estimated by the IRG for the year 2000, could be 100-200 thousand cubic feet of LLW material.³⁹

Approximately two million cubic feet of commercial LLW are buried annually in the United States, and that amount increases each year. Since 1962, six commercial burial sites have been licensed.⁴⁰ Two are permanently closed, in part due to leakage problems. A third has been closed since April 1978 pending license renewal. Another is open but has limited its monthly intake of waste to 1977 levels which will be cut by half in the near future. The last two remain open. If current practices continue, 275,000 cubic feet of LLW will be buried per acre, and by the year 2000, 301 to 945 acres could be needed for commercial LLW. (See Appendix E.)

The Department of Energy manages 14 active and 2 closed burial sites for federal LLW. By 2000, between 137 and 690 acres will be required for burial of these wastes.

Federal studies have revealed that some of the existing burial sites are not adequately containing the wastes. Some radionuclides have migrated into the surrounding soil. The long term environmental and public health impacts are uncertain.

Other disposal methods for LLW improvements in shallow burial technology and increased standardization of disposal practices are necessary. However, as is the case for HLW storage, the basic questions to be resolved are political, not technical. Locating LLW disposal sites will be increasingly difficult as the need for additional sites increases.

The main sources of LLW from decommissioning are: contaminated and activated concrete, contaminated metal from pumps, pipes, and miscellaneous equipment, and processed liquid solvents from decontamination procedures. Immediate dismantlement of a commercial reactor could generate over 16,000 cubic meters

of contaminated concrete and metal as well as activated materials and spent fuel.⁴¹ Contaminated concrete represents 71 percent by volume of all contaminated materials.

In some respects, the LLW situation parallels the HLW considerations. Decommissioning nuclear power plants generates a small amount of LLW in comparison with the total volume of such wastes from all sources. But the development of LLW management policy could have an impact on decommissioning practices. For example, the location of LLW disposal sites will determine the distance decommissioning LLW will have to be shipped, which in turn will affect decommissioning costs.

Radioactive waste management and its relation to commercial nuclear power are evolving issues. Although decommissioning wastes may not be large in relation to the overall waste problem, the availability of AFRs or permanent high-level waste storage facilities and of adequate low-level waste facilities will affect the decommissioning problem. Interim or permanent spent fuel and waste repositories are necessary if reactor owners are to undertake immediate dismantlement of nuclear power plants that cease operation in the late 1990s and early in the next century. If waste storage is unavailable or inadequate, decommissioning will be delayed or limited to partial completion.

DECOMMISSIONING AND THE ECONOMICS OF NUCLEAR POWER

The estimated costs for decommissioning a nuclear power plant vary according to the type of reactor, the decommissioning method chosen and other factors. Cost estimates are as high as \$129 million. (See Appendix H.) In comparison, today's construction costs for a large commercial nuclear power plant (1,000 megawatts) total \$1-2 billion. The cost estimates are presented in Part II of this paper; the financing questions in Part III. To frame these discussions a brief overview of nuclear power economics is useful.

In the late 1950s the advocates of nuclear power proclaimed that electricity generated by nuclear plants would be too cheap to meter. In 1967 the Atomic Energy Commission (AEC, forerunner to the NRC) estimated that the construction cost per kilowatt hour capacity for nuclear plants going on-line in 1973 would be \$130, but the actual construction costs for different plants were 50 to 280 percent higher. In 1974 the AEC estimated the construction cost

to be \$700 per kilowatt hour capacity for plants starting up in the 1980s, but the real costs are about \$1,000 per kilowatt hour capacity.⁴² A study in late 1979 estimated capital costs for a plant coming on-line in 1990 to be \$1,670-\$1,804 per kilowatt.⁴³

There are many reasons beside the general rate of inflation for the cost increases. By the early 1970s it took 70 percent more time to build a nuclear plant than had been anticipated in the 1960s; the construction and licensing of a nuclear plant now require a decade. The capital costs of nuclear plants have risen faster than those of coal-fired plants and show no signs of slowing down.⁴⁴ Changing federal regulations have added to construction time and total costs. And more stringent safety requirements, sure to come after the Three Mile Island incident, could increase costs still further.

Whether or not electricity generated by nuclear power now holds a price advantage over electricity from coal-fired plants is the subject of intense debate.⁴⁵ After hearings in 1978, the Wisconsin Public Service Commission noted the wide range of views on the question of whether coal or nuclear is less expensive. The commission noted that among the views represented was the position that it was "impossible to tell." The New York Public Service Commission, based on its record of hearings, could find "no credible bottom line comparison" between the generation costs for coal and nuclear.⁴⁶

In the past, some estimates have shown nuclear to be less expensive than coal, for example 1.5 cents per kilowatt hour from nuclear versus 2 cents for coal. However, some people argue that such estimates understated nuclear costs by failing to account for the costs of waste storage, decommissioning, tougher federal safety standards, and tax subsidies. Whatever the case, the cost of nuclear power has risen dramatically.

Escalating construction costs, uranium price increases, and stricter safety rules may seriously jeopardize the future economic viability of nuclear power. "September 1974 was the high point for America's nuclear power industry. At that time there were 239 reactors totaling more than 237,000 megawatts capacity either operating, under construction or on order."⁴⁷ Since that time the annual growth rate of electricity demand has decreased from 7 percent to about 3.5-4.0 percent. This decline and rising costs have combined to force many utilities to cancel or defer plans for nuclear power plant construction. And new orders do not balance cancellations and deferrals.⁴⁸ Today only 166 reactor units are operating or in the pipeline.⁴⁹

According to Professor Albert Wohlstetter, University of Chicago, the major American manufacturers of nuclear plants in 1976 lost a total of \$1.3-\$2.8 billion due to cancellations and deferrals. And the total generating capacity of nuclear plants in this country now forecast for the year 2000 is less than half the 1975 estimate and less than one-third of the 1972 forecast.⁵⁰

Thus, the economic future of nuclear power is unclear. Increasing costs and slower growth of demand for electricity have played a major role in the cancellations and deferrals of nuclear plants and in the declines in the nuclear sector's forecasted total generating capacity.

Major financial institutions have begun to seriously question the economics of nuclear power. The nation's life insurance companies, with assets totaling \$352 billion, are a significant source of financing for electric utilities. In 1978 the Equitable Life Assurance Society, the third largest life insurance company in the United States, started "reviewing its investment practices and casting a cool eye at the nuclear sector."⁵¹ A December 1979 study by a subsidiary of Basche Halsey Stuart Shields, Inc. was titled "Nuclear Energy: Dark Outlook" and predicted "the uncertainty of costs will escalate to the point where nuclear plants are an unattractive financial proposition."⁵²

In sum, while the electric utilities do not trivialize decommissioning costs, they are confident that they can finance them. However, given the uncertainty of the overall picture of nuclear power economics, any addition to costs, including decommissioning, must be examined carefully.

FOOTNOTES - PART I

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Also see: U.S. Nuclear Regulatory Commission, (NRC), Technology, Safety, and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station, NUREG/CR-0130, Volume 1, Prepared by Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington, (Washington D.C.: NRC June 1978), p. 2-1. (Y3.N88:25/0130).

2. Joseph A. Sefcik, "Decommissioning Commercial Nuclear Reactors," Technology Review, June/July 1979, pp. 56-59.

U.S. Nuclear Regulatory Commission (NRC), Proceedings: State Workshops for Review of the Nuclear Regulatory Commission's Decommissioning Policy, NUREG/CP-0003, (Philadelphia, Pa.; Atlanta, Ga.; Albuquerque, N.M.; September 18-30, 1978) (Washington D.C.: NRC, December 1978), discussion by Robert Bernero, pp. 78-79. (Y3.N88:27/0003).

3. Significant radioactive isotopes in a commercial-size reactor:

<u>Isotope</u>	<u>Half-Life(years)</u>	<u>Radiation</u>
Cobalt-60	5.2	Gamma & Beta
Iron-55	2.4	X-ray & Gamma
Nickel-63	92.0	Beta
Nickel-59	80,000	X-ray & Gamma
Niobium-94	20,000	Gamma

Sources:

Peter B. Erickson, "U.S. Licensed Reactor Decommissioning Experience," in U.S. Nuclear Regulatory Commission, Proceedings: State Workshops for Review of the Nuclear Regulatory Commission's Decommissioning Policy, NUREG/CP-0008, (Columbia, S.C.; Seattle, Wa.; September 11-14, 25-27, 1979), (Washington D.C.: NRC, December 1979), pp. 437-448. (Y3.N88:27/0008).

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California State Task Force on Nuclear Energy and Radioactive Materials, "Radioactive Materials in California," draft report of the secretary for resources, Part V titled "Decontamination and Decommissioning Radioactive Facilities," (unpublished, June 1978).

Sefcik, "Decommissioning," pp. 57-59.

NRC, State Workshops, NUREG/CP-0003, pp. 70-71 and p. 163.

4. Harwood, "The Cost of Turning it Off," pp. 17-18.
U.S. General Accounting Office (GAO), Cleaning up the Remains of Nuclear Facilities--A Multibillion Dollar Problem. Energy Research and Development Administration, Nuclear Regulatory Commission: Report to the Congress. (Washington D.C.: Government Printing Office, June 16, 1977), p. 3. (GA 1.13: EMD-77-46).
U.S. Congress. House. Committee on Government Operations. Nuclear Power Costs, Part I. Hearings... 95th Congress, 1st Session, 1977, p. 233. (Y4.G74/7: N88/3/pt. 1).
5. U.S. Nuclear Regulatory Commission (NRC), Program Summary Report, NUREG-0380, Volume 4, Number 4, April 25, 1980, pp. iv-v. The 67 licensed operating units exclude three that are licensed but shut down indefinitely--TMI #2, Indian Point #1, and Humboldt Bay. The figure for operating capacity does not include these units. Of the 67 licensed units, 25 are BWRs (boiling water reactors) and 46 are PWRs (pressurized water reactors). One is a HTGR (high temperature gas reactor). Of the total 166 units, 58 are BWRs, 107 PWRs and the 1 HTGR. Foreign power reactor operating units totaled 159 with 72,496 MWe capacity as of the end of March 1980. Additionally, 110 foreign units are under construction, and 67 units are planned.
6. U.S. Energy Information Administration (Department of Energy), Annual Report to Congress, 1979, Volume 2, (Washington D.C.: DOE/EIA; 1979), pp. 3 and 157. (E3.1: 979/v.2).
7. GAO, Cleaning Up, pp. 3-8.
U.S. Congress, Nuclear Power Costs, Part 1, pp. 327-332.
Robert W. Ramsey, Jr., "ERDA Work on Decommissioning," (mimeographed, Washington D.C.: June 1977).
National Conference of State Legislatures (NCSL), Energy Report to the States, Vol. 4, No. 11, (Denver, Co.: NCSL, June 9, 1978), p. 153.
U.S. Nuclear Regulatory Commission (NRC), Plan for Reevaluation of Nuclear Facilities, NUREG-0436, Revision 1, (Washington D.C.: NRC, December 1978), p. 11-16.
8. Organization for Economic Cooperation and Development (OECD), Nuclear Energy Agency, Objectives, Concepts and Strategies for the Management of Radioactive Waste Arising from Nuclear Power Programmes, (Paris, France: OECD, September 1977), p. 90.
Interagency Review Group (IRG), Report to the President by the Interagency Review Group on Nuclear Waste Management, (U.S. Department of Energy: Washington D.C., March 1979), p. 80.
9. IRG, Report, p. 81.

10. Ibid., p. 81.
11. NRC, Plan for Reevaluation, NUREG-0436, pp. 14-15.
12. Bob Rankin, "Nuclear Policy: Carter Halts Use of Plutonium as Fuel," Congressional Quarterly Weekly Report, 35 (April 9, 1977): 681-682.
13. U.S. Nuclear Regulatory Commission, (NRC), Technology, Safety, and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant, NUREG-0278, Volume 1, prepared by K.J. Schneider, et al., Northwest Laboratory for NRC, (Washington D.C.: NRC, 1977), section 2 (Y3.N88: 10/0278/v.1).

A man-rem is the average radiation dose in a rem multiplied by the number of people in the exposed group. A rem is a measure of the quantity of any ionizing radiation with the same biological effectiveness as one standard unit dose of x-rays.

Source:

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14. IRG, Report, pp. 10, 84.
 OECD, Objectives, pp. 129, 131.
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15. AIF, An Engineering Evaluation, Chapter 4, p. 4-21.
 AIF, Summary Report, p. 32.
16. OECD, Objectives, p. 32.
17. IRG, Report, pp. 9-10.
18. Ibid., pp. 9-10.
 OECD, Objectives, p. 29.
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 GAO, Nuclear Energy's Dilemma, pp. 2-3.
 MISTIC, Nuclear Power Reactors, p. 15.
 Luther J. Carter, "Radioactive Wastes: Some Urgent Unfinished Business," Science, December 2, 1977, p. 885.
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19. 10 C.F.R. (Code of Federal Regulations) 50, Appendix F, covers NRC policy on siting fuel reprocessing plants and related waste management facilities.
20. Transuranics are man-made elements, those with atomic numbers higher than 92, and include such long-lived radionuclides as plutonium-239 and neptunium-237.
21. OECD, Objectives, p. 133.
NRC, Technology, NUREG/CR-0130, Volume 2, p. C-24.
22. NRC, Technology, NUREG/CR-0130, Volume 2, p. C-23, C-24, and G-25. Also see Appendix I of this paper.
23. NRC, State Workshops, NUREG/CP-0003, p. 166, discussion by R.I. Smith.
NRC, Technology, NUREG/CR-0130, Volume 2, p. C-23, C-24.
24. NRC, Technology, NUREG/CR-0130, Volume p. G-99.
25. See Appendix A for an inventory to all categories of nuclear waste.
26. Carter, "Radioactive Wastes," p. 661.
Arthur Fisher, "What Are We Going to Do About Nuclear Waste," Popular Science, December 1978, p. 93.
Carl E. Behrens, "Nuclear Waste Management," Issue Brief Number IB75012 (Washington D.C.: Congressional Research Service, Library of Congress, January 1979), p. 2.
27. IRG, Report, p. 35.
Fisher, "Nuclear Waste," p. 94-96.
Edmund Faltermayer, "Burying Nuclear Trash Where it Will Stay Put," Fortune, 26 (March 1979), pp. 102, 104.
28. Behrens, "Nuclear Waste Management," p. 6.
Terry Lash, Natural Resources Defense Council, Testimony Before the Minnesota Legislature (mimeographed, 10 April 1979), p. 7.
29. Luther J. Carter, "Nuclear Wastes: Popular Antipathy Narrows Search for Disposal Sites," Science, 23 September 1977, p. 1265.
30. IRG, Report, p. 59 and IRG Appendix H, p. 21.

31. U.S. Nuclear Regulatory Commission (NRC), Proposed Rulemaking on the Storage and Disposal of Nuclear Waste--Waste Confidence Rulemaking. Statement of Position of the U.S. Department of Energy (DOE/NE-0007). 15 April 1980. p. I-4 (E1.68:0007).
32. IRG, Report, Appendix D, p. 3. (See Appendix C of this paper.)
33. IRG, Report, p. 62.
NCSL, Energy Report to the States, p. 85.
President Jimmy Carter, "Radioactive Waste Management Program," Weekly Compilation of Presidential Documents, Presidential Message to Congress, Vol. 16, No. 7, February 12, 1980, outlines President Carter's plan for expediting waste storage as a follow-up to the IRG report.
34. IRG, Report, Appendix D, p. 25.
35. NRC, Proposed Rulemaking, April 15, 1980, p. I-4 and IV-1.
36. Roberta Walburn, "Stored fuel rods may remain after plant's use ends," Minneapolis, Tribune, June 19, 1980, p. 3B.
37. IRG, Report, pp. 10, 77-80, 105-109.
GAO, Major Unresolved Issues, p. 1.
MISTIC, Nuclear Power Reactors, p. 15.
Behrens, "Nuclear Waste Management," pp. 3-4.
38. IRG, Report, p. 78.
39. IRG, Report, Appendix D, p. D-8.
40. Existing commercial LLW burial sites as of 1978:

<u>Site</u>	<u>Status</u>	<u>Millions of Cubic Feet Buried</u>
Barnwell, S.C.	Open for limited shipments	3.52
Beatty, Nevada	Open	1.97
Hanford, Wash.	Open	0.51
Maxey Flats, Ky.	Closed	4.95
Sheffield, Ill.	Closed pending license renewal	2.40
West Valley, N.Y.	Closed	2.46
	TOTAL	15.81

Sources:

IRG, Report, Appendix D, p. D-12.

Behrens, "Nuclear Waste Management," p. 3.

William F. Holcomb, "Inventory (1962-1978) and Projections (to 2000) of Shallow Land Burial of Radioactive Wastes at Commercial Sites: An Update," Nuclear Safety, 21 (May-June 1980), 380-388.

41. NRC, Technology, NUREG/CR-0130, Vol. 1, p. 10-7, and Vol. 2, p. G-26 and Addendum, p. 4-9.
42. U.S. Congress. House. Committee on Interior and Insular Affairs. Subcommittee on Energy and the Environment. Oversight Hearings on Nuclear Energy--Overview of the Major Issues. Hearings... 94th Congress, 1st Session, April-May 1975, p. 175. (Y4.In8/414: 94-16, pt. 1).
43. Leonard Reichle, "The Economics of Nuclear Versus Coal," unpublished paper presented to the Richmond Society of Financial Analysts, Richmond, Va., October 30, 1979, p. 4. Reviews changing cost estimates. Reports that 1978 nuclear cost estimates were 708 percent higher than 1969 estimates, while coal estimates rose 509 percent. Suggests coal and nuclear nearly equal in 1990 at roughly 68-77 mills per kilowatt hour, with any advantage for one or the other depending on regional factors related to the type and pollution problems of the coal.
44. Irvin Bupp, et al., "The Economics of Nuclear Power," Technology Review, February 1975, p. 21.
45. U.S. Congress, Oversight Hearings, p. 181.
Ralph Nader and John Abbots, The Menace of Atomic Energy, (New York: Norton, 1977), pp. 213-217.
"Nuclear Ripples: Big Power Users Fear Atomic Plant Cutbacks Spell Trouble in the 1980s," Wall Street Journal, 19 April 1979, p. 1, 41.
46. Quoted in Robert Stobaugh and Daniel Yergin, editors, Energy Future--Report of the Energy Project at the Harvard Business School, (New York: Random House, 1979), p. 124.
47. Bob Rankin, "Competition With Coal: Troubled Nuclear Power Industry Looks to Government for Assistance," Congressional Quarterly Weekly Report 36:1 (11 March 1978): 622.

And for more current review of the status of nuclear reactor units see:
DOE/EIA, "Monthly Energy Review," May 1980, p. 71.

48. From June, 1974 to March, 1976 utilities canceled orders for 23 reactors and deferred another 143 that had been ordered or announced. Recent cancellations, deferrals, and new orders:

<u>Year</u>	<u>Cancellations</u>	<u>Deferrals</u>	<u>New Orders</u>
1976	2	7	3
1977	6	43	4

Sources:

Rankin, "Competition With Coal," p. 622.

Oversight Hearings, p. 173.

Nader and Abbots, Menace, p. 217.

49. NRC, Program Summary Report, April 25, 1980, p. iv.

50. Forecasts for the year 2000:

<u>Year Forecast Made</u>	<u>Total Capacity in Gigawatts*</u>
1972	1,200
1975	800
1977	380
1979	300 (high estimate)
	148 (low estimate)

*A gigawatt equals 1 million kilowatts.

Sources:

Rankin, "Competition With Coal," p. 621.

IRG, Report, p. 12.

DOE/EIA, Annual Report to Congress, 1978, Volume 3, pp. 222-233 and p. 272. Includes forecast range from 235 GWe to 300 GWe with the note that the high estimate was probably the maximum achievable by the year 2000 and includes a low estimate of 145GWe under some circumstances.

51. Richard Corrigan, "A New Threat to Nuclear," National Journal, 10 (December 9, 1978), 1989.

"Nuclear Dilemma: The Atom's Fizzle in an Energy-Short World," Business Week, 25 December 1978, pp. 54-68.

Jonathan Motl, "Troubles with Nuclear Power," The Minneapolis Star, January 19, 1979, p. 6A-7A.

52. Quoted by William J. Lanouette, "Under Scrutiny by a Divided Government: The Nuclear Industry Tries to Unite," National Journal, January 12, 1980, p. 48.

PART II

ALTERNATIVE APPROACHES TO DECOMMISSIONING NUCLEAR POWER PLANTS

INTRODUCTION

The possible approaches to decommissioning nuclear power plants range from prompt and complete dismantlement and removal of a plant from its site to permanent entombment of parts of a plant at its site. The nuclear literature describes numerous variations within this range. However, no one approach has gained wide acceptance as the best way to decommission a plant.

The Nuclear Regulatory Commission (NRC) regulatory guide on plant decommissioning describes four alternatives: mothballing; in-place entombment; removal of radioactive components and dismantling; and conversion to a new nuclear or fossil fuel system.¹ The first three alternatives will serve as the primary basis for the following discussion. However, it should be noted that the NRC guide is currently under review and changes in the decommissioning policies may result.

The preliminary preparation of a plant for decommissioning is similar for each decommissioning alternative. All non-contaminated systems in the plant are drained of fluids. Selected radioactive components are decontaminated with chemical agents. The chemicals are then removed and transported to off-site storage facilities. Other materials which are removed and transported for storage include: all spent fuel; in-core nuclear source material; spent resin materials radioactive liquid; and other non-fixed radioactive materials.

The disposition of the remaining radioactive materials and components is the major feature which differentiates the possible approaches to decommissioning. Such factors as costs, occupational and public hazards, and land use are determined by what happens to the radioactive materials in the plant. A general description of each of the decommissioning alternatives is presented here. It is important to note that the current NRC regulatory guide does not contain specific procedures for each decommissioning alternative. (See Appendix G.) Therefore, considerable variation may occur in the way two plants are decommissioned, even if the same alternative is used.²

FOUR DECOMMISSIONING APPROACHES

Mothballing

The NRC regulatory guide defines mothballing as follows:

Mothballing of a nuclear reactor facility consists of putting the facility in a state of protective storage. In general, the facility may be left intact except that all fuel assemblies and the radioactive fluids and waste should be removed from the site. Adequate radiation monitoring, environmental surveillance, and appropriate scrutiny procedures should be established under a possession-only license to ensure that the health and safety of the public is not endangered.³

In the mothballing approach, decontamination of piping systems is performed only to remove loosely adhering radioactive material which might result in airborne contamination if left in place.⁴ All doors and penetrations (ducts, lines, and hatches) from the outside into the containment, fuel, and other buildings are locked or sealed off. The estimated time required to mothball a plant is about one year.

The NRC regulatory guide states that physical barriers (fences, doors, etc.) of a mothballed plant should be inspected every three months. Furthermore, environmental surveys should be conducted every six months to ensure that no significant amounts of radiation are being released into the environment.⁵ Depending on the extent of physical security measures, the plant may require 24 hour/day surveillance.

The NRC definition of mothballing does not state how long the plant should remain in a state of "protective storage." However, the license obligations, under what is expected to be a possession-only license, cannot be terminated nor the site abandoned until all radioactive materials are removed or the radiation has decayed to levels that meet standards permitting unrestricted use.

Entombment

The NRC regulatory guide defines in-place entombment as follows:

In-place entombment consists of sealing all the remaining highly radioactive or contaminated components (e.g., the pressure vessel and reactor internals) within a structure integral with the biological shield after having all fuel assemblies, radioactive fluids and wastes, and certain

selected components shipped offsite. The structure should provide integrity over the period of time in which significant quantities... of radioactivity remain with the material in the entombment. An appropriate and continuing surveillance program should be established under a possession-only license.⁶

Entombment provides greater physical protection than mothballing for the radioactive components of the plant. The piping systems are totally decontaminated. The reactor vessel and its components, as well as any other components which contain significant radioactivity, are encased in a concrete isolation structure within the containment building. All doors and penetrations leading into the reactor portion of the plant are sealed off. Entombing a plant is estimated to require about two years.

Although the entombed plant does not require constant surveillance to prevent intrusion, inspection and environmental monitoring are necessary as for a mothballed plant and as required under the "possession-only" licenses which would detail the owner's responsibilities in lieu of the regular operating license. These requirements exist until all radioactive materials are removed or the radioactivity has decayed to acceptable levels.

Dismantlement

The NRC regulatory guide defines "removal of radioactive components and dismantling" as follows:

All fuel assemblies, radioactive fluids and waste, and other materials having activities above accepted unrestricted activity levels... should be removed from the site. The facility owner may then have unrestricted use of the site with no requirement for a license. If the facility owner so desires, the remainder of the reactor facility may be dismantled and all vestiges removed and disposed of.⁷

Unlike the previous two alternatives, dismantlement leaves no contaminated structures or equipment on the plant site. The site and facility first are prepared for dismantlement. Loose contamination is removed from access areas; temporary structures are erected for storing equipment; and temporary electric service is provided. All potentially contaminated piping and associated equipment are decontaminated. The most hazardous activity is the dismantlement of the reactor internals and reactor vessel, which are the most highly activated and contaminated components of the plant. They constitute a

substantial quantity of waste which must be cut into pieces suitable for shipment. The concrete biological shield also must be broken down for shipment. The waste generated during this process includes filters used to trap the airborne contamination generated during demolition. These filters, and all other radioactive wastes generated during the plant dismantlement, must be removed to a waste disposal site.⁸

When only non-radioactive structures and equipment remain, two alternative procedures are possible: complete removal or conversion. Complete removal involves the total dismantlement of all plant facilities. Non-radioactive materials may be salvaged or demolished and used for landfill. If radiation surveys indicate acceptable residual levels of radioactivity, the license may be terminated in order to release the site for unrestricted use. Total dismantlement and removal of a plant is expected to take six to seven years.

Conversion

The other procedure following dismantlement of the nuclear portions of a plant is conversion of the facility to a new nuclear or fossil fuel generating system. Rather than being salvaged or demolished for landfill, the original turbines and other non-contaminated buildings and equipment are reused in conjunction with a newly installed system for supplying steam.⁹

EXPERIENCE WITH DECOMMISSIONING

Each of these decommissioning alternatives has been used to decommission research reactors, critical facilities, and small prototype power reactors in the United States.¹⁰ In total, sixty-four reactor facilities and four demonstration power plants licensed by the NRC have been decommissioned thus far. The group of sixty-four included five power reactors, six test reactors, the nuclear ship Savannah, and fifty-two research reactors and critical facilities. Of the latter, forty-two were dismantled and dismantlement is planned for the other ten. All were very small plants rated in the tens and hundreds of watts (thermal). (Also see Appendix H.)

The four demonstration nuclear power plants that have been decommissioned are Piqua (45.5 MWt), Hallam (256 MWt), Bonus (50 MWt), and Elk River (58.2 MWt). The first three are entombed, and the Department of Energy is monitor-

ing the sites and entombment structures. The entombed reactors contained, respectively, 260,000 curies, 300,000 curies, and 50,000 curies of radioactivity.¹¹

The Elk River reactor is frequently cited in the decommissioning literature because it is the only commercial power reactor which has been completely dismantled. This small 58.2 MWt boiling water reactor, located at Elk River, Minnesota, was in commercial operation from 1964 to 1968 as a demonstration plant. It was dismantled by the Atomic Energy Commission (forerunner to the NRC) over a three year period from 1972 through 1974. A development and testing program was carried out on the cutting processes used on the highly radioactive components. Plasma torches operated by remote control were used to cut up the reactor vessel, internal piping, and thermal shield. The cutting was done underwater to reduce the radiation exposure for workers involved in the operation. Relatively little decontamination of piping and other equipment was necessary because the facility had been shut down four years prior to the start of dismantlement. Scrap metal and the contaminated and uncontaminated concrete were shipped to waste disposal grounds in Sheffield, Illinois. The total cost of the dismantlement, including surveillance and monitoring, was \$6.15 million (in 1974 dollars), compared to \$6 million for construction.¹²

Experience thus far with reactor decommissioning has provided a basis for identifying problems, developing and improving techniques, and preparing studies for the decommissioning of large commercial power reactors. In addition, the experience gained as well as the tools and techniques developed during routine operation, inspection, and repair of nuclear facilities will be applicable to future decontamination and decommissioning procedures. Finally, improved reactor designs can embody measures to aid in the decommissioning of future reactors.¹³

Conceptual Studies of Commercial-Size Power Reactors

Although there have been a number of research and prototype decommissionings, no decommissioning of a commercial-size reactor which has operated for 30 to 40 years has been undertaken in the United States or elsewhere. Detailed conceptual studies of commercial plant decommissionings have been carried out, based in part on data from the research and prototype reactor decommissionings. Two major U.S. studies of this type are briefly described below.

The Atomic Industrial Forum (AIF) funded a 1976 study about the decommissioning of pressurized and boiling water reactors (1144 megawatts electric MWe and 1178 MWe respectively) and high temperature gas reactors.¹⁴ For each reactor, five decommissioning alternatives were examined: mothballing; entombing; prompt dismantling; and two combination alternatives, mothballing-delayed dismantling and entombing-delayed dismantling. The study detailed procedures and end products, cost estimates, occupational radiation exposures, and pertinent regulations and guidelines.

The Battelle Memorial Institute's Pacific Northwest Laboratory, under a contract with the NRC, investigated a conceptual decommissioning of a 1175 MWe pressurized water reactor (PWR) power station at the end of its operating life.¹⁵ The report, published in June 1978, contains information on the technology, safety, and probable costs of immediate dismantlement and deferred dismantlement after a period of mothballing. An addendum issued in late 1979 further explores entombment, radiation hazards, and cost issues. Another report examining boiling water reactors (BWR) was issued recently.

These conceptual studies, although very useful, have several limitations. First, each study is general in nature and, consequently, cannot substitute for specific analysis of the institutional, economic, and design variables associated with individual plants. Further, the generic studies assume that a plant has operated routinely, according to all required procedures. In actuality, unusual occurrences during the operating life of a reactor may create complications for decommissioning. A report by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD) points out that:

The principal decommissioning uncertainties will arise from "glossed over" accidental contamination and spills, careless operation and poor housekeeping with respect to radioactive materials, and lack of up-to-date engineering drawings and records of plant modifications. Operators of nuclear facilities should therefore bear in mind the effect of their actions on decommissioning.¹⁶

More significant accidents, such as at Three Mile Island, may create major decommissioning problems.

Second each study assumes, for practical purposes, that the current set of regulations, as well as technologies, apply to decommissioning. Not only are these regulations under review at this time but further changes may occur in various related nuclear regulations prior to the time when decommissioning begins on a broad scale. Both studies acknowledge this problem and the fact that predicting the impact of regulatory and technical change is, at best, difficult.

Third, each study is essentially technical, focusing primarily on methods, timing, hazards, and cost estimation. In addition, each discusses the regulatory framework as it applies to safeguarding the health and safety of workers and the public. Relatively little attention is devoted to the problem of financing decommissioning or the various institutional arrangements related to that problem. Further, the studies contain no discussion of the implications of the timing and development of permanent high level waste storage and adequate low level waste facilities in relation to decommissioning. These matters must be approached through other studies and analyses.

Fourth, in the absence of any experience with decommissioning full-sized commercial reactors which have operated for 30 years or more, the conceptual studies are unavoidably limited to drawing upon theory and upon experience from decommissioning small scale reactors. In its review of previous decommissioning experience, the Battelle study states:

A review of the documented cases of decommissioning of nuclear facilities shows that, while the facilities decommissioned were generally small and had operated for relatively short periods of time, the problems encountered tended to be common to all decommissioning undertakings. The review also shows that a wealth of experience exists within the nuclear industry regarding methods and equipment for accomplishing decommissioning, and that there are no major technical impediments to the successful decommissioning of large commercial power reactors.¹⁷

The pressurized water reactor (PWR) used as a reference for the Battelle study has vessel walls 2.5 times thicker than Elk River, will have operated more than five times longer, and is rated at 3500 MWt rather than 58.2MWt. Further, the radiation levels in the Elk River reactor were far below those expected in large commercial reactors.¹⁸ Yet, the radiation dose data used in the Battelle study was derived from an evaluation of radiation in small plants operated for up to six years as well as on theoretical estimates. A

comprehensive study of decommissioning by the West German Association of Power Stations (VDEW) examined in detail five American nuclear power plant decommissionings, including Elk River. The German study's conclusion:

emphasized that experience gained from these plants whose output individually was 100 MWe could only be extrapolated to stations with an output of approximately 1300 MWe to a very limited extent.¹⁹

Both AIF and Battelle have identified some of the limits of relying on previous experience. The problems associated with the presence of nickel-59 and niobium-94 in activated reactor metals are a case in point. An AIF representative testifying at congressional hearings in 1977 noted that past experience suggested that cobalt-60 would be the principal radiation problem. But reviews of the first draft of the AIF study included some comments about the potential problem with nickel-59:

The immediate reaction of those involved in the study was that, you know, that is crazy. But when we looked into it and looked into the fact that the plants we are talking about decommissioning in the future are facilities that we expect to operate for about 40 years..., you do generate a quantity of this nickel-59 which had not really been present in the prior plants that had been decommissioned.²⁰

Current NRC regulations, which include mothballing and entombment as acceptable decommissioning alternatives, are based upon experiences where nickel-59 never appeared as a problem. AIF concluded that a "possession-only" license for a decommissioned and mothballed PWR could not be terminated for 505,000 years to allow time for radiation to decay to release levels.²¹ Battelle, focusing on both nickel and niobium, rejected entombment (at least with reactor internals) as a permanent option because no fabricated structure could be expected to outlast and successfully contain the sources of radioactivity entombed within it.²²

As a result of the AIF and Battelle studies, both mothballing and entombment appear to be unacceptable for permanent decommissioning. Care should be taken in referring to a mothballed or entombed reactor as having been "decommissioned." It would be more accurate to characterize the reactor as partially decommissioned, pending final removal or decay of the radiation and termination of the owner's license and obligations.²³

The fact that there is no actual experience with decommissioning large plants which have operated for 30 to 40 years gives rise to some of the uncertainty and controversy about decommissioning alternatives. This is evident in the following comparison of mothballing, entombment and dismantlement in terms of costs, occupational and public hazards from radioactivity, and land use.

COSTS OF DECOMMISSIONING

In the absence of actual experience and cost data on decommissioning a commercial sized nuclear plant, it is not surprising that estimates of costs for decommissioning alternatives vary widely in the nuclear literature. Assumptions and methodologies differ between studies, and each study defines, to some extent, its own decommissioning alternatives. Thus, the decommissioning approach, what it covers, the timing of various phases of decommissioning, and the type and size of the reactor may vary from study to study, making comparisons somewhat difficult. In addition, current regulations are applied although they contain few detailed standards or procedures for decommissioning. This body of regulations is currently under review, and changes in the immediate future as well as in the years prior to the start of decommissioning on a broad scale complicate the problem of estimating costs. Finally, the time between the initial operation of a reactor and its ultimate decommissioning is at least 30 to 40 years. Estimates of future costs and revenue requirements necessary to carry out decommissioning must weigh the impact of inflation on general price levels, and within the nuclear industry must account for changing technology as it relates to decommissioning, and must anticipate likely changes in regulations and waste disposal.

It is beyond the scope of this paper to critically examine and compare cost estimates. Instead, estimates from the AIF and Battelle studies are outlined briefly here. A number of additional estimates are presented in Appendix H. Cost estimates range from about \$3 million for initial mothballing expenditures to well over \$100 million for dismantlement. Utility estimates have tended to be much higher than those made by federal authorities or contractors, and some are three times higher than AIF's estimates for dismantlement.²⁴

Mothballing has been predicted to have the lowest initial cost because it entails the least amount of dismantlement and only minor construction of additional physical access barriers. However, its long-term costs are the highest because of the degree of surveillance required and the indefinite time period involved. Estimates of initial costs for mothballing are approximately \$3.4 million (AIF) and \$9.5 million (Battelle) at 1978 price levels plus subsequent annual costs ranging from \$80,000 to over \$200,000, depending on the degree of security required.

Prompt dismantlement has the highest initial costs but requires no continuing expenditures by the plant owner provided the radioactive components are completely removed. Dismantlement of only the nuclear portions of the plant has been estimated at \$30.3 million (AIF) and \$31.0 million (Battelle) in 1978 prices. Demolition of the non-radioactive portions of a plant would add 25-33 percent to these estimates. It is common to see the Battelle estimate quoted as \$42.1 million which includes dismantlement of all facilities plus the cost of shipping the spent fuel away from the site. However, non-nuclear demolition and shipment of spent fuel may not be decommissioning expenses in the view of some utilities and public service commissions. Spent fuel shipment is an operational expense, and it is difficult to distinguish non-nuclear demolition from measures taken in closing other types of power plants or industrial facilities in the absence of the public safety question posed by the radiation in parts of a nuclear plant.

Cost estimates for entombment fall between the estimates for dismantlement and mothballing but vary substantially. AIF estimated entombment at \$11.1 million and annual costs up to \$90,000 in 1978 prices. Battelle's estimates were \$21 million and \$40,000 annually. Entombment requires greater initial expenditures than mothballing because of the construction of more extensive physical barriers, but its annual surveillance costs tend to be lower. It should be noted that cost estimates for mothballing and entombment carry an additional element of uncertainty because of the probability that future measures in the form of maintenance or dismantlement will be necessary.

In addition to the reasons stated earlier, several other factors may affect the accuracy of cost estimates.²⁵ Deep geological storage of some highly activated, long-lived decommissioning wastes (approximately 88 cubic meters) could increase costs by \$1.8 million. Radiation levels higher than those anticipated, would raise decommissioning costs slightly. Contracting

out the decommissioning job rather than using utility staff might raise dismantlement costs by 26 percent. Regional variations in labor prices could increase costs, and doubling burial charges for low level storage could add 9 percent to the cost of dismantlement.

Other factors may decrease decommissioning costs in the future. These include new reactor designs, the use of improved technology at a net cost saving, economies of scale associated with decommissioning larger plants, increased experience and efficiency, and increases in the value of scrap materials salvaged from decommissioned plants.

Still another cause for variation among cost estimates, though not applicable to the two major studies, is the size of the plant. AIF estimated roughly an 18 percent savings on dismantling a 550 MWe plant rather than the 1144 MWe plant used in the study. The cost reductions estimated by Battelle were 48 percent for a 440 MWe plant and 21 percent for a 850 MWe plant.²⁶ Figures are for PWR plants, but estimates for BWRs are expected to be similar. It is nonetheless difficult to apply these factors in any shorthand fashion.

The Battelle study reviewed seven other European and American generic and site specific decommissioning analyses.²⁷ Variations among assumptions and methodologies were evident and in some cases substantial. Additionally, comparison was encumbered by differences in the amount of detail reported by each study. Several conclusions were drawn. First, "it is virtually impossible to make any detailed comparison among the various studies." Second, although dismantlement costs compared on a 1978 basis ranged from \$43 million for the Battelle and AIF studies to \$88 million, the higher cost estimates reflected decommissioning measures that may be excessively conservative or restrictive.²⁸ Complete removal of all structural foundations and cutting radioactive equipment to fit in relatively small containers for waste disposal are examples. Third, none of the studies identified any technical or safety impediments to decommissioning large PWRs, although reactor design changes, technical developments in decontamination, and alternative decommissioning approaches could reduce costs and radiation exposures. And finally, Battelle observed that realistic cost estimates can be derived only from detailed site specific analyses.

OCCUPATIONAL AND PUBLIC HAZARDS FROM RADIATION

As noted in Part I, the radionuclides of most concern in decommissioning are: iron-55, cobalt-60, nickel-59, nickel-63, carbon-14, and niobium-94. (See Appendix I). Of these, cobalt-60 presents the greatest hazard immediately after shutdown of the reactor and over the next 80 to 100 years during which time the rate of decay of the cobalt-60 controls reductions in the radiation dose rate.²⁹ Its intensity, at any given time, determines whether remote or manual operations should be used and the degree of personnel shielding necessary. However, after the first century, it is the nickel-59 and niobium-94 that predominate in determining the rate of reduction in the radiation dose rate from activated materials. Because of their long half-lives, 80,000 and 20,000 years respectively, these radionuclides continue to emit radiation substantially above safe release levels for extremely long periods of time.³⁰

Of the three primary decommissioning alternatives, prompt dismantlement presents the greatest occupational radiation hazard. The Battelle study's estimate of the occupational radiation dose from dismantlement is 1404 man-rems plus another 103 man-rems from the transportation of waste materials.³¹ Mothballing is estimated to entail doses of 426 man-rems during initial stages plus 14 from transportation of decontamination wastes and an additional 14 for up to 100 years of safe storage. Entombment is estimated to entail doses of 900 man-rems plus 16 during transportation of wastes. The AIF study estimates are lower: approximately 150 man-rems for mothballing, 130 for entombment, and 630 for dismantlement.³² Differences between studies are attributable to varying assumptions about radiation present, decontamination procedures, and personnel shielding.

The principal impact of radiation on the public is expected to occur during transportation of waste materials to a disposal site. Because prompt dismantlement results in the largest volume of radioactive wastes and entails moving them at a time when they are most radioactive, it presents the greatest short term hazard to the public. Battelle estimated the volume of PWR dismantlement wastes at approximately 18,000 cubic meters.³³ AIF estimated such wastes at 13,000 cubic yards. The cancelled Tyrone nuclear power plant in Wisconsin would have required about 2,600 shipments of radioactive wastes after dismantlement, 875 for entombment, and 225 for mothballing.³⁴

Although prompt dismantlement results in the greatest occupational and short-term hazards, it does not present long-term risks to the public at or around the plant site. Permanent mothballing and entombment, on the other hand, may require maintenance and surveillance for extremely long periods, well beyond 100,000 years. There appear to be no cost-benefit analyses on the public health danger posed by maintaining radioactively contaminated buildings, waste tanks, equipment, and grounds encased in concrete.³⁵ Their permeability and resistance to weather is unknown or unspecified. The Battelle study notes that a 100,000 year time span vastly exceeds the known lifetime of any fabricated structures.

LAND USE

Complete dismantlement clears the plant site and, provided that sources of radiation are effectively removed, permits unrestricted use of that site.³⁶ However, dismantlement requires land for the disposal of the radioactive materials--2.5 acres in the case of a large plant such as the proposed but canceled Tyrone plant. Mothballing and entombment leave radioactive materials on the site requiring maintenance and surveillance. The land commitment estimated for Tyrone was 12 acres. Burial of materials that would have been removed from the Tyrone plant during mothballing or entombment was estimated to require 0.05 acres and 0.05 to 0.1 acres respectively.³⁷

"The proliferation of sites permanently committed to the containment of radioactive materials" is presented as one reason why permanent entombment was found unsatisfactory by the Battelle study.³⁸ Another problem raised by entombed or mothballed plants is how the use of adjacent land can and should be restricted. Such activities as mining obviously would jeopardize the security of the radioactive material.

OTHER DECOMMISSIONING ALTERNATIVES

Problems related to costs, radiation doses, and the adequacy of physical and institutional arrangements of the primary decommissioning options led to consideration of several variations. These are recommissioning, entombment without the highly activated reactor internals, mothballing followed by delayed dismantlement, and entombment followed by delayed dismantlement. The

periods of delay associated with the latter two alternatives vary but are typically 30, 50, or 100 years.

Recommissioning

Recommissioning has been characterized as a measure to be taken in lieu of decommissioning.³⁹ It is not mentioned in NRC regulations, guides, or studies. Recommissioning involves refurbishing a nuclear plant and continuing power generation beyond the period of the initial operating license. It is unlike conversion described earlier, in which a new nuclear system is installed in conjunction with existing turbines. Recommissioning entails only selective repair and equipment replacement to satisfy NRC design and safety criteria and to enable re-licensing of the plant. Essentially, extending a nuclear plant's operating life through recommissioning is proposed as an economically attractive alternative to decommissioning the plant after its initial operating license expires. Whether the economics justify the option is unknown. Moreover, re-licensing has never occurred, and it is expected that changes in NRC regulations would be required. Even if a plant were recommissioned, ultimately decommissioning still would be necessary.

Entombment Without Reactor

Entombment without reactor internals involves dismantling and removing those activated metal reactor components that contain long-lived radionuclides prior to entombing the remaining contaminated equipment and materials.⁴⁰ Radiation left in the entombed plant would be expected to decay in about 100 years, permitting termination of the possession-only license at that time. However, according to Battelle estimates, the procedure incurs higher radiation exposures for workers than simple entombment because of removing and transporting the reactor. Occupational radiation doses from this entombment/removal and transportation process would be approximately 1,000 man-rems and 21 man-rems respectively or two-thirds the level associated with prompt dismantlement. Procedures for demonstrating that the entombed radiation has in fact decayed to unrestricted levels so that license termination can be permitted are unclear. Interestingly, removing the reactor also removes the primary rationale for using the more secure physical access and containment barriers normally associated with entombment. Battelle estimated the cost of entombment/reactor removal at nearly \$25 million (1978) or \$29 million including 100 years of monitoring and surveillance. Battelle did not include costs for final disposition of the structure.

Delayed Dismantlement

The rationale for delaying dismantlement is twofold. First, permitting radiation to decay reduces occupational exposures associated with removal and transportation of the reactor internals and other radioactive wastes and reduces the overall volume of such wastes. Consequently, the complexity and cost of the dismantlement process are reduced. Battelle estimated that delaying dismantlement 30 years would reduce occupational radiation exposures to less than 2 percent of the level associated with prompt dismantlement.⁴¹ After 50 years, exposures would be down to 0.16 percent, and after 100 years, the level would be 0.08 percent. These reductions are attributable primarily to the decay of cobalt-60. Reductions in the volume of contaminated wastes for disposal also contribute to cost reductions. Battelle estimated radioactive waste volumes in cubic meters for different periods of delay prior to dismantlement: for either prompt dismantlement or after 30 years delay--17,900; after 50 years--1,830; and after 100 years--1,780.⁴²

The second advantage of delay is that combining a period of "protective storage" with provisions for ultimate dismantlement avoids the disadvantages of permanent mothballing or entombment. Dismantlement, even though delayed, removes the uncertainty that deterioration of physical containment structures or lapses in institutional arrangements will permit radiation to escape and endanger the public at some future time. However, although the long term concerns will be eliminated, some argue that even delays of a few decades are cause for concern with respect to the adequacy and assurance of institutional and financial arrangements.

The distinction between entombment/delayed dismantlement and mothballing/delayed dismantlement relates to the extent of physical access and containment barriers constructed and the degree of surveillance required during the storage period. With the entombment/dismantlement approach, the entombment used would be a more easily demolished structure than that used in permanent entombment. Openings would be sealed but voids within the plant would not be filled with concrete. The choice between using entombment or mothballing would depend on cost and site specific considerations. Mothballing might be used when the site already is under surveillance because of other facilities located there. Entombment might be used at a remote site.

Comparison of cost estimates in studies or deferred dismantlement are somewhat difficult because of differences in assumptions.⁴³ Examples of differences are the content and cost of preparatory measures and the extent of surveillance employed. These differences can determine whether the delayed approach appears more or less costly than prompt dismantlement of the plant. AIF, with reference to a PWR and a 108 year delay, estimated the cost of entombment/delayed dismantlement to be \$23 million (1978). Mothballing/delayed dismantlement could cost between \$20 and \$33 million (1978), depending on the extent of security involved. Battelle estimated the costs of safe storage/delayed dismantlement of a PWR for three different periods: 30 years, \$40.8 million; 50 years, \$35.8 million; and 100 years, \$39.8 million (1978). Cost reductions from further reduction in the volume of wastes beyond fifty years would be negligible and offset by the cost of continuing surveillance.

Occupational radiation doses resulting from the two delayed dismantlement alternatives depend on the nature of measures taken prior to the period of delay. These measures include the extent of decontamination and the duration of the delay between initial preparations and final dismantlement. The AIF study states that the primary radioactivity in a PWR will have decayed to safe levels 104 years after plant shutdown. The total decommissioning radiation dosage from the two delay alternatives is estimated to range from 440 to 460 man-rem.⁴⁴ The Battelle study, however, notes that:

Relatively little reduction in accumulated occupational radiation dose is estimated to result from deferment of the decommissioning sequence beyond 30 years, and virtually no reduction results from deferment beyond 50 years.⁴⁵

The Battelle study estimated the total radiation exposure would be approximately 1,529 man-rem if a plant were promptly dismantled. Total decommissioning radiation doses associated with delayed dismantlement and different periods of safe storage were: 30 years, 487 man-rem (mostly due to preparations for safe storage); 50 years, 459 man-rem; and 100 years, 458 man-rem. (Appendix H provides a more complete breakdown of Battelle's estimates.)

Battelle and AIF differ on what period of delay provides substantial reduction in costs. AIF tends to focus on the 100 year period, and Battelle's analysis seems to imply a 50 year period. The report by the Nuclear Energy Agency, Organization for Economic Cooperation and Development, states that:

The optimum delay period will have to be determined for each decommissioning case as it is a function of the isotopes involved, their concentration and distribution, the benefits to the decommissioning operations resulting from the delay, and the surveillance costs during the delay period.⁴⁶

Battelle also notes that:

In practice, the choice [of dismantlement] will probably be made based on a detailed analysis of which approach is most financially advantageous to the station owner.⁴⁷

Exactly what criteria will ultimately be applied to decisions about decommissioning alternatives is an evolving issue. Conclusions depend not only on which are selected but upon the emphasis accorded to different criteria. A further discussion of potential regulatory changes is found in Part III of this report.

ACCIDENT-RELATED DECOMMISSIONINGS

One of the many questions raised by the Three Mile Island Plant accident in 1979 is how to decommission a plant after a severe accident. An accident which necessitates decommissioning (e.g. loss of coolant with all fuel cladding bursting) conceivably could occur at any time during the lifetime of a plant. Yet most studies of nuclear power plant decommissionings implicitly assume that a plant's final shut-down occurs after 30 to 40 years of normal operation.

Those studies which do examine the effects of an accident usually focus on individual components within a plant. Few studies investigate the total state of a plant after a severe accident. One such study--"Analysis of the Effects of Severe Accidents on the Decommissioning of Nuclear Power Plants"--was undertaken by the German government and completed in 1976.⁴⁸ The following is a brief review of some of the decommissioning problems identified by this study.

A principal difficulty with both conceptual studies of several accidents and emergency standby decommissioning plans is the large number of possible accidents and the complexity of processes which may occur during an accident. The decommissioning of a normal plant may be based in part on known characteristics of the plant and its radioactivity. Experimental decommissionings have led to the development of standardized procedures, techniques, and equipment.

But for a decommissioning necessitated by an accident, advance planning and development may be impossible:

Preliminary extensive detailed planning is not sensible and is basically impossible since the problems which occur are to a certain extent specific to the facility and the accident in question and the range of variation is very wide...Because of the large number of possible accidents and because of the complexity of the damaging effects and the resulting demands, universal equipment (for different plants, accidents, missions) are only advisable to a very limited extent...⁴⁹

The lack of advanced planning for an accident-related decommissioning necessitates many ad hoc decisions and improvisations after such an accident occurs. A major challenge is determining the post accident condition of the plant, including its core or fuel elements. Remotely controlled special equipment must be used to record conditions since the vast quantities of radiation released in the plant prohibit entry. Even if special equipment is available, many uncertainties remain, which further complicate decommissioning planning:

The use of such equipment is made difficult by the local conditions in the plant, by the damage and by the debris lying in the area. Thus in some portions of the safety vessel, the current condition can only be recorded to a limited extent or cannot be recorded at all.⁵⁰

Data collected on the condition of the plant provides the basis for decommissioning requirements and procedures. The feasibility of decommissioning within a few years of an accident depends "mainly on the efficiency of a remote pre-decontamination and on the availability of remotely controlled special equipment."⁵¹

A detailed examination of a hypothetical accident-related decommissioning is beyond the scope of this paper. However, from the brief comments above, it should be evident that the personnel, time, money, and risk involved in a decommissioning after a severe accident are far greater than for a decommissioning at the end of a plant's life.

FOOTNOTES - PART II

1. U.S. Atomic Energy Commission (AEC), Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, (Washington D.C.: AEC, June 1974), p. B-2. (Reproduced in Appendix G of this paper.)
2. U.S. Congress. House. Committee on Science and Technology. Decommissioning and Decontamination. Hearings... 95th Congress. 1st Session, 1977, pp. 55-56. (Y4 Sci 2: 95/20).
 U.S. Congress. House. Committee on Government Operations. Nuclear Power Costs, Part I. Hearings... 95th Congress, 1st Session, 1977, pp. 342, 343. (Y4. G74/7: N88/3/pt. 1).
 Atomic Industrial Forum, (AIF), (National Environmental Studies Project) An Engineering Evaluation of Nuclear Power Reactor Decommissioning Alternatives: Summary Report. (AIF/NESP-009, 009SR). Prepared by William J. Manion and Thomas S. LaGuardia, Nuclear Energy Services, Inc. (Washington D.C.: Atomic Industrial Forum, November 1976), pp. 11-14.
3. AEC, Termination, p. 1.86-2. It should be noted that the provisions of the Regulatory Guide are only recommendations; they are not required by law.
4. U.S. Nuclear Regulatory Commission (NRC), Atomic Safety and Licensing Board, "Applicants' Testimony of Albert A. Weinstein Response to Contentions 6.C and 12.E." Northern States Power Company (NSP), Minnesota and Wisconsin, et al., Tyrone Energy Park, Unit 1, Docket No. STN50-484, May 6, 1977.
5. AEC, Termination, p. 186-2.
6. AEC, Termination, p. 186-2.
7. AEC, Termination, p. 186-2.
8. Organization for Economic Cooperation and Development (OECD). Nuclear Energy Agency. Objectives, Concepts and Strategies for the Management of Radioactive Waste Arising from Nuclear Power Programs. (Paris, France: OECD, September 1977), p. 134.
9. AEC, Termination, p. 186-2.
10. Peter B. Erickson, "U.S. Licensed Reactor Decommissioning Experience," in U.S. Nuclear Regulatory Commission, Proceedings: State Workshops for Review of the Nuclear Regulatory Commission's Decommissioning Policy, NUREG/CP-0008. (Columbia, S.C.; Seattle, Wa.; September 11-14, 25-27, 1979). (Washington D.C.: NRC, December 1979), pp. 437-448. (Y3.N88: 27/0008).
11. U.S. Nuclear Regulatory Commission (NRC), Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130. Volume 1. Prepared by Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington. (Washington, D.C.: NRC, June 1978),

- pp. (3-1) - (3-22). (Y3.N88: 25/0130/v.1). Referred to in text as the Battelle study.
12. Joseph A. Sefcik, "Decommissioning Commercial Nuclear Reactors," Technology Review, June/July 1979, p. 67.
 13. U.S. Nuclear Regulatory Commission (NRC), Facilitation of Decommissioning Light Water Reactors, NUREG/CR-0569, prepared for NRC by E.B. Moore, Jr., Battelle Memorial Institute, Pacific Northwest Laboratory, Richland Washington. (Washington, D.C.: NRC, December 1979). (Y3.N88: 25/0569).
 14. AIF, An Engineering Evaluation, 1976, pp. 11-14.
 15. NRC, Technology, NUREG/CR-0130, 1978. Includes volumes 1 and 2 plus an addendum issued in August 1979. The boiling water reactor report was available too late for inclusion here.
 16. OECD, Objectives, p. 130.
 17. NRC, Technology, NUREG/CR-0130, Volume 1, pp. (2-4) - (2-5).
 18. U.S. Nuclear Regulatory Commission (NRC), Proceedings: State Workshops for Review of the Nuclear Regulatory Commission's Decommissioning Policy, NUREG/CP-0003, (Philadelphia, Pa.; Atlanta, Ga.; Albuquerque, N.M.; September 18-30, 1978), (Washington D.C.: NRC, December 1978), pp. 78, 119, and 165. (Y3.N88: 27/0003).
 19. A. Martin et al., A Preliminary Study of the Decommissioning of Nuclear Reactor Installations, report to the Nuclear Inspectorate, Contract # A7261 1328, (Epsom, Surrey, England: Associated Nuclear Services; July 1977), p. 31.
 20. U.S. Congress, House, Committee on Science and Technology, Decommissioning and Decontamination, pp. 100-101.
 21. AIF, An Engineering Evaluation: Summary Report, pp. 2 and 19.
 22. NRC, Technology, NUREG/CR-0130, Volume p. 4-5.
 23. NRC, State Workshops, NUREG/CP-0003, pp. 74-75.
 24. Vincent L. Schwent, "Costs and Financing of Reactor Decommissioning: Some Considerations," Draft Paper 261:A:01, (California Energy Commission; September 9, 1978), 17 pp. This also appears in U.S. NRC State Workshops (NUREG/CP-0003), pp. 294-317. Additionally, it should be noted that a British study (see Martin, footnote 19) comparing AIF's study with the German VDEW study found the German estimates to be two to four times higher and concluded that they were more reliable. (See also Appendix H of this paper.)
 25. NRC, Technology, NUREG/CR-0130, Volume 2, Appendix G, "Immediate Dismantlement Activities, Manpower and Costs," p. G-29, and addendum, p. 2-6 and 2-7.

26. AIF, An Engineering Evaluation: Summary Report, p. 21.
NRC, Technology, NUREG/CR-0130, Addendum, pp. (2-1) - (2-7).
27. NRC, Technology, NUREG/CR-0130, Volume 1, pp. (12-1) - (12-10).
28. AIF's original estimate raised to 1978 price levels and, for both, assuming decommissioning by dismantlement of all facilities and removal of spent fuel from the site. Assumptions vary in other studies.
29. NRC, Technology, NUREG/CR-0130, Volume 1, p. 7-38 and Volume 2, Appendix C, "Estimates of Residual Radioactivity," p. C-24.
30. AIF and Battelle reach similar conclusions.
31. NRC, Technology, NUREG/CR-0130, Addendum, p. 2-5, and see Appendix I of this paper.
32. AIF, An Engineering Evaluation: Summary Report, p. 3.
33. NRC, Technology, NUREG/CR-0130, Volume 1, p. 10-7, and Volume 2, Appendix G, p. G-26.
34. NRC, "Applicants' Testimony of Albert A. Weinstein," 1977, p. 76.
35. NRC, Technology, NUREG/CR-0130, Volume 1, p. 2-9.
36. The Battelle study notes that no data are available on the levels of radioactivity in the soil surrounding the facilities after 40 years of operation. Thus the sort of decontamination effort required to restore the site to unrestricted use is not known.
37. NRC, "Applicants' Testimony of Albert A. Weinstein," 1977, p. 77.
38. NRC, Technology, NUREG/CR-0130, Volume 1, p. 2-2.
39. F.W. Kleimola and O.B. Falls, Jr., Recommissioning - An Alternative to Decommissioning, paper presented at the American Nuclear Society Winter Meeting, Washington, D.C., November 1978 (Jackson, Michigan: NucleDyne Engineering Corp., 1978).
40. NRC, Technology, NUREG/CR-0130, Volume 1, Addendum, Section 4.
41. Ibid., p. 3-68.
42. Ibid., Volume 2, Appendix H, Table H.5-1, p. H-31.
43. See Appendix H of this paper.
44. AIF, An Engineering Evaluation: Summary Report, p. 3.
45. NRC, Technology, NUREG/CR-0130, Volume 1, p. 2-9.

46. OECD, Objectives, p. 129.
47. NRC, Technology, NUREG/CR-0130, Volume 1, p. 2-14.
48. NIS, Nuclear Engineering Service, Inc., Analysis of the Effects of Severe Accidents on the Decommissioning of Nuclear Power Plants, research project (reactor safety-155) prepared by I. Auler, et al., under contract with the Federal Ministry for Research and Technology. Report #203. Nuclear Regulatory Commission translation #129, (Frankfurt, Main, West Germany, June 30, 1976).
49. Ibid., pp. 2 and 43.
50. Ibid., p. 36.
51. Ibid., p. 1.

PART III

REGULATIONS AND FINANCING

INTRODUCTION

This part is presented in two sections. The first outlines the major characteristics of the regulatory framework within which decommissioning must be considered. Primarily it focuses on the Nuclear Regulatory Commission (NRC). The second section discusses the problem of financing the cost of decommissioning. Although the NRC plays a role in the financing problem, it is clear that the major actors are the utilities and the public service commissions in each state.

REGULATIONS ON DECOMMISSIONING

Background

Since 1974 when the Energy Reorganization Act split up the Atomic Energy Commission, the NRC--the Nuclear Regulatory Commission--has been the agency responsible for regulating the private uses of nuclear materials.¹ The major divisions of the NRC include the Office of Nuclear Reactor Regulation, the Office of Nuclear Material Safety and Safeguards, and the Office of Nuclear Regulatory Research. The first two regulate, respectively, nuclear reactors and nuclear fuel cycle facilities. The latter is a support office providing the agency with its own research capability.

The NRC's authority, derived from statute and detailed in a body of regulations, entails overseeing nuclear power plants, uranium mills, facilities making or processing nuclear fuel, and users of source, by-product, and special nuclear material.²

It is the purpose of this review to determine the extent to which NRC regulations cover the activity of decommissioning a nuclear power plant. While this paper focuses primarily on the decommissioning of nuclear power plant reactors, other regulations in existence apply to decommissioning uranium mills, reprocessing plants, and other nuclear facilities.

The NRC itself began an evaluation of its regulatory framework for decommissioning in 1975.³ The regulations coming under review appear in 10 CFR

Parts 30, 40, 50, and 70 which include licensing for production and utilization facilities and licensing for by-product, source, and special nuclear materials. Concurrently, in mid-1977, the NRC was petitioned by the Public Interest Research Group (PIRG) and others requesting a rulemaking covering specific financial arrangements and procedures for decommissioning.⁴

In March 1978, the NRC issued a "Plan for Reevaluation of NRC Policy on Decommissioning Nuclear Facilities" later revised in December 1978. Also in March 1978, the NRC published its "Advanced Notice of Proposed Rule Making on Decommissioning Criteria for Nuclear Facilities."⁵ As expressed in the Federal Register, the NRC's objective is consideration of regulatory amendments for more specific guidance on decommissioning criteria. The review builds on primary technical studies contracted in 1975 and submitted between 1977 and 1980.⁶ The Commission, using these studies as well as its own "Plan," conducted a public hearing and three state workshops on the subject in mid-1978. Additional reports and revisions were completed in 1979, and a second round of state workshops took place in September 1979.⁷

Pertinent Regulations

Numbered items below briefly summarize NRC regulations that are pertinent to decommissioning and are currently in effect. The paragraphs following each summary elaborate and comment on the foregoing regulation. It is this set of regulations and the potential need for others that is being reviewed by the Commission.⁸ However, the studies of technology, safety and costs of decommissioning commissioned by the NRC, and mentioned earlier, assume that future decommissioning would be carried out under the existing regulatory framework.

1. Regulations in 10 CFR 50, Section 50.33(f) require the NRC to obtain, prior to issuing a license, sufficient information to demonstrate the applicant's financial qualifications for (a) operating a nuclear facility, and (b) shutting it down and maintaining it in a safe condition.

The regulation applies to production and utilization facility licenses not to facilities operated under material licenses. It is noteworthy that it refers to maintaining a facility rather than final disposal of a facility or its wastes. The requisite financial evaluation is a general one and occurs far in advance of the decommissioning activity. The evaluation does not include detailed plans or cost estimates for decommissioning.

Other regulations, 10 CFR Part 50, Section 50.71, "Maintenance of Records, Making Reports," require licensees to provide updates on their financial status to the NRC.

The NRC has "no requirement that licensees make specific financial provisions to cover the cost of future decommissioning" except in the case of uranium mills.⁹

2. Regulations in 10 CFR Part 50, Section 50.82(a) cover termination of production and utilization licenses. Licensees applying to terminate a license may be required by the NRC to provide information on proposed site decontamination, disposal of radioactive wastes, and dismantling and disposal of the facility. Section 50.82(b) provides that the NRC may, upon receiving satisfactory information, authorize dismantling, disposal, and the termination of the license in accordance with any conditions specified in the order of authorization.

The phrasing of the regulation emphasizes the deferment of any detailed consideration of decommissioning until the end of the facility's useful life and particularly whenever application is made to terminate the license. Although the regulation mentions dismantling, it does not require it.¹⁰

However, the regulation does require that dismantling of the facility and disposal of components be performed in accordance with regulations and "not be inimical to the common defense and security or to the health and safety of the public."¹¹

The regulation underscores the NRC's authority to set explicit conditions for appropriate dismantling and disposal.

3. Guidelines acceptable to the NRC for "Termination of Operating Licenses for Nuclear Reactors" are stated in NRC Regulatory Guide 1.86 issued in current form in June 1974. The guide defines four acceptable methods of decommissioning: mothballing, in-place entombment, removal and dismantling, and conversion to a new nuclear or fossil fuel system. Additionally, it prescribes, in the NRC's view, acceptable procedures and standards for surveillance, security, and decontamination.¹²

Compliance with regulatory guides is not required. They do not carry the weight or authority of regulations. However, the guides embody the NRC's conception of acceptable methods of implementation and compliance with regulations. On this point, an NRC review has concluded that Regulatory Guide 1.86 is "flawed as a regulatory document."¹³ The review identified numerous definitional problems and open issues that will be addressed in the NRC's review of decommissioning.

Regulatory Guide 1.86 does not impose a specific mode of decommissioning. It neither lays out a definite timetable nor suggests an NRC preference in decommissioning. The guide outlines steps for the licensee to follow in changing from an operating to a possession-only license, a status which entails reduced surveillance requirements.

The guide concludes with a chart showing "Acceptable Surface Contamination Levels."¹⁴ Licensees must decontaminate the site to levels consistent with those in the guide before the NRC will authorize termination of the license and its attendant responsibilities. However, these limits relate to contamination and do not discuss hazards related to induced radiation in activated metals and concrete.

As a variation from Regulatory Guide 1.86, the Battelle Pacific Northwest Laboratory study of reactor decommissioning notes that the NRC may issue a modified-operating license rather than a possession-only license in the early phases of decommissioning.¹⁵ The reason is that many plant operations after shut-down of the reactor will remain much the same and require the care and procedures called for in the full operating license. The study notes that "(A)ctive operations will be conducted in the plant involving radioactive material and utilization of existing systems and components that will result in release of effluents to the environment. Additionally, unplanned releases of radioactive material are possible from accidents during decommissioning."¹⁶ In summary, the NRC's license status decision is important in assuring adequate safeguards.

4. 10 CFR Part 51 covers "Licensing and Regulatory Policy and Procedures for Environmental Protection." Under these regulations, specifically Section 51.5.6(7), amendments to licenses and authorizations for decommissioning of a reactor may or may not require an environmental impact statement of proposed actions.

A review of four past nuclear reactor power plant environmental impact statements (EIS) as well as those covering Northern States Power's (NSP) Minnesota plants revealed that decommissioning was given only perfunctory treatment.¹⁷ Each refers to the task as one arising near the end of the plant's useful life, and each briefly outlines four "alternative levels of restoration at the plant site." While none patently states that economics alone would determine the appropriate level of restoration, each emphasizes that at current land values complete restoration would probably not be justified by an economic analysis.

Without complete removal of all radioactive equipment and materials, the land occupied by the facility would be lost to productive uses.

Amendments to NRC regulations will "constitute a major Federal action significantly affecting the quality of the human environment and as such will require the preparation of an environmental impact statement pursuant to Section 102(2)(c) of the National Environmental Policy Act (NEPA)."¹⁸ The NRC is preparing a generic environmental impact statement covering the general problem of decommissioning and providing a basis for NRC regulatory changes.¹⁹ Thus, the NEPA/EIS process is being brought to bear more forcefully on the problems of decommissioning than in the past.

Whether individual plants will need an EIS when application for license amendment is made to begin decommissioning is unclear. The existence of the generic EIS and the results of site specific environmental appraisals could justify, in the NRC's view, a determination not to proceed with a full EIS.²⁰ This would require a formal "negative declaration" by the NRC stating the absence of need for an EIS based on the appraisal.

Other Regulatory Factors

Various regulations cover functions similar to those for decommissioning. Materials handling, security, transportation, worker safety, and disposal are now monitored by the NRC and other federal and state agencies. However, where decommissioning departs from current activities pertinent regulations and procedures may require modification.

Transportation of radioactive materials and wastes is regulated by the NRC and the Department of Transportation, often in cooperation with states which have adopted DOT standards.²¹ Occupational radiation exposure in nuclear plants is regulated by the NRC, and it is expected that strict oversight and regulation would continue during decommissioning due to the highly contaminated working areas and the dismantlement processes involved. Environmental radiation emissions come under both NRC and Environmental Protection Agency (EPA) rules. Under the President's Reorganization Plan Number 3 of 1970, the 1977 Clean Air Act amendments, and the Safe Drinking Water Act, the EPA assumed a predominate role in identifying and regulating environmental radiation impacts beyond the boundaries of a nuclear plant. Thus, the NRC no longer has exclusive control of radioactive emissions into the air or water. The EPA has not set specific decommissioning regulations, but it is developing contamination limits for re-

leasing soils to unrestricted use, one step in plant decommissioning.²² Regulations covering radiation limits for induced activity in equipment and concrete prior to unrestricted release have not been developed. Finally, in the case of air emissions of radioactive pollutants, state regulatory authority under the Clean Air Act is increased as states are not pre-empted from setting standards more stringent than EPA standards.²³

Generally, NRC authority pre-empts state regulation over nuclear power plants under Section 274 of the 1959 Atomic Energy Act. For limited purposes however, a state may take over the NRC's regulatory role by becoming an "Agreement State." The regulatory programs of Agreement States must conform to NRC regulations and standards.²⁴ As of early 1980, there are 26 Agreement States. Minnesota is a Non-Agreement State. The NRC could permit Agreement States to oversee decommissioning, but it is doubtful that states, either agreement or non-agreement, could impose more rigorous decommissioning regulations than the NRC due to federal pre-emption of the regulatory function.²⁵

In addition to agreement state powers, states exercise authority in several areas: permits and monitoring of transportation; land use and facility siting; environmental impact assessments; setting standards and monitoring air emissions; monitoring health risks for workers and citizens; evaluating methods of generation, pricing, and transmission of electricity; and evaluating the rate implications of design and safety factors.²⁶ Decommissioning raises questions in each of these areas.

Policy Questions

Clearly, the NRC as the prime regulator of commercial nuclear power is the lead agency in expediting policy changes. Extensive reviews are currently underway, and draft regulations are expected in late 1981. The NRC has identified five principal areas of concern: mode, timing, planning, financial assurance, and residual radiation. Although no decisions have been made, an NRC discussion paper provides preliminary indications of possible regulatory changes.²⁷ The primary objective would be dismantlement of nuclear facilities, removal of radiation, and release of sites for unrestricted use at the earliest practical date after facilities cease operations.²⁸ Decommissioning plans, for all kinds of nuclear facilities including reactors, would be required. Residual radiation limits, based on the ALARA concept (as low as reasonably achievable, from 10 CFR 50 Appendix I), are under discussion within the NRC and

between the NRC and EPA. State workshops in 1978 included references to maximum exposure limits of 1 mrem per year. Currently, a limit of 5 mrem per year to the maximum exposed individual is being examined as a standard for release of a site for unrestricted use. The standard would be for exposure in addition to normal background radiation and involves questions of what is technically measurable and the pathways through which analysis of exposure should be modeled.²⁹

The mode and timing of decommissioning, as present in the discussion paper, would depend on the half-life of the most critical and/or abundant radionuclide present in the facility at shut-down.³⁰ Three categories would be involved: half-life about 5 years; half-life about 30 years, and half-life greater than 30 years. Alternative acceptable modes and timing for decommissioning would be established for each category. Under this system, reactors would be either dismantled immediately or held in safe storage for thirty years and then dismantled. Entombment would be unacceptable.

Thus far, the NRC's failure to adopt more definitive regulations on decommissioning and waste disposal has impaired the ability of states and plant owners to adequately plan for decommissioning. Partially for this reason, the role of states in decommissioning remains an open and serious question. Adopting a wait-and-see approach, states will forego opportunities to influence final NRC regulations. Alternatively, effective participation in the process requires a thorough review of decommissioning to identify principal state concerns and objectives. Moreover, participating in policy review and implementation necessitates adequate budgets and staffing.

FINANCING DECOMMISSIONING

Introduction

The financial treatment of decommissioning is a major policy problem. Health and safety, as well as economic considerations, warrant thorough evaluation of alternative approaches to adequate financing. Because the radiological hazards created during the nuclear generation of electricity persist for extremely long periods of time, the obligation to protect the public is likewise persistent and serious. Decommissioning is a necessary step in meeting that obligation, and its cost is an inescapable one associated with the investment in nuclear power and requires adequate financial planning and funding.³¹

The choice of nuclear power as a source of electricity rests partially on a comparison of its economic costs with those of available alternatives. To be properly evaluated, the price of nuclear power must include the costs of decommissioning. Failure to account for those costs biases the choice in favor of the nuclear option. Building future costs into current analysis and pricing is one function of mechanisms for financing decommissioning.

As noted earlier, current NRC regulations require only a general assessment of financial capacity to shut-down and safely maintain a facility. That determination occurs prior to licensing. Furthermore, the NRC admits a tendency to rely on the relatively protected position of publicly regulated utilities as a sufficient guarantee of their financial capacity to decommission power reactors.³²

A Public Interest Research Group (PIRG) petition challenged the adequacy of the NRC's approach to the financing question.³³ The petition called upon the NRC to implement rules requiring licensees to post bonds to be held in escrow, create funded escrow accounts, or utilize sinking funds linked to a surety arrangement in order to ensure the future availability and adequacy of decommissioning funds. The NRC denied that part of the petition calling for specific funding requirements.³⁴ As justification, the NRC cited the adequacy of current financial evaluations, questions about its own authority to require specific arrangements and guarantees, and the unavailability in the market of large, long term bonds as well as the fact that such bonds would not necessarily accomplish the goals contained in the PIRG petition. The extent of NRC authority in this area has been questioned on several occasions, but the NRC is continuing to review the financing problem as principal regulatory concern.³⁵ In fact, the NRC's own discussion paper on the issue indicates that "the goals in the area of financing the decommissioning of nuclear facilities should be to provide a very high degree of assurance that the licensee will pay the costs and to allow a wide latitude of approaches to implement that assurance."³⁶

Generally, specific arrangements for financing decommissioning result from the interaction of state public service regulators and the affected utilities as well as public and private intervenors in the rate setting processes of the different states. Additionally, the Federal Energy Regulatory Commission (FERC) which regulates interstate sales of electricity plays a role in setting interstate standards. Of 32 utilities responding to a 1977 General Account-

ing Office (GAO) survey, 15 had established no special provisions for funding decommissioning.³⁷ The rationale in those instances appears to have been the expectation that the cost of decommissioning would be repaid from revenues generated after the work occurs. Examples of other arrangements implemented or considered by several states are described in Appendix J.

Several characteristics of the decommissioning problem highlight the significance of choosing a financing mechanism, and illustrate the complexity of the issue.³⁸ They include: (1) the substantial costs of decommissioning, (2) the future nature of decommissioning, (3) the uncertain solvency of facility owners at the time of decommissioning, and (4) the possibility of premature shut-down of a nuclear power plant.

(1) Substantial Costs

Accomplishing decommissioning will require a substantial expenditure by plant owners.³⁹ Different methods have different costs, and although those costs are not great in relation to the original capital cost of a plant, none are trivial. Moreover, unlike the cost of construction or the cost of refueling a nuclear plant, the cost of decommissioning is an expense which generates no new revenues, a fact which led one analyst to note that utilities have "no direct economic incentive...to decommission."⁴⁰ Cost estimates, made at different times, for complete dismantlement range up to \$100 million or more, at a time when the capital cost of a plant is approximately \$1 billion. In percentage terms, this ranges up to about 10 percent of capital cost, but a figure as high as 24 percent of capital investment has also been suggested. However, when expressed in terms of revenue requirements to fund decommissioning in relation to total revenue requirements, which includes amortization for capital and fuel as well as operational expenses, the percentages are smaller. Chapman, in an analysis for the California Energy Commission estimated decommissioning revenues to range from 3 to 8 percent of total revenues.⁴¹ Nonetheless, the cost is not negligible, and if not paid by the facility owners and power users, it is a substantial cost that will have to be paid by the public.

(2) Future Nature of Decommissioning

Under normal circumstances, decommissioning will occur at least thirty to forty years after a reactor commences operation, and if prompt dismantlement is the option selected, six to eight years will elapse while decommissioning is in progress. Alternatively, some scenarios call for delays of thirty years, which

the NRC might set as the maximum, or for delays up to 100 years prior to dismantlement. Perpetual mothballing or entombment, although probably not acceptable, would necessitate indefinite annual expenditures. Exactly what time periods will be involved is uncertain. Facility owners are presently allowed considerable latitude, and regulatory changes have not yet limited the range of choices.

In any case, although available cost estimates are current, the expenditure will occur far in the future complicating the task of estimating future costs and the revenue requirements to pay for decommissioning. Various uncertainties have already been identified in Part II of this report. However, it is worth reiterating that the rate of inflation, interest, and tax policy are important considerations. The net effect on costs of these and other factors is unclear, but thirty or more years of inflation, even at 5 to 7 percent will escalate costs into the hundreds of millions of dollars.⁴² Assuming higher rates for inflation adds substantially to final costs for decommissioning.

To accurately anticipate decommissioning costs, estimates must be periodically updated over the life of the facility. To adequately fund decommissioning from revenues generated during the facility's operating life, revenue requirements and financing mechanisms must be likewise adjusted to reflect changing factors. Failure to do so opens the door for additional changes in costs and revenue needs after the facility has closed and at a time when the only source of revenue will be non-benefiting ratepayers or the public.

(3) Uncertain Solvency of Facility Owner

Under NRC regulations the obligation to carry out decommissioning falls to the licensee owning the reactor. Given the concern for accomplishing decommissioning and doing so in an equitable manner, it is worth questioning "the future ability of utilities to pay the future costs of decommissioning..."⁴³

Ownership patterns vary. Examples of reactor owners are publicly-owned utilities, investor-owned utilities, agencies or corporations of states or the federal government, joint ownership by several utilities (possibly from different states), or some combination of these alternatives. The Battelle study for the NRC listed operating or planned power reactors as 81 percent investor-owned and 19 percent publicly-owned.⁴⁴

The financial integrity and future solvency of these owners depends in part on the economics of nuclear power. Demand for electricity, the cost of fuel, charges for waste disposal, and the attractiveness of other power options

affect the ability to generate revenues and finance decommissioning nuclear plants. Accidents can also affect the cost of operation and the cost, timing, and financing of decommissioning. General Public Utilities, owner of the Three Mile Island plant, declared itself in danger of insolvency shortly after the accident at TMI.⁴⁵

On the other hand, it is argued that the question of future solvency is not an issue because the relatively sheltered status of publicly regulated utilities gives them the right to earn a fair rate of return, even under adverse economic situations. Utilities, the argument concludes, will therefore continue to have the ability to generate revenues sufficient to cover decommissioning.⁴⁶ Even so, the Public Interest Research Group, some regulators, and others have taken the opposite view arguing that relying solely on the facility owner provides an insufficient guarantee of the adequacy and availability of funds. In addition, an NRC draft report (discussing financing options and acknowledging the special status of regulated utilities) states that relying on an unfunded reserve (one financing approach) "is so fraught with uncertainty as to be questionable under the NRC's responsibility to assure that a utility is financially qualified to safely shut down a licensed reactor."⁴⁷ This statement, though not NRC policy, reflects the view that leaving the funding question strictly to the utilities is inadvisable and suggests the need for some sort of guarantees to strengthen the assurance of fund availability.

(4) Premature Shut-down

Nuclear facilities may be closed prematurely for a variety of reasons. Three Mile Island demonstrates the possibility of an accident-related shut-down. The NRC has closed, at least tentatively, other plants upon discovering design faults or unstable geological characteristics at the site.⁴⁸

An accident might radically escalate cost estimates and alter the decommissioning timetable. Converting the damaged TMI reactor to fossil fuel generation, for example, could cost \$1.4 to \$1.7 billion.⁴⁹ Returning it to nuclear service was by August 1980 estimated at more than \$800 million. The pre-accident estimate of decommissioning costs was \$95 million.

On the other hand, premature closure for other reasons might reduce estimates by taking the reactor out of operation before it builds up the intense levels of radiation associated with a full operating life.

Further, even the normal operating lifetime of a reactor is not firmly established. None has completed the expected life cycle at this time, and consequently, no hard data exists to demonstrate the number of years of operation to expect from today's large commercial reactors.⁵⁰

Planning a financing mechanism to generate sufficient decommissioning funds during the lifetime of the reactor is complicated by uncertainties related to the possibility of premature shut-down and the accuracy of the expectation of thirty to forty years of operation.⁵¹

Criteria for Financing Mechanisms

The foregoing discussion of decommissioning offers guidance in selecting criteria for evaluating alternative funding mechanisms. Additionally, principles of economics and public service regulation relate to the question. However, there appears to be more agreement about applicable criteria than on the implications and ranking of those criteria for the choice of a financing mechanism.

Briefly, the criteria cover the (1) sufficiency, (2) availability, (3) equitable distribution, and (4) cost of decommissioning funding.⁵² Each is stated and discussed below.

(1) Sufficiency

Sufficient funds must be collected to cover the full costs of decommissioning. To accomplish this, financing mechanisms used must be adjustable to accommodate changing cost estimates, which reflect technology, regulation, and inflation.

(2) Availability

Adequate funds should be available at the time of decommissioning. Concern over availability arises from questions about future existence and solvency of the facility owner. It is also important in the event of a premature shut-down of the facility, which might interrupt some funding mechanisms. The first point may be interpreted to mean the facility owner or utility should not be the custodian of collected decommissioning funds. The second implies the need for either prepayment of full costs or some form of bonding or insurance to assure both the sufficiency and availability of funding. Wood's analysis of the financing issues for the NRC ranked assurance of the availability of funds as the most important criteria for selecting an appropriate financing mechanism, and

Chapman preferred a funded method for that reason. Both sufficiency and availability are important and related criteria.

(3) Equitable Distribution

Considerations of equity require that the beneficiaries (users) of the electricity generated by a nuclear plant bear the full cost of decommissioning that plant. A suitable financing mechanism should avoid shifting the cost burden to future, non-benefiting generations. Additionally, it should ensure that the cost is shared equitably among users during the productive life of the facility. Although fully matching estimates and revenues to actual cost may not be possible, pursuit of this objective will minimize the discrepancy and the potential impact on non-benefiting ratepayers or the public.

(4) Cost

The financing mechanism with the lowest cost consistent with satisfying all other criteria should be selected. Some utilities have argued that this, rather than assurance, is the most important criteria. That assertion may reflect their view that assurance is no problem due to their sheltered status as well as the point that consumers deserve the best deal they can get. However, if a high degree of importance is attached to the sufficiency, availability, and equity criteria, it is not appropriate to choose among financing alternatives solely on the basis of cost. It should be recognized that guaranteeing, to some reasonable extent, that these criteria will be satisfied will probably involve additional costs. However, at least one study indicates that the choice of financing method has "little or no economic significance" in the total cost of electricity.⁵³

Alternative Financing Mechanisms

It is beyond the scope of this paper to thoroughly analyze and compare alternative financing mechanisms for the purpose of choosing among them.⁵⁴ This discussion attempts to outline basic approaches, list alternative mechanisms, and offer some comments. Ultimately, the choice of a specific mechanism must be carefully assessed to determine its performance in relation to the criteria set forth earlier.

In addition, federal income tax policy is one other factor affecting the cost of alternative decommissioning financing mechanisms. The Internal Revenue Service allows deductions against income taxes for depreciation of capital assets but regards decommissioning as an expense that can only be deducted when

it is incurred. Accruals during the service life of the facility to build up a decommissioning fund are taxable although credits would be extended once the expenditures occur. The need to pay income taxes on accruals and fund earnings raises the cost to consumers. However, an NRC analysis indicates that the IRS will allow, on a case by case basis, annual deductions for decommissioning accruals under certain circumstances. Essentially, funds must be immediately segregated from the utility's assets, placed in a blind trust not controlled by the utility, and invested in tax exempt securities.⁵⁵ Whether this could happen has been disputed by Northern States Power Company which concluded that the IRS would probably not permit such exemptions.⁵⁶

Four basic approaches exist for funding decommissioning:

- paying the cost when incurred and subsequently recovering the cost;
- collecting sufficient funds gradually over the expected life of the facility;
- prepaying the cost into a special fund prior to operation and then recovering that expense during the life of the facility; and
- use of bonding or insurance in conjunction with one of the first three approaches.

Various specific financial and accounting mechanisms are available to implement these approaches and enable a utility to recover its costs. Each entails different implications for consumers, facility owners, and the public. The options briefly discussed below are: (1) expensing, (2) depreciation, (3) funded mechanisms, and (4) bonding and insurance.

(1) Expense Costs as Incurred

Under this method, the utility defers funding decommissioning until the costs are incurred in the future. The actual expenditure is amortized and recovered from revenues in the years during and after decommissioning. The GAO study, mentioned earlier, reported that 15 of 32 utilities surveyed planned to recover costs in this manner.

Expensing the costs presents two problems. First, it depends on the future solvency of the utility and its capacity to generate sufficient funding. Second, it requires future ratepayers who have not benefited from the operation of the facility to pay for decommissioning. For these reasons, it appears unacceptable and has been rejected in several studies. However, if actual costs incurred during decommissioning exceed the amounts estimated and accumulated

during the life of the plant, those added costs will be amortized and paid by future, nonbenefiting ratepayers.

(2) Depreciation Mechanisms

A depreciation mechanism collects funds gradually over the life of the plant. Normally, it enables the owner to recover a portion of the plant's original capital cost in each year of operation. Depreciation schedules for nuclear plants run approximately 27 to 30 years depending on what time is certified by the supervising public service regulator. Establishing the number of years for depreciation of a nuclear plant is complicated by the lack of any complete histories for large commercial reactors.

Decommissioning expenses may be incorporated in a plant's depreciation schedule in what is known as a salvage adjustment. At the end of its life, a facility is not necessarily totally worthless. The sale of scrap building materials or equipment generates a salvage value. However, in the case of nuclear facilities, contaminated materials must be disposed of rather than sold, and this is the cost of decommissioning. Disposal expenses in excess of salvage values constitute negative net salvage value, a net cost the utility must pay to dispose of the facility.

Adding an estimate of negative net salvage and the original capital cost yields an amount that may be depreciated to recover both the original capital and the net disposal cost. Recovery is accomplished by building the depreciation schedule into the rates charged to consumers. The technique is called negative net salvage value depreciation.⁵⁷

On the utility's books, funds collected for decommissioning could be lumped together with recovered capital cost, as accumulated depreciation, or identified in a separate account. The latter approach would highlight the amount accrued for decommissioning and might facilitate adjusting accrual rates for changing estimates of costs and salvage.⁵⁸

Typically, funds recovered through depreciation are retained by the utility. The company is free to use the monies as it sees fit, and in fact, providing a utility with interim funds has been seen as an attractive feature of this approach.⁵⁹ Consequently, with this approach the availability of future funding for decommissioning would depend on the solvency of the utility.

Alternatively, depreciation accruals for decommissioning could be paid into a fund and restricted to use for future decommissioning. Such a fund could be within, or outside, of the utility.

The amount of funds collected under depreciation would not be sufficient to cover the cost of decommissioning in the event of a premature shut-down of the facility. Only near the end of the schedule do accumulations begin to approach the full cost of decommissioning. This problem might be resolved by using a bond or some form of insurance to cover the deficiency when routinely accumulating funds are insufficient.

Depreciation mechanisms must also be evaluated in terms of equity. Some formulas would cause ratepayers early in the life of the facility to pay more in real terms than ratepayers later in the operating life. Other methods, adjusted to price level rather than straight line, would correct this problem but result in high nominal accruals in later years. In addition, depreciation accruals are not normally tax deductible. This raises the cost of setting aside decommissioning monies. Further, tax treatment may place a tax burden on current ratepayers while giving a tax break to future ratepayers when the expenditure is incurred and deducted at the time of decommissioning.

(3) Funded Mechanisms

Funded mechanisms accumulate and set aside real assets for the sole purpose of decommissioning. The utility recovers its payments to the fund from rates paid by its customers over the life of the facility. The monies generated may be held either by the utility in a special account, or alternatively, transferred to a trust until required for decommissioning. The latter approach minimizes reliance on the future solvency of the utility.

Funded mechanisms may be of at least two types: prepaid lump sum or an annual payment sinking fund.

PREPAID LUMP SUM: This option requires the utility to pay a lump sum into the fund prior to operating the reactor. Properly calculated, this amount combined with investment returns over the life of the fund should be sufficient to cover decommissioning costs and minimize the potential burden on future ratepayers. The prepaid lump sum has the advantage of forcing the investor to weigh the cost of decommissioning in the choice of nuclear power over alternative power sources.⁶⁰

SINKING FUND: A sinking fund requires the utility to make an annual payment to a decommissioning fund. The amount of this annuity is calculated by estimating removal costs, inflation, and return on invested funds. When accumulated and combined with investment earnings, these annual payments should

equal the future cost of decommissioning. However, equal annual payments might be inequitable because the real value of early contributions would be relatively greater than those of later ratepayers. To avoid this, the design might strive to equalize the real value of payments at different points of time.

Neither mechanism would provide sufficient funds in the event of premature shut-down.⁶¹ The value of the fund approximates the full cost of decommissioning only near the end of the facility's operating life.

Both funds could be adjusted periodically to account for changing estimates of cost, inflation, and earnings. To mitigate this problem might require some form of bond or insurance.

The cost of funded approaches depends on several factors. Among them are: whether annual payments to the fund are tax deductible; whether fund investments are in tax exempt securities; and what opportunity costs are involved with a particular mechanism.

(4) Bonding and Insurance

The purpose of requiring a bond is to insure the sufficiency and availability of decommissioning funds.⁶² The technique minimizes the likelihood of the public or non-benefiting ratepayers having to assume the costs of decommissioning. Bonding or insurance could be required when the utility is the sole custodian of decommissioning funds or to cover fund deficiencies in the event of premature shut-down. As pointed out earlier, the NRC found that bonds of \$50 million over a forty year period are currently unavailable. Additionally, because of renewal procedures used by bonding companies, long term assurance is not necessarily guaranteed. Alternatively, some form of insurance in conjunction with a particular funding option could provide adequate assurance when the utility is custodian of the decommissioning funds or cover fund deficiencies in the event of premature shut-down.⁶³

Summary

Accomplishing decommissioning requires foresight and planning. Deferring consideration of financing implies a serious disregard for the welfare of future generations that will be forced to bear the cost. Current beneficiaries of nuclear power should do no less than pay its full cost.

Setting up satisfactory financing arrangements is a complicated task. Several steps are involved:

- determining the preferred method of decommissioning;

- estimating the future costs associated with that method;
- devising an equitable mechanism for collecting sufficient funds to meet decommissioning costs;
- providing means for adjusting the funding mechanism to accommodate changing estimates and economic circumstances and;
- incorporating adequate guarantees that the task of decommissioning will be carried out.

While the federal government and the Nuclear Regulatory Commission are major actors in determining the proper methods for waste disposal and decommissioning, the states and their respective public service regulators play major roles in dealing with the financing problem.

FOOTNOTES - PART III

1. U.S. General Accounting Office (GAO), Cleaning up the Remains of Nuclear Facilities--A Multibillion Dollar Problem. Report to the Congress. (Washington D.C.: Government Printing Office, June 16, 1977), p. 1.
2. "By-product material" means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material. "Source material" means (1) uranium, thorium or any combination thereof, or (2) ores which contain by weight one-twentieth of one percent (0.05 percent) or more of (i) uranium, (ii) thorium, or (iii) any combination thereof. "Special nuclear material" means (1) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, or (2) any material artificially enriched by any of the foregoing, but not including source material.
3. U.S. Nuclear Regulatory Commission (NRC), Plan for Reevaluation of NRC Policy on Decommissioning Nuclear Facilities, NUREG-0436, Revision 1. (Washington D.C.: NRC, December 1978), p. ii.
4. 42 F.R. (U.S. Federal Register), 40063 and as supplemented 42 F.R. 59574.
5. 43 F.R. 10370, "Decommissioning Criteria for Nuclear Facilities--Advance Notice of Proposed Rulemaking," March 13, 1978, pp. 10370-10371.
6. U.S. Nuclear Regulatory Commission (NRC), Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor, NUREG/CR-0130, Volumes 1, 2, and Addendum. Prepared by Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington. (Washington D.C.: NRC, June 1978 and August 1979). (Y3.N88:25/0130). A similar study covering a boiling water reactor was issued in 1980 too late for inclusion in this study. Battelle also studied decommissioning a reprocessing plant, NUREG/CR-0278.
7. U.S. Nuclear Regulatory Commission (NRC), Proceedings: State Workshops for Review of the Nuclear Regulatory Commission's Decommissioning Policy, NUREG/CP-0003, (Philadelphia, Pa.; Atlanta, Ga.; Albuquerque, N.M.; September 18-30, 1978), (Washington D.C.: NRC, December 1978), (Y3.N88:27/003).
U.S. Nuclear Regulatory Commission (NRC), Proceedings: State Workshops for Review of the Nuclear Regulatory Commission's Decommissioning Policy, NUREG/CP-0008, (Columbia, S.C.; Seattle, Wa.; September 1979). (Washington D.C.: NRC, December 1979). (Y3.N88:27/0008).
8. U.S. Nuclear Regulatory Commission (NRC), Decommissioning Commercial Nuclear Facilities: A Review and Analysis of Current Regulations, NUREG/CR/-0671. Prepared by A.H. Schilling, et al. (Pacific Northwest Laboratory and Battelle Human Affairs Research Centers) for NRC (Washington D.C.: NRC, August 1979). This source provides an extensive review of a wide range of regulations and levels of authority related to decommissioning.

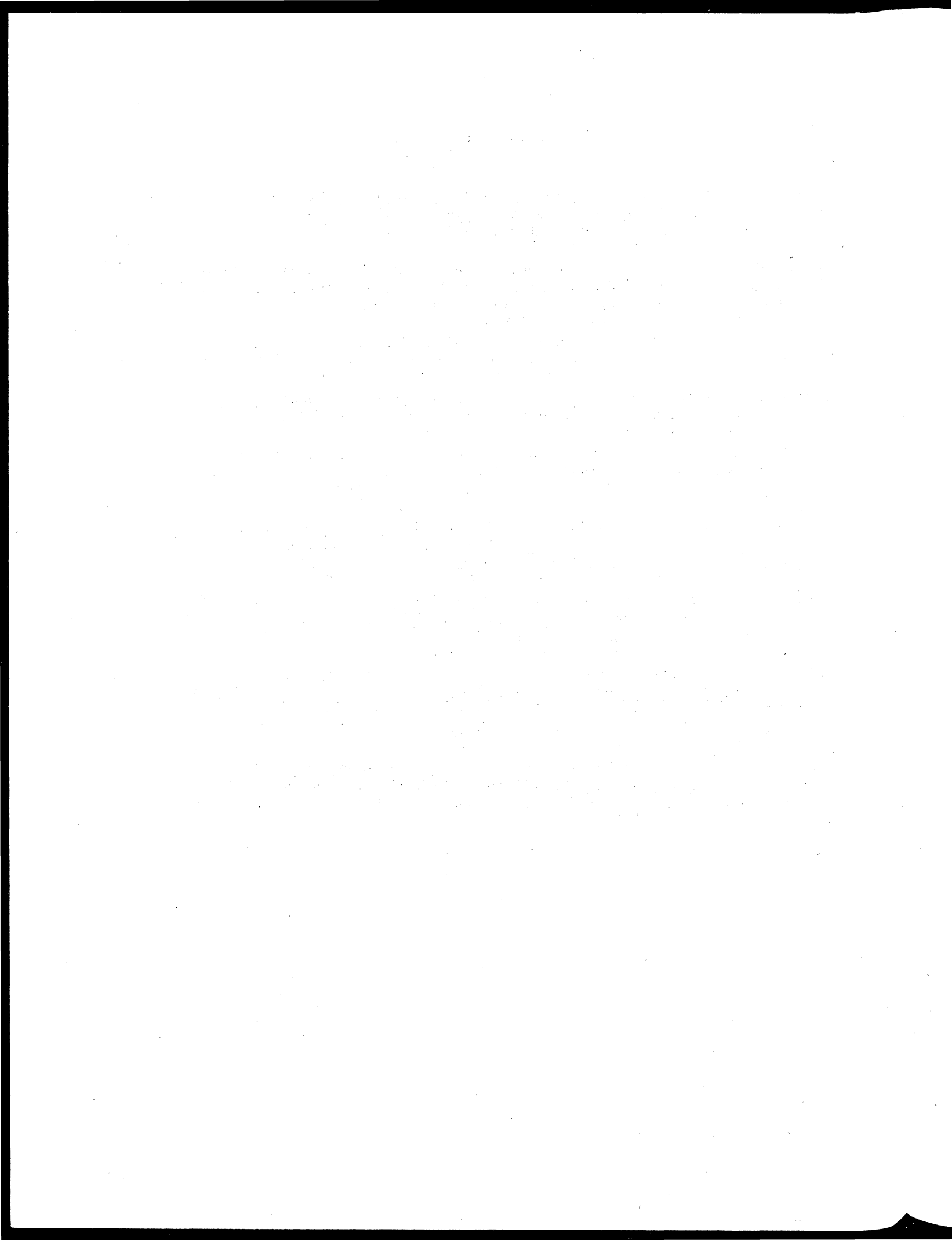
9. GAO, Cleaning Up, p. 16.
10. NRC, Plan for Reevaluation, NUREG-0436, p. 5.
11. 10 C.F.R. (U.S. Code of Federal Regulations) 50.82 (1980 ed.).
12. U.S. Atomic Energy Commission (AEC), Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, (Washington D.C.: AEC, June 1974). Reproduced in Appendix G of this paper.
13. NRC, Decommissioning, NUREG/CR-0671, p. 2-34.
14. AEC, Termination, p. 5.
15. NRC, Technology, NUREG/CR-0130, Volume 1, p. 5-2.
16. Ibid., p. 5-2.
17. The statements checked were: (1) NUREG-0285, Shoreham Unit #1, Long Island Lighting Company, October 1977, (2) NUREG-0343 Palisades, Consumer Power Company, February 1978, (3) NUREG-0417, Edwin I. Hatch Unit #2, Georgia Power Company, March 1978, (4) NUREG-0434, Fort Calhoun Station Unit #2, Omaha Public Power District, March 1978, and (5) the NSP statements for Monticello and Prairie Island I & II.
18. 43 F.R. 103 0-10371.
19. U.S. Nuclear Regulatory Commission (NRC), Draft Generic Environmental Impact Statement on Decommissioning Nuclear Facilities, NUREG-0586, forthcoming.
20. NRC, Decommissioning, NUREG/CR-0671, p. 2-17.
21. Ibid., p. 3-16.
22. NRC, Technology, NUREG/CR-0130, Volume 1, p. 5-6.
23. Model Interstate Scientific and Technical Information Clearinghouse (MISTIC), Nuclear Power Reactors: An Overview of Selected Issues, report prepared by Rhett D. Speer, et al. for MISTIC, (Denver: National Conference of State Legislatures, April 1979).
U.S. NRC, Decommissioning, NUREG/CR-0671, p. 3-14.
24. U.S. Congress, House Committee on Science and Technology, Subcommittee on Environment and the Atmosphere. Decommissioning and Decontamination. Hearings...95th Congress. 1st Session, 1977, p. 69.
MISTIC, Nuclear Power Reactors, p. 7.
U.S. NRC, Decommissioning, NUREG/CR-0671, p. 2-41.
25. A 1968 Minnesota effort to impose more stringent standards for radioactive emissions was rejected by the courts in "Northern States Power v. The State of Minnesota (1971)." The preemption clause which was the basis for the decision appears in the Atomic Energy Act of 1954. In addition, California efforts to restrict licensing of new plants pending solution of the waste problem was recently ruled impermissible by federal district courts

on grounds of federal supremacy. See "Three California Laws Blocking Nuclear Plant Work are Overturned," Wall Street Journal, April 28, 1980, p. 2.

26. MISTIC, Nuclear Power Reactors, pp. 8&9.
27. U.S. Nuclear Regulatory Commission (NRC), Thoughts on Regulation Changes for Decommissioning, NUREG-0590, Draft Report, Revision 1. Prepared by G.D. Calkins. (Washington D.C.: NRC, December 1979).
28. Ibid., p. 3.
29. Ibid., p. 6.
U.S. Nuclear Regulatory Commission (NRC), Residual Radioactivity Limits for Decommissioning, NUREG-0613, prepared by Enrico F. Conti. (Washington D.C.: NRC, October 1979).
Louis Battist, in NRC, State Workshops, NUREG/CP-0008, pp. 268-277.
30. NRC, Thoughts, NUREG-0590, pp. 3-4.
NRC, State Workshops, NUREG/CP-0008, pp. 376-377.
31. New York (state of) Public Service Commission (PSC), Case 27353 (Consolidated Edison Company of New York, Inc. - Electric Rates), Opinion No. 79-8 (Opinion and Order Determining Revenue Requirement). Issued April 6, 1979, p. 9.
32. The rationale is that publicly regulated utilities will be able to get approval for rates to cover the cost and that as regulated monopolies protected from competition their continuity is assured. Also noted in the Battelle study cited as NRC, Technology, NUREG/CR-0130, Appendix D, p. D-3. Also in NRC, Plan for Reevaluation, NUREG-0436, p. 42.
33. 42 F.R. 40063 and as supplemented in 42 F.R. 59574.
34. 44 F.R. 36523, June 22, 1979, "Response to and Partial Denial of Petition for Rulemaking Filed by The Public Interest Research Group, et al.," (NRC docket number PRM-50-22).
35. NRC, Plan for Reevaluation, NUREG-0436, Attachment E.
36. NRC, Thoughts, NUREG-0590, p. 5.
37. GAO, Cleaning Up, p. 6.
38. There are several good sources on issues related to financing decommissioning. Several are used as the basis for this discussion:
California State Task Force on Nuclear Energy and Radioactive Materials, "Radioactive Materials in California," draft report of the secretary for resources, Part V titled "Decontamination and Decommissioning Radioactive Facilities," (unpublished, June 1978).

- Vincent L. Schwent, "Costs and Financing of Reactor Decommissioning: Some Considerations," Draft paper 261:A:01, (California Energy Commission: September 9, 1978). 49.
- Benjamin Ewers, Jr., "Financial Evaluation of Nuclear Plant Decommissioning Costs," unpublished paper, Northern States Power Co., Nov. 14, 1978. 50
- Preston A. Collins, (Gilbert Associates, Inc.), "Financing and Accounting Alternatives for Decommissioning Nuclear Plants." A paper presented at New Orleans, La. to the Southeastern Electric Exchange, September 28, 1978. 51
- NRC, Technology, NUREG/CR-0130, Volume 2, Appendix D.
- U.S. Nuclear Regulatory Commission (NRC), Assuring the Availability of Funds for Decommissioning Nuclear Facilities, NUREG-0584, draft, Revision 1, by R.S. Wood, (Washington D.C.: NRC, December 1979). 52
- Duane Chapman, Nuclear Economics: Taxation, Fuel Cost and Decommissioning, report to the California Energy Commission, A.E. Res. 79-26 (Ithaca: Cornell University, Department of Agricultural Economics, October 29, 1979). 53
54
39. Ewers, "Financial Evaluation," p. 4.
Schwent, "Costs and Financing," p. 5. 55
40. NRC, Assuring the Availability of Funds, NUREG-0584, p. 3.
41. Chapman, Nuclear Economics, p. 55. The Chapman analysis was based on the Battelle cost estimate and the higher alternative of 10 percent of capital cost, but Chapman indicated his view that higher estimates, perhaps up to 24 percent, would be more realistic based on his perception that the cost of complex technological systems have been repeatedly underestimated as well as on the rate of cost increases in the nuclear industry. 5
42. The rate of inflation assumed differs among studies but has been generally between 5 and 8 percent. Chapman also presents figures based on a 14 percent inflation rate. 5
43. Schwent, "Costs and Financing," p. 5.
44. NRC, Technology, NUREG-0130, Volume 2, Appendix D, p. D-1.
NRC, Assuring the Availability of Funds, NUREG-0584, p. 6.
45. William Glasgall, "Owner of Damaged Nuclear Plant Says It Faces Insolvency," Minneapolis Tribune, May 10, 1979, p. 9A.
46. NRC, Assuring the Availability of Funds, NUREG-0584, p. 2.
47. Ibid., p. 38.
48. Nucleonics Week, August 1, 1977, p. 4 as cited by Schwent, "Costs and Financing," p. 7, n. 2.

49. "Fossil Fuel Conversion at Three Mile Island Could Cost \$1.7 Billion," Wall Street Journal, March 5, 1980, p. 22. TMI construction cost reported as \$780 million.
50. N.Y., P.S.C., Consolidated Edison, Case 27353, opinion 79-8, pp. 7-8.
Tim Laslavic (Pennsylvania Public Utility Commission) letter to Robert Bernero (U.S. NRC), October 11, 1978, p. 2. Copy mailed to author of this paper.
51. Schwent, "Cost and Financing," p. 8. He draws heavily on Ewers, "Financial Evaluation."
52. These criteria appear in slightly different ways in different discussions. Additionally, the need for flexibility to accommodate differing ownership patterns has been noted.
53. Chapman, Nuclear Economics, pp. 52 and 60.
54. Several studies provide insights on this very complex issue. However, each approaches it from different institutional and analytic perspectives (see footnote 38).
55. NRC, Assuring the availability of funds, NUREG-0584, pp.13-16. Collins also discusses tax impacts and recommends changing the tax code to exempt tax commissioning funds. Chapman's analysis in terms of overall nuclear economics investment and of taxation led him to conclude that the present worth of the income tax liability on a plant is negative, i.e., a subsidy.
56. NSP, Initial Brief by Gene R. Sommers, "In the Matter of the Petition of Northern States Power Company for Depreciation Certification for Expected Decommissioning Costs of the Monticello and Prairie Island Nuclear Steam Generating Facilities," Minnesota Public Utilities Commission, Docket No. E002/D-79-956, brief dated 8/20/80, pp. 15-19.
57. In Pennsylvania, however, this approach is prohibited by statute and the courts, which ruled that future removal costs should be recovered after the fact not through prospective changes in a depreciation schedule.
"Nuclear Plant Decommissioning Costs," Public Utilities Fortnightly, 103 (April 26, 1979): 54-56.
58. Ewers, Financial Evaluation, pp. 4-6 and Collins, Financing and Accounting, p. 7.
59. Chapman, Nuclear Economics, p. 46.
60. NRC, Technology, NUREG-0130, Vol. II, Appendix D, p. D-15.
61. Schwent, "Costs and Financing," p. 11.
62. Ibid., pp. 13 & 14.
63. NRC, Assuring the Availability of Funds, NUREG-0584, pp. 31-35.



PART IV

CONCLUSION

COMMENT

Policy studies often conclude with an ardent plea for further study. Formulating sound policy recommendations is always more difficult than describing policy problems. Calling for more study can be a way to avoid this difficult task, but it can also reflect a recognition of the true nature of policy problems: they lack closure. Answers inevitably lead to new questions; solutions create new problems.

We would not be so pretentious as to believe that we have written the definitive paper on nuclear power plant decommissioning. We have attempted only to provide an introduction to decommissioning which helps those who want to think about the subject as a policy issue. Therefore, if this paper stimulates further questions and study, it will fulfill its purpose.

But we will not eschew the task of setting forth our policy recommendations based on our conclusions from this analysis.

RECOMMENDATIONS

Nuclear Wastes and Decommissioning

Federal agencies have issued over 5,000 reports on nuclear waste problems. There is general agreement on two points. First, underground storage is the most technically feasible alternative for high level wastes. Second, for both high- and low-level wastes, the most difficult problems are not technical but political (that is, siting of disposal facilities).

As the federal government develops nuclear waste policies, more explicit consideration must be given to decommissioning. The ramifications of specific waste storage decisions on decommissioning must be examined carefully and integrated into overall waste storage policy.

We believe the most effective step that states can take is to require utilities, owning existing or proposed nuclear plants, to submit plans on decommissioning and on waste disposal. Further, states should not permit new nuclear plants unless the utilities can demonstrate that they can safely and

permanently dispose of all nuclear wastes as they are generated, safely decommission the plant, and adequately guarantee the financing of both. Most important, states also should press the federal government for an effective, not merely expedient, solution to the permanent disposal of nuclear wastes.

This approach will help focus public attention on the problems of decommissioning and nuclear wastes by generating utility proposals, public hearings, and ongoing discussion.

Nuclear Plant Design

There is no ideal way to decommission a nuclear power plant. One reason for this, according to the Nuclear Energy Agency (OECD), is that decommissioning has not been considered in the design of nuclear plants.

Studies should be undertaken to illuminate the possible relationships and trade-offs between design criteria which would facilitate decommissioning and those which emphasize other factors (such as, plant operations, safety, and total costs).

Decommissioning Methods

Current NRC regulations permit utilities to choose a decommissioning method. The NRC allows mothballing, entombment, and dismantlement. We believe that permanent mothballing and entombment are unacceptable, and the NRC should not permit them. They leave plant structures standing which remain radioactive for thousands of years, and in our judgment, this entails far too many uncertainties and potential long-term risks.

Based upon current cost estimates, decommissioning technology, and radiation exposures, prompt dismantlement for plants in operation thirty to forty years can be seriously questioned as well. This method creates larger quantities of radioactive waste material than any other method and poses the greatest occupational health hazards. It is also the most expensive according to most cost studies. The risks and costs of dismantlement may be greater than the potential benefits of completely clearing the plant site within five to eight years after shutdown.

We believe that mothballing/delayed dismantlement and entombment/delayed dismantlement may strike the best balance between decommissioning costs, institutional and land use considerations, and public and occupational health and safety. They should be included in NRC regulations as approved decommission-

ing alternatives. However, it is clear that further cost-benefit analysis of the tradeoffs between alternatives will be necessary in order to make an informed decision. Also, the NRC should revise its regulations so that the procedures for decommissioning, including surveillance and maintenance, are set forth more explicitly.

Financing

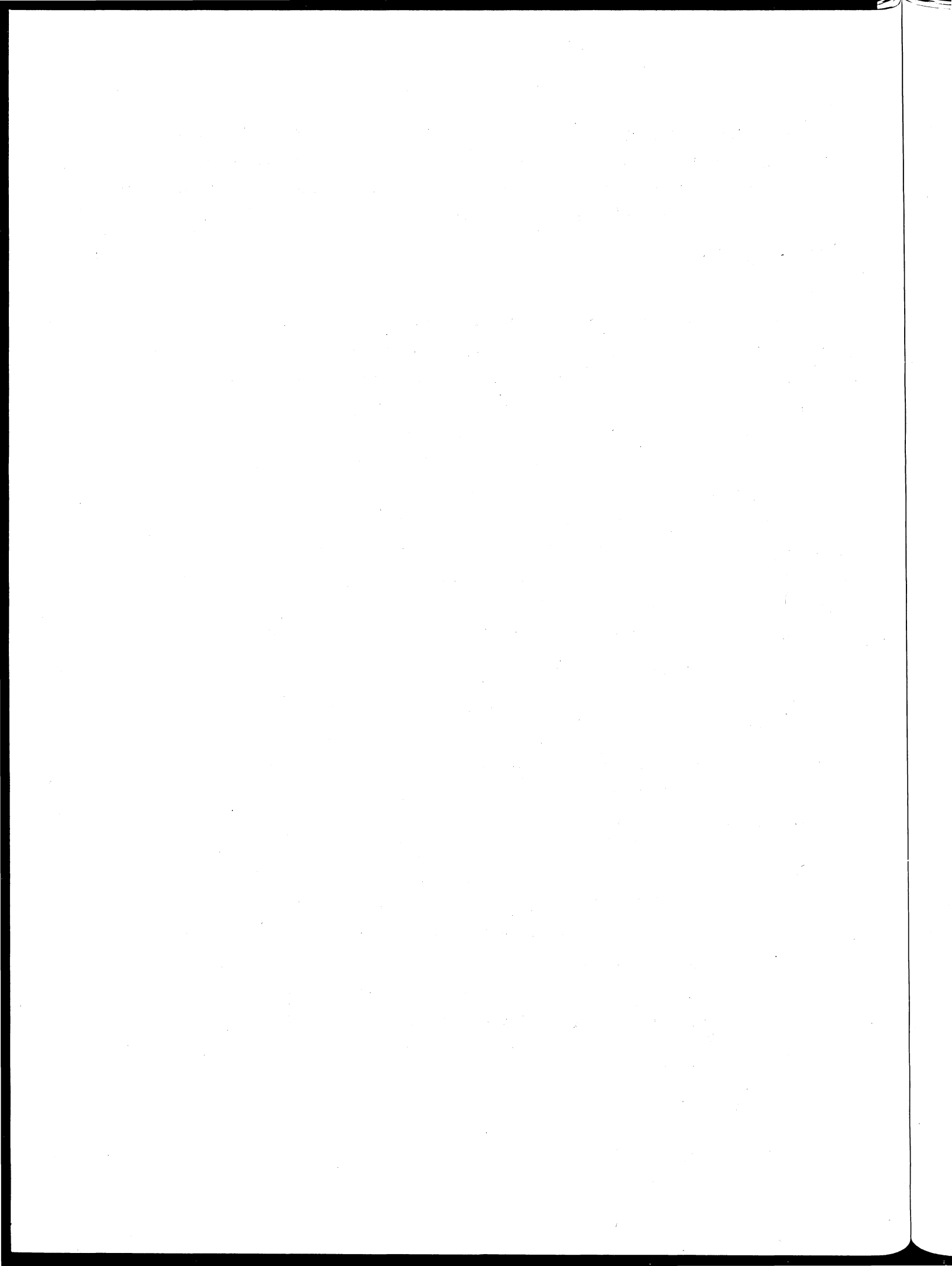
It is our conclusion that NRC and state regulatory policy must include arrangements for financing decommissioning. Ambiguity about preferable methods and standards for decommissioning exacerbates the task of developing accurate cost estimates on which to build suitable financing mechanisms. Nevertheless, implementing an acceptable financing scheme at the earliest possible date is the only means of ensuring that the costs of decommissioning will be reflected in the cost of nuclear power to current beneficiaries.

We believe current cost estimates may be used as the basis for financing arrangements provided allowance is made for periodic adjustment to reflect changing cost estimates. Financing arrangements can be established at this time by state public service regulators.

Our review of decommissioning and financing issues suggests the following criteria for selecting a financing method:

- 1) Current charges for nuclear generated electricity should reflect the future cost of decommissioning and waste disposal.
- 2) The mechanism adopted should allow periodic adjustment to reflect changing cost estimates.
- 3) Funds for decommissioning should be guaranteed prior to licensed operation of a commercial nuclear power plant.
- 4) Decommissioning funds, as collected, should be placed in a secure account specifically set aside for that purpose.

Finally, it is our conclusion that, while provision of least-cost financing and equitable treatment of consumers are important considerations, the most fundamental concern must be for public health and safety. This suggests that assigning responsibility for decommissioning, specifying proper methods, and assuring adequate financing are the most important criteria to be applied.



APPENDIX A

INVENTORY OF NUCLEAR WASTES IN THE UNITED STATES

(as of 1/1/77)

HIGH LEVEL WASTE (thousands of cubic feet)

Commercial	80
DOE	9,400
	<hr/>
Total	9,480

COMMERCIAL SPENT FUEL (metric tons of heavy metal)

2,300*

TRANSURANIC WASTE (kilograms)

Commercial	123
DOE	1,100
	<hr/>
Total	1,223

LOW LEVEL WASTE (millions of cubic feet)

Commercial	15.8
DOE	37.8
	<hr/>
Total	53.6

URANIUM MILL TAILINGS (million tons)

140

Source: Intragency Review Group (IRG) on Nuclear Waste Management, Report to the President (Washington, D.C., March 1979), p. 11 and Appendix D, p. 28.

*Amount more than doubles for 1980.

APPENDIX B

SPENT FUEL ACCUMULATIONS
(metric tons of heavy metal)

CASE I			CASE II	
Year	Annual	Cumulative	Annual	Cumulative
1977	1,000	3,300	1,000	3,300
1978	1,100	4,400	1,100	4,400
1979	1,300	5,700	1,300	5,700
1980	1,300	7,000	1,300	7,000
1981	1,400	8,400	1,400	8,400
1982	1,600	10,000	1,900	11,900
1983	1,900	11,900	1,900	11,900
1984	2,200	14,100	2,200	14,100
1985	2,700	16,800	2,700	16,800
1986	2,900	19,700	2,900	19,700
1987	3,400	23,100	3,400	23,100
1988	3,600	26,700	3,600	26,700
1989	3,700	30,400	3,900	30,600
1990	3,700	34,100	4,200	34,800
1991	3,800	37,900	4,600	39,400
1992	3,800	41,700	4,900	44,300
1993	3,800	45,500	5,200	49,500
1994	3,800	49,300	5,700	55,200
1995	3,700	53,000	6,000	61,200
1996	3,700	56,700	6,500	67,700
1997	3,700	60,400	6,900	74,600
1998	3,600	64,000	7,300	81,900
1999	3,600	67,600	7,800	89,700
2000	3,500	71,100	8,100	97,800

Case I: Nuclear generating capacity in the year 2000 equals 148 gigawatts.

Case II: 380 gigawatts.

(A gigawatt equals 1 million kilowatts.)

Source: Interagency Review Group (IRG) on Nuclear Waste Management, Report to the President (Washington, D.C., March 1979), Appendix D, p. 28.

APPENDIX C

ESTIMATED TIMETABLE FOR
COMMERCIAL REACTOR DECOMMISSIONING

<u>Decommissioning Begins By</u>	<u>Number of Reactors</u>	
	<u>Year</u>	<u>Total</u>
2000	5	-
2005	11	6
2010	49	38
2015	81	32
2020	140	59

These estimates are based on:

- (1) an assumption of a 35-year lifetime for commercial reactors;
- (2) an assumption that there will be no accidents requiring unscheduled, permanent reactor shut-downs;
- (3) various estimates on the number of nuclear power plants scheduled to commence operations by 1985.

Source: compiled by Dave Aquilina.

APPENDIX D

NUCLEAR POWER PLANTS AND THE YEAR
THEIR ON-SITE SPENT FUEL STORAGE
REACHES FULL CAPACITY

<u>Year</u>	<u>Plant</u>	<u>Utility</u>	<u>State</u>
1979	LaCrosse	Dairyland Power Cooperative	Wisconsin
1983	Surry 1	Virginia Electric & Power Co.	Virginia
1984	H.B. Robinson	Carolina Power & Light Co.	S. Carolina
	Brunswick 1	Carolina Power & Light Co.	N. Carolina
	Brunswick 2	Carolina Power & Light Co.	N. Carolina
	Calvert Cliffs 1	Baltimore Gas & Electric	Maryland
	Calvert Cliffs 2	Baltimore Gas & Electric	Maryland
1985	Prairie Island 1	Northern States Power	Minnesota
	Prairie Island 2	Northern States Power	Minnesota
1986	Yankee Rowe	Yankee Atomic Power Co.	Massachusetts
	Humboldt Bay	Pacific Gas & Electric	California
	Midland 1	Consumers Power Co.	Michigan
	Midland 2	Consumers Power Co.	Michigan

Source: Nuclear Assurance Corporation, as cited in Robert J. Samuelson, "Now That We've Got the Reactors, What Do We Do With the Used-Up Fuel?" National Journal, 5 November 1977, p. 1730.

APPENDIX E

TOTAL COMMERCIAL LOW LEVEL WASTE
(millions of cubic feet)

CASE I

<u>Year</u>	<u>Reactors & Fuel Cycle</u>	<u>Non-Fuel Cycle</u>	<u>D & D¹</u>	<u>Total</u>		<u>Burial Acres Required²</u>
				<u>Ann.</u>	<u>Cum.</u>	
1980	2.87	1.0	0	3.87	14.26	51.85
1985	2.15	1.5	0	3.65	29.97	108.98
1990	1.03	2.0	0	3.03	45.03	163.75
1995	1.03	2.5	0	3.53	62.68	227.93
2000	1.03	3.0	0.01	4.04	82.84	301.24

1/ Decommissioning and Decontamination: 5 reactors mothballed.

2/ At 275,000 ft³/acre

CASE II

<u>Year</u>	<u>Reactors & Fuel Cycle</u>	<u>Non-Fuel Cycle</u>	<u>D & D¹</u>	<u>Total</u>		<u>Burial Acres Required²</u>
				<u>Ann.</u>	<u>Cum.</u>	
1980	2.87	1.0	0	3.87	14.26	51.85
1985	5.98	1.5	0	7.48	44.40	161.45
1990	9.14	2.0	0	11.14	93.60	340.36
1995	13.28	2.5	0.1	15.88	164.24	597.24
2000	17.84	3.0	0.1	20.94	260.00	945.45

1/ Decommissioning and Decontamination: 5 reactors dismantled.

2/ At 275,000 ft³/acre

Case I: 148 gigawatt capacity in 2000.

Case II: 380 gigawatt capacity in 2000.

Source: Interagency Review Group (IRG) on Nuclear Waste Management, Report to the President (Washington, D.C., March 1978), Appendix D, p. 8.

APPENDIX F

COST ESTIMATES FOR NUCLEAR
WASTE MANAGEMENT TO THE YEAR 2000

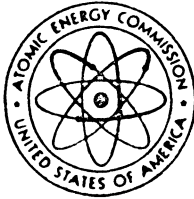
(billions of undiscounted, constant 1977 dollars)

	<u>CASE I</u>	<u>CASE II</u>
High Level Waste Repositories	3.0 - 3.8	5.6 - 7.3
Away-From-Reactor Storage	0.7 - 0.9	0.7 - 0.9
Low Level and Transuranic Waste Operations	0.6 - 0.9	1.8 - 2.4
High Level Waste Treatment	4.2 - 5.2	3.5 - 4.4
DOE Transportation	<u>1.0 - 1.2</u>	<u>1.9 - 2.1</u>
Subtotal	9.5 -12.0	13.5 -17.1
DOE R & D Programs	1.5 - 1.7	1.5 - 1.7
Contingency	<u>2.0 - 3.0</u>	<u>3.0 - 4.0</u>
Total Costs	13.0 -16.7	18.0 - 22.8

Case I: 148 gigawatt capacity in 2000.

Case II: 380 gigawatt capacity in 2000.

Source: Interagency Review Group (IRG) on Nuclear Waste Management,
Report to the President (Washington, D.C., March 1979), Appendix D, p. 32.



U.S. ATOMIC ENERGY COMMISSION

REGULATORY GUIDE

DIRECTORATE OF REGULATORY STANDARDS

REGULATORY GUIDE 1.86

TERMINATION OF OPERATING LICENSES FOR NUCLEAR REACTORS

A. INTRODUCTION

Section 50.51, "Duration of license, renewal," of 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires that each license to operate a production and utilization facility be issued for a specified duration. Upon expiration of the specified period, the license may be either renewed or terminated by the Commission. Section 50.82, "Applications for termination of licenses," specifies the requirements that must be satisfied to terminate an operating license, including the requirement that the dismantlement of the facility and disposal of the component parts not be inimical to the common defense and security or to the health and safety of the public. This guide describes methods and procedures considered acceptable by the Regulatory staff for the termination of operating licenses for nuclear reactors. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

When a licensee decides to terminate his nuclear reactor operating license, he may, as a first step in the process, request that his operating license be amended to restrict him to possess but not operate the facility. The advantage to the licensee of converting to such a possession-only license is reduced surveillance requirements in that periodic surveillance of equipment important to the safety of reactor operation is no longer required. Once this possession-only license is issued, reactor operation is not permitted. Other activities related to cessation of operations such as unloading fuel from the reactor and placing it in storage (either onsite or offsite) may be continued.

A licensee having a possession-only license must retain, with the Part 50 license, authorization for special nuclear material (10 CFR Part 70, "Special Nuclear Material"), byproduct material (10 CFR Part 30, "Rules of General Applicability to Licensing of Byproduct Material"), and source material (10 CFR Part 40, "Licensing of Source Material"), until the fuel, radioactive components, and sources are removed from the facility. Appropriate administrative controls and facility requirements are imposed by the Part 50 license and the technical specifications to assure that proper surveillance is performed, and that the reactor facility is maintained in a safe condition and not operated.

A possession-only license permits various options and procedures for decommissioning, such as mothballing, entombment, or dismantling. The requirements imposed depend on the option selected.

Section 50.82 provides that the licensee may dismantle and dispose of the component parts of a nuclear reactor in accordance with existing regulations. For research reactors and critical facilities, this has usually meant the disassembly of a reactor and its shipment offsite, sometimes to another appropriately licensed organization for further use. The site from which a reactor has been removed must be decontaminated, as necessary, and inspected by the Commission to determine whether unrestricted access can be approved. In the case of nuclear power reactors, dismantling has usually been accomplished by shipping fuel offsite, making the reactor inoperable, and disposing of some of the radioactive components.

Radioactive components may be either shipped offsite for burial at an authorized burial ground or secured

USAEC REGULATORY GUIDES

Regulatory Guides are issued to describe and make available to the public methods acceptable to the AEC Regulatory staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations; and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

Published guides will be revised periodically, as appropriate, to accommodate comments and to reflect new information or experience.

Copies of published guides may be obtained by request indicating the divisions desired to the U.S. Atomic Energy Commission, Washington, D.C. 20545. Attention: Director of Regulatory Standards. Comments and suggestions for improvements in these guides are encouraged and should be sent to the Secretary of the Commission, U.S. Atomic Energy Commission, Washington, D.C. 20545. Attention: Chief, Public Proceedings Staff.

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| 2. Research and Test Reactors | 7. Transportation |
| 3. Fuels and Materials Facilities | 8. Occupational Health |
| 4. Environmental and Siting | 9. Antitrust Review |
| 5. Materials and Plant Protection | 10. General |

on the site. Those radioactive materials remaining on the site must be isolated from the public by physical barriers or other means to prevent public access to hazardous levels of radiation. Surveillance is necessary to assure the long term integrity of the barriers. The amount of surveillance required depends upon (1) the potential hazard to the health and safety of the public from radioactive material remaining on the site and (2) the integrity of the physical barriers. Before areas may be released for unrestricted use, they must have been decontaminated or the radioactivity must have decayed to less than prescribed limits (Table I).

The hazard associated with the retired facility is evaluated by considering the amount and type of remaining contamination, the degree of confinement of the remaining radioactive materials, the physical security provided by the confinement, the susceptibility to release of radiation as a result of natural phenomena, and the duration of required surveillance.

C. REGULATORY POSITION

1. APPLICATION FOR A LICENSE TO POSSESS BUT NOT OPERATE (POSSESSION-ONLY LICENSE)

A request to amend an operating license to a possession-only license should be made to the Director of Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545. The request should include the following information:

- a. A description of the current status of the facility.
- b. A description of measures that will be taken to prevent criticality or reactivity changes and to minimize releases of radioactivity from the facility.
- c. Any proposed changes to the technical specifications that reflect the possession-only facility status and the necessary disassembly/retirement activities to be performed.
- d. A safety analysis of both the activities to be accomplished and the proposed changes to the technical specifications.
- e. An inventory of activated materials and their location in the facility.

2. ALTERNATIVES FOR REACTOR RETIREMENT

Four alternatives for retirement of nuclear reactor facilities are considered acceptable by the Regulatory staff. These are:

- a. **Mothballing.** Mothballing of a nuclear reactor facility consists of putting the facility in a state of protective storage. In general, the facility may be left intact except that all fuel assemblies and the radioactive

fluids and waste should be removed from the site. Adequate radiation monitoring, environmental surveillance, and appropriate security procedures should be established under a possession-only license to ensure that the health and safety of the public is not endangered.

- b. **In-Place Entombment.** In-place entombment consists of sealing all the remaining highly radioactive or contaminated components (e.g., the pressure vessel and reactor internals) within a structure integral with the biological shield after having all fuel assemblies, radioactive fluids and wastes, and certain selected components shipped offsite. The structure should provide integrity over the period of time in which significant quantities (greater than Table I levels) of radioactivity remain with the material in the entombment. An appropriate and continuing surveillance program should be established under a possession-only license.

- c. **Removal of Radioactive Components and Dismantling.** All fuel assemblies, radioactive fluids and waste, and other materials having activities above accepted unrestricted activity levels (Table I) should be removed from the site. The facility owner may then have unrestricted use of the site with no requirement for a license. If the facility owner so desires, the remainder of the reactor facility may be dismantled and all vestiges removed and disposed of.

- d. **Conversion to a New Nuclear System or a Fossil Fuel System.** This alternative, which applies only to nuclear power plants, utilizes the existing turbine system with a new steam supply system. The original nuclear steam supply system should be separated from the electric generating system and disposed of in accordance with one of the previous three retirement alternatives.

3. SURVEILLANCE AND SECURITY FOR THE RETIREMENT ALTERNATIVES WHOSE FINAL STATUS REQUIRES A POSSESSION-ONLY LICENSE

A facility which has been licensed under a possession-only license may contain a significant amount of radioactivity in the form of activated and contaminated hardware and structural materials. Surveillance and commensurate security should be provided to assure that the public health and safety are not endangered.

- a. Physical security to prevent inadvertent exposure of personnel should be provided by multiple locked barriers. The presence of these barriers should make it extremely difficult for an unauthorized person to gain access to areas where radiation or contamination levels exceed those specified in Regulatory Position C.4. To prevent inadvertent exposure, radiation areas above 5 mR/hr, such as near the activated primary system of a power plant, should be appropriately marked and should not be accessible except by cutting of welded closures or the disassembly and removal of substantial structures

and/or shielding material. Means such as a remote-readout intrusion alarm system should be provided to indicate to designated personnel when a physical barrier is penetrated. Security personnel that provide access control to the facility may be used instead of the physical barriers and the intrusion alarm systems.

b. The physical barriers to unauthorized entrance into the facility, e.g., fences, buildings, welded doors, and access openings, should be inspected at least quarterly to assure that these barriers have not deteriorated and that locks and locking apparatus are intact.

c. A facility radiation survey should be performed at least quarterly to verify that no radioactive material is escaping or being transported through the containment barriers in the facility. Sampling should be done along the most probable path by which radioactive material such as that stored in the inner containment regions could be transported to the outer regions of the facility and ultimately to the environs.

d. An environmental radiation survey should be performed at least semiannually to verify that no significant amounts of radiation have been released to the environment from the facility. Samples such as soil, vegetation, and water should be taken at locations for which statistical data has been established during reactor operations.

e. A site representative should be designated to be responsible for controlling authorized access into and movement within the facility.

f. Administrative procedures should be established for the notification and reporting of abnormal occurrences such as (1) the entrance of an unauthorized person or persons into the facility and (2) a significant change in the radiation or contamination levels in the facility or the offsite environment.

g. The following reports should be made:

(1) An annual report to the Director of Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545, describing the results of the environmental and facility radiation surveys, the status of the facility, and an evaluation of the performance of security and surveillance measures.

(2) An abnormal occurrence report to the Regulatory Operations Regional Office by telephone within 24 hours of discovery of an abnormal occurrence. The abnormal occurrence will also be reported in the annual report described in the preceding item.

h. Records or logs relative to the following items should be kept and retained until the license is terminated, after which they may be stored with other plant records:

- (1) Environmental surveys,
- (2) Facility radiation surveys,
- (3) Inspections of the physical barriers, and
- (4) Abnormal occurrences.

4. DECONTAMINATION FOR RELEASE FOR UNRESTRICTED USE

If it is desired to terminate a license and to eliminate any further surveillance requirements, the facility should be sufficiently decontaminated to prevent risk to the public health and safety. After the decontamination is satisfactorily accomplished and the site inspected by the Commission, the Commission may authorize the license to be terminated and the facility abandoned or released for unrestricted use. The licensee should perform the decontamination using the following guidelines:

a. The licensee should make a reasonable effort to eliminate residual contamination.

b. No covering should be applied to radioactive surfaces of equipment or structures by paint, plating, or other covering material until it is known that contamination levels (determined by a survey and documented) are below the limits specified in Table I. In addition, a reasonable effort should be made (and documented) to further minimize contamination prior to any such covering.

c. The radioactivity of the interior surfaces of pipes, drain lines, or ductwork should be determined by making measurements at all traps and other appropriate access points, provided contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement should be assumed to be contaminated in excess of the permissible radiation limits.

d. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated in excess of the limits specified. This may include, but is not limited to, special circumstances such as the transfer of premises to another licensed organization that will continue to work with radioactive materials. Requests for such authorization should provide:

(1) Detailed, specific information describing the premises, equipment, scrap, and radioactive contaminants and the nature, extent, and degree of residual surface contamination.

(2) A detailed health and safety analysis indicating that the residual amounts of materials on surface areas, together with other considerations such as the prospective use of the premises, equipment, or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

e. Prior to release of the premises for unrestricted use, the licensee should make a comprehensive radiation survey establishing that contamination is within the limits specified in Table I. A survey report should be filed with the Director of Licensing, U.S. Atomic Energy Commission, Washington, D.C. 20545, with a copy to the Director of the Regulatory Operations Regional Office having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report should:

- (1) Identify the premises;
- (2) Show that reasonable effort has been made to reduce residual contamination to as low as practicable levels;
- (3) Describe the scope of the survey and the general procedures followed; and
- (4) State the finding of the survey in units specified in Table I.

After review of the report, the Commission may inspect the facilities to confirm the survey prior to granting approval for abandonment.

5. REACTOR RETIREMENT PROCEDURES

As indicated in Regulatory Position C.2, several alternatives are acceptable for reactor facility retirement. If minor disassembly or "mothballing" is planned, this could be done by the existing operating and maintenance procedures under the license in effect. Any planned actions involving an unreviewed safety question

or a change in the technical specifications should be reviewed and approved in accordance with the requirements of 10 CFR §50.59.

If major structural changes to radioactive components of the facility are planned, such as removal of the pressure vessel or major components of the primary system, a dismantlement plan including the information required by §50.82 should be submitted to the Commission. A dismantlement plan should be submitted for all the alternatives of Regulatory Position C.2 except mothballing. However, minor disassembly activities may still be performed in the absence of such a plan, provided they are permitted by existing operating and maintenance procedures. A dismantlement plan should include the following:

- a. A description of the ultimate status of the facility
- b. A description of the dismantling activities and the precautions to be taken.
- c. A safety analysis of the dismantling activities including any effluents which may be released.
- d. A safety analysis of the facility in its ultimate status.

Upon satisfactory review and approval of the dismantling plan, a dismantling order is issued by the Commission in accordance with §50.82. When dismantling is completed and the Commission has been notified by letter, the appropriate Regulatory Operations Regional Office inspects the facility and verifies completion in accordance with the dismantlement plan. If residual radiation levels do not exceed the values in Table I, the Commission may terminate the license. If these levels are exceeded, the licensee retains the possession-only license under which the dismantling activities have been conducted or, as an alternative, may make application to the State (if an Agreement State) for a byproduct materials license.

TABLE I

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDE ^a	AVERAGE ^{b c}	MAXIMUM ^{b d}	REMOVABLE ^{b e}
U-nat, U-235, U-238, and associated decay products	5,000 dpm α /100 cm ²	15,000 dpm α /100 cm ²	1,000 dpm α /100 cm ²
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm ²	300 dpm/100 cm ²	20 dpm/100 cm ²
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1000 dpm/100 cm ²	3000 dpm/100 cm ²	200 dpm/100 cm ²
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above.	5000 dpm β - γ /100 cm ²	15,000 dpm β - γ /100 cm ²	1000 dpm β - γ /100 cm ²

^aWhere surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

^bAs used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

^cMeasurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

^dThe maximum contamination level applies to an area of not more than 100 cm².

^eThe amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

APPENDIX H

COST ESTIMATES FOR DECOMMISSIONING

Cost estimates vary considerably but will improve slowly as further study advances the quality of existing generic studies and provides information concerning the impact of site specific factors. Schwent has reported costs ranging from \$35 million to \$128.5 million for dismantlement.¹ In 1977, complete dismantlement of Three Mile Island Units I and II was estimated to cost approximately \$95 million each. Northeast Utilities' Millstone I and II were estimated at \$59 million each. San Onofre Unit I was estimated, in 1977, at \$63-\$78 million for dismantlement. Chapman, in a study for the California Energy Commission, used conventional estimates based on generic studies, but argued that estimates on the order of 25 percent of capital cost would be more reasonable.² A 1979 Edison Electric Institute survey of selected utilities revealed estimates for decommissioning, method unspecified, ranging from lows of \$10-20 million to around \$60 million.³ However, several estimates also approached \$100 million.

Clearly, estimates for rate-making purposes require thorough site specific analysis and periodic updating. Other parts of this appendix report costs estimated by generic studies and Northern States Power Company.

1. AIF STUDY COST ESTIMATES

<u>Decommissioning Method</u>	<u>Estimated Costs</u> (millions of dollars)	
	<u>1975</u>	<u>1978*</u>
Prompt dismantlement		
• nuclear facilities only	20.3	30.3
• non-radioactive facilities	6.6	9.9
Mothballing		
• preparations	2.3	3.4
• annual surveillance	.08-.167	.12-.25
Entombment		
• preparations	7.4	11.1
• annual surveillance	.058	.09
Mothballing/delayed dismantlement at 108 years		
• nuclear facilities only	13.3-21.8	20-33
Entombment/delayed dismantlement at 108 years		
• nuclear facilities only	15.2	22.7

*Notes: Estimates are for a 3411 MWt/1144 MWe pressurized water reactor (PWR). The 1975 estimates do not include a 25 percent contingency. To facilitate comparison with Battelle's estimates the second column here reports estimates inclusive of a 25 percent contingency and raised to 1978 price levels using the implicit GNP deflator (Business Conditions Digest, April 1980, p. 8, Table 1). This procedure understates actual 1978 levels if costs associated with the nuclear industry and decommissioning have risen more rapidly than the general price level. The range of costs associated with mothballing options reflects differing degrees of security and surveillance. The AIF study also estimates costs for decommissioning a 3579 MWt/1178 MWe boiling water reactor (BWR). These are slightly higher than for PWR dismantlement. The original 1975 estimates were \$26.4 million (nuclear) and \$4.8 million (non-radioactive), and in 1978 with the 25 percent contingency, they are \$39.4 million and \$7.2 million respectively. Costs for other options are roughly similar to those for a PWR. Cost reductions for dismantlement of a smaller, 550 MWe plant are 18 percent (PWR) and 20 percent (BWR).

Source: Atomic Industrial Forum (AIF), An Engineering Evaluation of Nuclear Power Reactor Decommissioning Alternatives: Summary Report. (AIF/NESP-009SR). Prepared by William J. Marion and Thomas S. LaGuardia, Nuclear Energy Services, Incorporated. (Washington D.C.: Atomic Industrial Forum; November 1976), pp. 11-14.

2. BATTELLE NORTHWEST LABORATORY COST ESTIMATES

<u>Decommissioning Method</u>	Estimated Costs (millions of dollars) <u>1978</u>
Immediate dismantlement	
• nuclear facilities only	31.0
• non-radioactive facilities	8.0
• spent fuel shipment	3.1
• deep geological storage of some decommissioning waste (potential)	2.3
Safe storage	
• preparations	9.5
• annual surveillance	.08
Safe storage/deferred dismantlement (nuclear facilities only)	
• 30 years	40.8
• 50 years	35.8
• 100 years	39.8
Entombment	
• with reactor internals	21.0
• reactor internals removed	24.7
• annual surveillance	.04
• storage to 100 years (final disposition not included)	
• with internals	25.0
• without internals	28.7

Notes: Estimates are for a 3500 MWt/1175 MWe PWR and include a 25 percent contingency factor. Costs for a BWR are expected to be roughly similar. Battelle has developed a set of scaling factors for adjusting estimates to smaller plants. Under that system, the estimated cost and percentage reductions are as follows for immediate dismantlement:

<u>Reactor (PWR's)</u>	<u>Size (MWt)</u>	<u>Cost* (millions)</u>	<u>Percent Reduction*</u>
Trojan	3500	31.0	0
Turkey Point	2550	24.5	21
R.E. Ginna	1300	16.1	48
Yankee-Rowe	600	11.3	64

*Costs do not cover spent fuel disposal or non-radioactive demolition. Similar reductions apply to other options and radiation exposures. Trojan was used for the original study.

Source: U.S. Nuclear Regulatory Commission (NRC), Technology, Safety, and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130 Addendum. Prepared by Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington. (Washington

D.C.: NRC, August 1979, section 2, p. 4, Table 2.1-2 and section 3, p. 63, Table 3.3-4.) Costs reported earlier, in Volume 2 of NUREG/CR-0130, Appendix H, are similar but lump together nuclear, non-nuclear, and spent fuel disposal costs.

3. COST ESTIMATES FOR DECOMMISSIONING NORTHERN STATES POWER (NSP) NUCLEAR PLANTS

<u>Decommissioning Method</u>	<u>Cost Estimates (millions of 1979 dollars)</u>		
	<u>Prairie Island</u>		<u>Monticello</u>
	<u>Unit 1</u>	<u>unit 2</u>	
Prompt removal/dismantlement	51.7	14.8	54.6
Total	66.5		54.6
Safe storage/entombment/delayed dismantlement (after 100 years)			
• entombment	14.0	1.7	14.5
• dormancy	9.4	3.4	9.4
• delayed dismantlement	32.1	11.6	25.6
Subtotal	55.5	16.7	
Total	72.2		49.6*

*Corrected for rounding error.

Notes: All estimates include a 25 percent contingency factor and include all plant facilities. Spent fuel removal is included as an undistributed cost. Monticello is a 545 MWe BWR. Prairie Island Units 1 and 2 are both 530 MWe PWR's and would be decommissioned sequentially.

Source: Nuclear Energy Services, Inc. (same organization that did the AIF study), Decommissioning Study of the Monticello Nuclear Generating Plant, (Revision 1), September 1979, p. 4, and Decommissioning Study of Prairie Island Generating Plant Units 1 and 2, (Revision 1), September 1979, p. 5. These studies were based on the AIF study, regional factors, and plant designs.

FOOTNOTES - APPENDIX H

1. Schwent, Vincent L., "Cost and Financing of Reactor Decommissioning: Some Considerations," draft paper 261:A:01. California Energy Commission, September 9, 1978, pp. 2-3. Also in NUREG/CP-0003, pp. 294-317.
2. Chapman, Duane, Nuclear Economics: Taxation, Fuel Cost and Decommissioning, for the California Energy Commission, A.E. Res. 79-26 (Ithaca: Cornell University, Department of Agricultural Economics, October 29, 1979), p. 51.
3. Falletich, Edward L., "Analysis of Survey on Nuclear Decommissioning and Depreciation," a paper presented to the AGA-EEI Depreciation Committee, June 25-27, 1979 (Mr. Falletich is with Detroit Edison Company, Detroit, Michigan), pp. 10-11.

APPENDIX I

RADIATION EXPOSURES AND DECOMMISSIONING

The estimates of radiation exposure to workers and the public vary. Those prepared for the Nuclear Regulatory Commission appear below. Estimates made for the Atomic Industrial Forum study were lower than those reported here. Differences arise from the degree of decontamination assumed, work procedures, and the original inventory of radiation estimated. The substantial decline in potential exposures over the first century after shutdown is largely attributable to the decay of cobalt-60. Subsequently the dose rate is dominated by niobium-94 and nickel-59 radiation.

PRINCIPAL RADIONUCLIDES

The chart below comes from the NRC study of an 1175 MWe pressurized water reactor. It shows the major sources of radiation which contribute to the radiation dose rate of the reactor core shroud at shutdown; it does not summarize the entire plant, however. The inventory of radionuclides varies with the type of material and the material's location, function, and exposure to radiation within the plant.

SELECTED CORE SHROUD RADIOACTIVITY AT REACTOR SHUTDOWN

<u>Radionuclide</u>	<u>Half-life (years)</u>	<u>Emission</u>	<u>Radioactivity (curies)</u>	<u>External Dose Rate (R/hr)</u>
⁵⁵ Fe	2.7	1β, γ	1.3 x 10 ⁶	0.11
⁶⁰ Co	5.3	β, γ	9.6 x 10 ⁵	560,000
⁹⁴ Nb	20,000	β, γ	5.4	2.0
⁵⁹ Ni	80,000	1β, γ	7.4 x 10 ²	0.09

Source: NUREG/CP-0003, p. 226 (Report based on Battelle's NRC study, NUREG/CR-0130).

OCCUPATIONAL AND PUBLIC EXPOSURES

DECOMMISSIONING ESTIMATED RADIATION DOSES

(man-rems)

<u>Mode</u>	<u>Occupational</u>		<u>Public</u>	<u>Unal- located</u>	<u>Total</u>
	<u>Decommission</u>	<u>Transport</u>			
Prompt dismantlement	1404	103	22	-	1529
Emtombment					
• with reactor internals	900	16	4	-	920
• internals removed	1000	21	4	-	1025
Safe storage and deferred dismantlement					
• preparations	426	14	3	-	-
• storage for:					
30 years				14	-
50 years				14	-
100 years				14	-
• dismantlement at:					
30 years				30	487
50 years				2	459
100 years				1	458

Source: NUREG/CR-0130, Addendum, (Battelle Northwest Laboratory), sec. 2, p. 5; the percentage of dismantlement occupational dose left after 10 years is 26.9 percent; after 30 years, 1.96 percent; and after 50 years, 0.16 percent (from Addendum, sec. 3, p. 68).

APPENDIX J

STATE ACTION ON DECOMMISSIONING FINANCING

As already pointed out, a 1977 General Accounting Office survey indicated that many utilities made no specific provisions to collect funds during the reactor's operational life to cover the future costs of decommissioning. That situation reflected several factors. Existing NRC policy on decommissioning is very ambiguous leaving a great deal of latitude to facility owners. Further, potential changes in NRC policy were uncertain then and now, in 1980, remain unclear. Also pending policy changes complicated the problem of making reasonable cost estimates, a task already open to question due to the lack of solid experience and the need for additional engineering studies. It appears, in addition, that some utilities expected to amortize the cost of decommissioning only after the expenditure.

REGULATORY ACTION

In fact, in Pennsylvania this deferred approach was required. State Superior Court rulings prevent the Pennsylvania Public Utilities (PUC) from including prospective negative salvage values in depreciation allowances.¹ It was the court's view that removal expenses should be capitalized and amortized only after the utility had incurred the cost. Despite utility petitions; the PUC, for a time, was compelled to prohibit negative salvage value depreciation.

However, in a 1978 rate case, the PUC approved annual expense allowances to collect decommissioning funds. Its decision emphasized "vital health and safety issues" and the concept that "(t)hose who now enjoy the benefits of this technology can do no less than assure that it will not impose an unreasonable financial burden on future ratepayers."

The PUC's approach excludes the costs of removing non-nuclear portions of the power plant because they entail no health and safety risks. The required funds are estimated periodically, collected annually, and invested as an annuity in tax-exempt state bonds that are held in escrow until required for decommissioning. Both the annuity and the interest earned are tax exempt. The PUC requires adjustment of the annual annuity requirement to reflect changing estimates.

Other states have not confronted this problem and instead operate on the premise that the "customer who benefits from the electricity produced by nuclear power pay(s) for all of the costs of nuclear power."² Thus even future costs such as decommissioning must be calculated and recovered in current rates.

The Wisconsin Public Service Commission (PSC) includes estimates of net salvage values in calculating annual depreciation rates for all electric generating facilities.³ The cost of decommissioning is factored in as negative net salvage in the depreciation schedule on nuclear facilities. The PSC updates cost estimates periodically.

The California Public Utilities Commission (PUC) applies straight line remaining life (SLRL) depreciation allowances that include estimates of net negative salvage values from decommissioning.⁴ Decommissioning costs, reflected in the rates, are recovered over the depreciated life of the plant. Estimates of net salvage are updated to incorporate changes.

Another California regulator, the Sacramento Municipal Utility District (SMUD) which is independent of the PUC, applies straight line total life depreciation over 30 years. However, zero salvage value is estimated, and no decommissioning funds are collected to cover any excess of costs over salvage.

The Connecticut Public Utilities Control Authority (PUCA), in a 1977 rate case, permitted Connecticut Light and Power to collect funds through depreciation charges to cover the future cost of mothballing three reactors--Millstone I and II and Connecticut Yankee.⁵ However, the PUCA also requires the company to obtain an annual bond guaranteeing the availability of decommissioning funds collected up to that point in time.

In Minnesota, Northern States Power (NSP) uses negative net salvage value depreciation over a 30 year plant life to obtain decommissioning funds.⁶ NSP operates three reactors at power plants in Minnesota--Monticello and Prairie Island (Units I and II). The original total facility cost is placed at \$567 million (in 1979 prices). NSP depreciates these plants at 110 percent of capitalized value. The extra ten percent represents the estimated excess of removal costs over salvage value and was included in depreciation rates certified by the Minnesota Public Utilities Commission in 1978. NSP retains control of the collected funds.

However, in that ruling the Commission also expressed "grave reservations" concerning the appropriateness of the cost estimates and ordered a review of

the matter. NSP commissioned an engineering study by Nuclear Energy Services, Inc. (NES, also authored the Atomic Industrial Forum generic study) and conducted an in-house economic analysis of alternative financing mechanisms and future revenue requirements. As a result NSP estimates immediate dismantlement costs at \$121.1 million (1979) for all three facilities. Additionally, the utility has requested the PUC to allow recovery of decommissioning costs through an internal sinking fund with revenues invested in utility assets. NSP would discontinue recovery through the negative salvage values now built into its depreciation rates.

The issues of cost and recovery mechanisms will continue to come before state utility regulators in the continuing effort to account for decommissioning costs in ways consistent with the financing criteria discussed in Part III. Just how much the situation has changed since the 1977 General Accounting Office study remains uncertain, although a mid-1979 survey by the Edison Electric Institute provides some indication.⁷ The survey covered twenty-one companies, together owning thirty reactors. On average, the estimated reactor service life, for depreciation purposes, was just under thirty years. The average net salvage ratio was 10.9 percent, with several estimates in excess of 20 percent and a few above 30 percent. Twenty of the twenty-one preferred cost recovery through an internal depreciation reserve. The preferred method of decommissioning varied: mothballing, 2; entombment, 2; prompt removal/dismantlement, 9; entombment with delayed removal dismantlement, 2; and no specific plans, 4. Cost estimates reported in the survey varied from low estimates of \$10-20 million to around \$60 million. However, estimates for Philadelphia Electric's facilities approach \$100 million (1979). Estimates for Consumers Power's Big Rock and Palisades plants suggest how estimates have changed over time, at least in some cases. For Big Rock, the 1974 estimate was \$2.3 million, but the proposed estimate, in 1978 prices, is \$31.4 million. For Palisades, the 1974 estimate stood at \$8.7 million, but the proposed estimate, in 1978 prices, is \$60.7 million.

OTHER STATE ACTION

State legislatures and legislative committees have also considered the decommissioning problem. Vincent Schwent, with the California Energy Commission has reviewed legislative activities on decommissioning, and the NRC staff made available a review of such activity for the authors of this report.⁸ The NRC study covers legislative actions but not regulatory actions. However, it is unclear in some cases whether proposed or implemented measures apply explicitly to reactor decommissioning or generally to those handling radioactive materials.

Tennessee authorizes the Commissioner of Public Health to require certain classes of licensees who use, store, or handle radioactive materials to post a performance bond and to contribute to a perpetual care trust fund (HB-1473, signed 3/12/76). Virginia enacted similar requirements (HB-488, signed 4/10/76). Georgia allows the Department of Human Resources to require bonds from licensees to assure the availability of funds in the event of abandonment, insolvency, or other inability of the licensee to meet Department Requirements, and the Division of Environmental Protection may require bonds for permittees of radioactive storage, concentration, or burial facilities (H-420, approved 4/16/79). Maine, in June 1979, created a special study commission on decommissioning which is scheduled to submit a comprehensive report in January 1981.

Numerous other proposals, on decommissioning funding, have been introduced over the last two years in the legislatures of several states. These range from study commissions to requirements for posting bonds equal to at least 30 percent of the decommissioning cost or 30 percent of the total capital cost of the facility. The disposition of these bills is unknown.

In relation to uranium mining and radioactive waste disposal facilities several states have enacted laws. New Mexico permits assessing a fee on yellow cake at each uranium mill to fund continuing monitoring and clean-up operations after mills close (signed 4/7/77). Arizona requires similar fees as well as posting of bonds against abandonment or default (H-2324, approved 6/4/78). Illinois requires similar fees to finance a trust fund for perpetual care of radioactive waste disposal sites (signed 9/20/77). Legislatures in Wyoming, Kansas, Washington, and Nevada have also approved monitoring fees, bonds, or perpetual care trust funds for various activities involving radioactive materials.

Legislation also has been proposed to cover funding of post-accident cost recovery or premature decommissioning. None was reported passed by the NRC review.

The difficulty with reviewing legislative activity is that the number and variety of proposals can be misleading. Few legislative proposals, on any subject, finally pass. Many do not even receive substantive hearings. Of those that pass, not all are signed by the governor. And of those signed, implementation is another hurdle to be crossed. Further, what is applicable and appropriate for one type of radiation problem, ownership and licensing, and regulatory situation may or may not be appropriate for other circumstances. Consequently, legislative "reviews" like those done by Vincent Schwent and the NRC indicate increasing legislative activity on decommissioning but must be carefully evaluated in order to identify substantive consideration and proposals.

FOOTNOTES - APPENDIX J

1. Laslavic, Tim, "Nuclear Facility Decommissioning: A Short Introductory paper," prepared for Pennsylvania Public Utility Commission (PUC) Task Force on Policy, November 8, 1978. And including PUC order in Pennsylvania Electric Company at R.I.D. 392, on 2/24/78. And in Public Utilities Fortnightly, April 26, 1979, pp. 54-56.
2. Grube, Rudolph M. and Armand R. Soucy (A Utility Viewpoint), and Eric A. Leighton (A Regulatory Viewpoint), "Financial Accounting for the back end of the nuclear fuel cycle," Nuclear News, November 1979, p. 55, see specifically p. 122 and p. 125 for the principle mentioned here. These articles provide an excellent review of some aspects of the financing issues.
3. State of Wisconsin Public Service Commission, "Advance Plans for Construction of Facilities, Findings of Fact, Conclusion of Law and Order," 05-EP-1, 8/17/78, pp. 20-21.
4. California State Task Force on Nuclear Energy and Radioactive Materials, "Radioactive Materials in California," draft report of the secretary for resources, Part V, titled "Decontamination and Decommissioning Radioactive Facilities," unpublished, June 1978.
5. Connecticut Public Utility Control Authority, Connecticut Light and Power, Docket Number 770319, 10/25/77, p. 45.
6. Minnesota Public Utilities Commission, In the Matter of the Petition of Northern States Power Company for Depreciation Certification for Expected Decommissioning Costs of the Monticello and Prairie Island Nuclear Steam Generating Facilities. Initial Brief of Applicant Northern States Power Company. August 1980. Docket Number PSC-80-139-HC; E002/D-79-956. Also, Commission Order Docket Number E-002/D-77-1068A which orders the NSP analysis.
7. Falletich, Edward L., "Analysis of Survey on Nuclear Decommissioning and Depreciation," a paper presented to the A.G.A.-EEI Depreciation Committee, June 25-27, 1979 (Mr. Falletich is with the Detroit Edison Company, Detroit, Michigan), reports the results of an Edison Electric Institute survey.
8. Schwent, Vincent L., "State Regulatory Impact on Decommissioning Financing Approaches and Their Cost," Nuclear News, April 1980, pp. 46-50, provides a lucid discussion of financing issues (also in NUREG/CP-0008, pp. 475-487); and an unpublished "Summary of State Legislation Related to Decommissioning for the Period January 1975 - present," provided by Frank Cardile, staff, U.S. Nuclear Regulatory Commission.

GLOSSARY

Selected abbreviations, acronyms, terms, and definitions related to nuclear energy and directly related to decommissioning work are defined and explained in this section. The first part contains abbreviations and acronyms, and the second part contains terms and definitions.

ABBREVIATIONS AND ACRONYMS

AFRs	away from reactor sites
AIF	Atomic Industrial Forum
ALARA	as low as reasonably achievable
BWR	boiling water reactor
Ci	curie
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GAO	General Accounting Office
HLW	high level waste
HTGR	high temperature gas reactor
IRG	Interagency Review Group on Nuclear Waste Management (U.S. Department of Energy)
LWR	light water reactor
mr	milliroentgen
mrad	millirad
mrem	millirem, see rem also
MWe	megawatts, electric (roughly one-third of MWt)
MWt	megawatts, thermal
NRC	Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development
PIRG	Public Interest Research Group
PWR	pressurized water reactor
R	roentgen
rad	radiation absorbed dose
rem	roentgen equivalent man
SNM	special nuclear material
VDEW	West German Association of Power Stations

DEFINITIONS

Activity:	Sometimes used for the term "radioactivity."
Airborne radioactive material:	Radioactive particulates, mists, fumes, and/or gases in air.
ALARA:	A philosophy to maintain exposure to radiation <u>as low as is reasonably achievable</u> .
Cask:	A heavily shielded shipping container for radioactive materials. Some casks weigh as much as 100 tons.
Containment building:	A strongly reinforced structure that encloses the nuclear steam supply system. Also called reactor building.
Contamination:	Radioactive material or materials that have been deposited on the surfaces of structures or equipment or that have been mixed with another material.
Curie:	The special unit of activity. One curie equals 3.7×10^{10} nuclear transformations per second. (Abbreviated Ci.) Several fractions of the curie are in common usage: <ul style="list-style-type: none">• millicurie. One-thousandth of a curie. Abbreviated mCi.• microcurie. One-millionth of a curie. Abbreviated μCi.• nanocurie. One-billionth of a curie. Abbreviated nCi.• picocurie. One-millionth of a microcurie. Abbreviated pCi; replaces the term $\mu\mu$c.
Decay, radioactive:	A spontaneous nuclear transformation in which a particle, gamma radiation or x radiation is emitted following orbital electron capture or spontaneous fission of the nucleus.
Dose, absorbed:	The mean energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad equals 0.01 Joules/kilogram in any medium (100 ergs per gram).
Dose, equivalent:	Expresses the amount of effective radiation in man, in rems, when modifying factors have been considered. The product of absorbed dose multiplied by a quality factor multiplied by a distribution factor.

Dose, occupational: The exposure of an individual to radiation above background as imposed by his employment.

Dose, radiation: As commonly used, it is the quantity of radiation absorbed in a unit mass of a medium, frequently a human organ.

Dose rate: The radiation dose delivered per unit time and measured, for instance, in rems per hour.

Exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

Half-life, radioactive: The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Each radionuclide has a unique half-life. Measured half-lives vary from millionths of a second to billions of years.

Man-rem: Used as a unit measure of radiation dose for a population and calculated by summing the dose equivalent in rems received by each person in the population. Also, it is used as the absorbed dose of one rem by one person with no rate of exposure inferred.

Maximum-exposed individual: A hypothetical individual in the general population who is located at the point of highest ground-level concentration of radioactive materials and is subject to the greatest concentration of the radioactive materials that are discharged from the plant.

Millirad: A unit of absorbed dose (one-thousandth of a rad).

Milliroentgen: A submultiple of the roentgen, equal to one-thousandth of a roentgen. (See roentgen.)

Possession-only license: A license issued to a nuclear facility owner by the NRC entitling the licensee to own a nuclear facility but not operate it.

Primary coolant system: The system that confines the coolant that transports heat from the reactor fuel to the steam generators. It includes the reactor vessel, pressurizer, pumps and piping, and the steam generators.

Rad: The unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradi-

ated material at the place of interest. One rad equals 0.01 Joules/kilogram of absorbing material.

- Radiation 1) The emission and propagation of radiant energy; for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves. 2) The energy propagated through space or through a material medium; for example, energy in the form of alpha, beta, and gamma emissions from radioactive nuclei.
- Radioactive material: Any material or combination of materials which spontaneously emits ionizing radiation and which has a specific activity in excess of 0.002 microcuries per gram of material. (49 CFR 173.389(e).)
- Radioactivity: The property of certain nuclides of spontaneously emitting particles or gamma radiation or of emitting x radiation. Often shortened to "activity."
- Radioactivity, induced: Radioactivity produced in a substance after bombardment with neutrons or other particles. The resulting radioactivity is "natural radioactivity" if formed by nuclear reactions occurring in nature, and "artificial radioactivity" if the reactions are caused by humans.
- Regulatory Guides: Regulatory guides are issued to describe and make available to the public methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide other guidance to applicants for nuclear operations. Guides are not substitutes for regulations and compliance with them is not explicitly required. Methods and solutions different from those set out in the guides are acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the NRC.
- Rem: A unit of radiation dose equivalent. "Dose equivalent" means the absorbed dose in rads multiplied by appropriate factors to account for differences in biological effectiveness (or impact) due to the quality of radiation (e.g. its type and energy level) and its spatial distribution in the body. The term "rem" stands for roentgen equivalent man. (One millirem or mrem = 0.001 rem.)
- Remote maintenance: Maintenance by remote means, i.e. the human is separated by a shielding wall from the item being maintained.

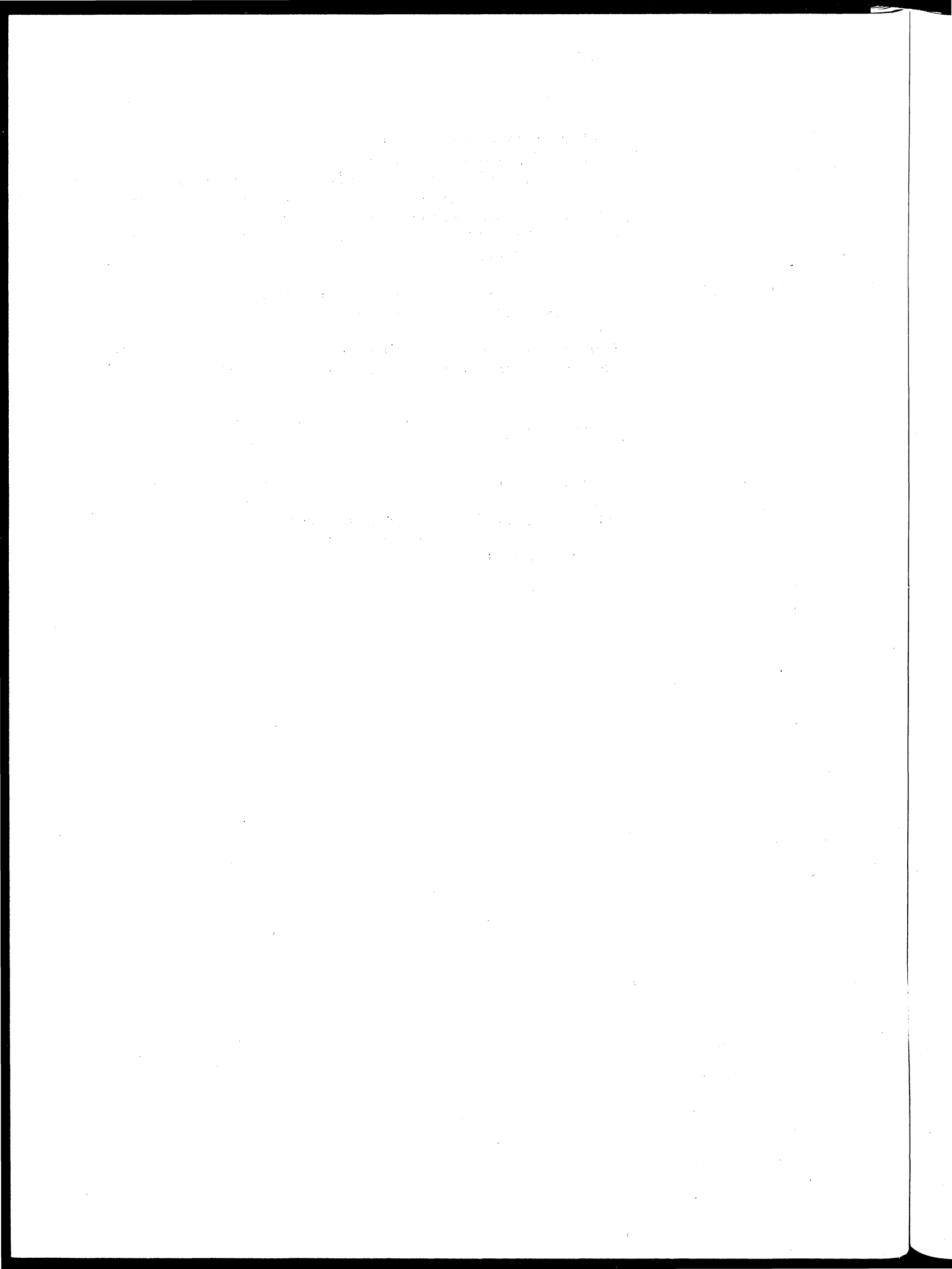
Roentgen: A unit of exposure to ionizing radiation. It is that amount of gamma or x rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions. One roentgen equals 2.58×10^{-4} coulombs per kilogram of air. (See also exposure.)

Short-lived radio-nuclides: For this study, those radioactive isotopes with half-lives less than about ten years.

Special nuclear material: Plutonium, uranium enriched in the isotope 233 or 235, and any other material as defined in 10 CFR 51 by the NRC.

Spent fuel: Nuclear fuel that has been removed from the reactor for disposal.

Transuranic: Transuranic elements all have atomic numbers higher than uranium (which is 92) in the periodic table. All are unstable, decaying radioactively, with half-lives that range from fractions of a second to tens of millions of years.



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