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Revised Analyses of Decommissioning for the Reference Boiling Water Reactor Power Station

Effects of Current Regulatory and Other Considerations on the Financial Assurance Requirements of the Decommissioning Rule and on Estimates of Occupational Radiation Exposure

Main Report

Draft Report for Comment

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ABSTRACT

On June 27, 1988, the U. S. Nuclear Regulatory Commission (NRC) published in the Federal Register (53 FR 24018) the final rule for the General Requirements for Decommissioning Nuclear Facilities. With the issuance of the final rule, owners and operators of licensed nuclear power plants are required to prepare, and submit to the NRC for review, decommissioning plans and cost estimates. The NRC staff is in need of updated bases documentation that will assist them in assessing the adequacy of the licensee submittals, from the viewpoint of both the planned actions, including occupational radiation exposure, and the probable costs. The purpose of this reevaluation study is to update the needed bases documentation.

This report presents the results of a review and reevaluation of the PNL 1980 decommissioning study of the Washington Public Power Supply System's Washington Nuclear Plant Two (WNP-2) which is a boiling water reactor (BWR), located at Richland, Washington, including all identifiable factors and cost assumptions which contribute significantly to the total cost of decommissioning the plant for the DECON, SAFSTOR, and ENTOMB decommissioning alternatives. These alternatives now include an initial 5-7 year period during which time the spent fuel is stored in the spent fuel pool prior to beginning major disassembly or extended safe storage of the plant.

This report also includes consideration of the NRC requirement that decontamination and decommissioning activities leading to termination of the nuclear license be completed within 60 years of final reactor shutdown, consideration of packaging and disposal requirements for materials whose radionuclide concentrations exceed the limits for Class C low-level waste (i.e., Greater-Than-Class C). Costs for labor, materials, transport, and disposal activities are given in 1993 dollars. Sensitivities of the total license termination cost to the disposal costs at different low-level radioactive waste disposal sites, to different depths of contaminated concrete surface removal within the facilities, and to different transport distances are also examined. Although not considered as a decommissioning expense under the current NRC regulatory framework , an estimate of the costs for demolition of the non-radioactive structures and for restoration of the site to a natural state is included in this report for informational purposes.

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EXECUTIVE SUMMARY

In the 1976 to 1980 time frame, two studies were carried out for the U.S. Nuclear Regulatory Commission (NRC) by the Pacific Northwest Laboratory (PNL) to examine the technology, safety, and costs of decommissioning large reference nuclear power reactor plants. Those studies (NUREG/CR-0130 [PWR] and NUREG/CR-0672 [BWR]) reflected the industrial and regulatory situation of the time. While the cost estimates from those reports were escalated to 1986 dollars in subsequent addenda reports, the technical and regulatory bases for the analyses remained as developed in the original studies. Many things have changed since 1980 that strongly influence when and how power reactors can best be decontaminated and decommissioned and how much that effort will cost.

With the publication of the Decommissioning Rule on June 27, 1988, in the Federal Register (FR 24018), owners and/or operators of licensed nuclear power plants are required to prepare and submit plans and cost estimates for decommissioning their facilities to the NRC for review. These submittals are reviewed by the NRC staff for adequacy of decommissioning planning and for reasonableness of the estimated cost of decommissioning the facilities, to assure that the work will be carried out in compliance with applicable regulations and to assure that sufficient money will have been accumulated in the plant's decommissioning fund to pay the costs of the decontamination and license termination activities.

The purpose of this study is to reevaluate the estimates of costs and radiation doses associated with license termination activities for the reference boiling water reactor (BWR) power station, in light of today's conditions. Included in this reevaluation was an examination of the range of parameters that influence costs and radiation doses. The results of this reevaluation provide much of the bases documentation needed by the NRC staff to perform their reviews of the adequacy and reasonableness of the licensee submittals, and will provide the basis for revising the funding certification amounts currently specified in 10 CFR 50.75(c).

The major factors considered in this reevaluation of the estimated costs and schedules for license termination at the reference BWR are:

- the demise of the spent nuclear fuel (SNF) reprocessing industry in the U.S., and the delays being encountered by the federal waste management system in its attempts to establish interim storage facilities and permanent disposal facilities for SNF, with the resultant accumulation of large inventories of SNF at the reactors by the time of shutdown
- the requirement promulgated by the U.S. Department of Energy (DOE) that the SNF must be cooled in the reactor pools for at least five years before it can be placed into dry storage, necessitating pool operation for at least five years following final reactor shutdown
- the difficulties being encountered by the regional waste compacts in siting regional low-level radioactive waste (LLW) disposal facilities has resulted in rapid and large increases in the costs of LLW disposal at existing disposal facilities, with even higher disposal rates forecast for future LLW disposal facilities.

These factors have combined to redefine the possible schedules and to increase the costs of the viable decommissioning alternatives.

DEFINITION OF DECOMMISSIONING ALTERNATIVES

In the original studies, three alternatives were defined for analysis: DECON (decontamination/dismantlement as rapidly after reactor shutdown as possible, to achieve termination of the nuclear license); SAFSTOR (a period of safe storage of the stabilized and defueled facility, followed by final decontamination/dismantlement and license termination); and ENTOMB (immediate removal of the highly activated reactor vessel internals for disposal, with the remainder of the radioactively contaminated materials relocated to within the reactor containment building which is then sealed. Upon sufficient passage of time, the radioactivity on the entombed materials must have decayed sufficiently to permit termination of the nuclear license).

The basic concept of the three alternatives remains unchanged. However, because of the accumulated inventory of SNF in the reactor storage pool and the requirement for at least five years of pool storage for the SNF before transfer to dry storage, the timing and steps in the process for each alternative have been adjusted to reflect present conditions and possibilities. For the DECON alternative, it is assumed that the owner has a strong incentive to decontaminate and dismantle the retired reactor facility as promptly as possible, thus necessitating transfer of the stored SNF from the pool to a dry storage facility on the reactor site. While continued storage of SNF in the pool is acceptable, the Part 50 license could not be terminated until the pool had been emptied, and only limited amounts of decontamination and dismantlement of the facility would be accomplished. It is also assumed that an acceptable dry transfer system will be available to remove the SNF from the dry storage facility and place it into licensed transport casks when the time comes for DOE to accept the SNF for disposal. Similar assumptions are made for the SAFSTOR and ENTOMB alternatives for convenience of analysis, even though extended use of the spent fuel pool might be more cost-effective for SAFSTOR. For the purpose of this study:

- DECON is comprised of four distinct periods of effort, 1) pre-shutdown planning/engineering and regulatory reviews, 2) plant deactivation and preparation for storage, 3) a period of plant safe storage with concurrent operations in the spent fuel pool until the pool inventory is zero, and 4) decontamination and dismantlement of the radioactive portions of the plant, leading to license termination. Because of the ongoing delays in development of the federal waste management system, it may be necessary to continue operation of a dry fuel storage facility on the reactor site beyond when the reactor systems have been dismantled and the Part 50 license terminated. However, these latter storage costs are presently considered operations costs, and are not chargeable to reactor license termination costs.

- SAFSTOR is comprised of five distinct periods of effort, with the initial three periods being identical with those of DECON. The fourth period of SAFSTOR is extended safe storage (< 60 years), without any fuel in the reactor storage pool, and the fifth period is decontamination and dismantlement of the radioactive portions of the plant.

  For SAFSTOR1, it is assumed that all of the radioactive materials in the stored facility except the reactor pressure vessel and the sacrificial shield will have decayed to unrestricted release levels by the end of the storage period, permitting license termination after removal of the activated reactor pressure vessel and sacrificial shield for disposal as LLW.

  For SAFSTOR2, it is assumed that all of the materials that were radioactive originally still exceed unrestricted release levels and are removed for disposal as LLW.

- ENTOMB is also comprised of five distinct periods of effort, with the initial three periods being identical with those of DECON. The fourth period is preparation for entombment, when all of the radioactive materials are consolidated within the Reactor Building and entombed. The fifth period is entombed storage for an extended time.

For ENTOMB1, the entombment period and the nuclear license continue until all of the contained radioactivity has decayed to unrestricted release levels. This period could be as short as 60 years or as much as 300 years after reactor shutdown, during which time the contained radioactivity decays sufficiently to reach unrestricted release levels, and permit termination of the nuclear license.

For ENTOMB2, it is assumed that those radioactive materials that won't decay to unrestricted release levels by the end of the entombment period, i.e, the activated reactor pressure vessel and the sacrificial shield, are removed for disposal during the preparations period, thus assuring unrestricted release of the entombed contents by 60 years after reactor shutdown.

For ENTOMB3, the entombment period of ENTOMB1 is extended from 60 years to 300 years, and no final radiation survey is required for license termination.

For all alternaives, unrestricted release of the facilities and site means that the residual radioactivity on the site is less than the limits specified in Regulatory Guide 1.86.

EVALUATION OF DECON, SAFSTOR, AND ENTOMB FOR THE REFERENCE BWR

Each of the decommissioning alternatives described above has been evaluated for the reference BWR (WNP-2 Nuclear Plant, an 1155-MW_e General Electric reactor) in terms of estimated cost, schedule, waste volumes disposed, and estimated radiation dose to the decommissioning workers. The DECON alternative is evaluated in detail, over all periods of effort. Because of the similarity of the first three periods of effort in all three alternatives, the SAFSTOR and ENTOMB alternatives are evaluated by examining principally just those efforts that replace or are in addition to the efforts previously evaluated for DECON, i.e., the effect of radioactive decay on the cumulative radiation dose received by workers, the potential reduction in the volumes of radioactive waste generated during the deferred decontamination and dismantlement period of SAFSTOR, and the reduced volumes of radioactive waste requiring disposal resulting from ENTOMB.

These analyses reflect the fact that the reference BWR is a single reactor facility, and the assumption that the low-level radioactive wastes are transported from the reference BWR location at Hanford, Washington, to the U.S. Ecology facility on the Hanford Reservation in Washington, for disposal. All costs are given in constant dollars of early 1993, regardless of when the expenditures occur in time. The results of the analyses of DECON, SAFSTOR, and ENTOMB for the reference BWR are summarized briefly in Table ES.1.

TABLE ES.1. Results of DECON, SAFSTOR, and ENTOMB Analyses

Alternative	Estimated Cost (millions 1993 \$)(a,b) (Constant \$)	(Present Value \$)(c)	Waste Volume Disposed (m^3)	Radiation Dose (person-rem)	Post-Shutdown (years)
DECON	158.2	133.6	14,282	962.5	6.3
SAFSTOR1(d)	224.3	121.6	1,117	558.2	60
SAFSTOR2(e)	303.1	134.2	14,282	567.9	60
ENTOMB1(f)	224.6	151.9	490	600.7	60
ENTOMB2(g)	228.8	155.2	1,139	665.3	60
ENTOMB3(h)	630.5	164.5	490	600.7	300

(a) Values are in constant early 1993 dollars, and include a 25% contingency.
(b) Highly activated pressure vessel internals removed in all alternatives. Wastes transported to and disposed of in the U.S. Ecology facility at Hanford, WA.
(c) See discussion on page xxv.
(d) Assumes only the reactor pressure vessel and sacrificial shield require disposal as LLW.
(e) Assumes all material originally radioactive is assumed to still exceed unrestricted release levels. No LLW volume reduction from DECON.
(f) Assumes no removal of the reactor pressure vessel or sacrificial shield. Nuclear license is continued for as long as necessary for the contained radioactivity to decay to unrestricted release levels. Costs are based on completion by 60 years after reactor shutdown, but annual costs (\$1.34 million/yr) would continue until the license is terminated.
(g) Assumes removal of the reactor pressure vessel and sacrificial shield required during preparations for entombment to assure license termination within 60 years following reactor shutdown.
(h) Assumes the reactor pressure vessel and sacrificial shield have decayed to unrestricted release levels, and the detailed termination survey is not required following 300 years of decay.

It is important to remember that, because the NRC's responsibility for the radiological health and safety of the public ends when the facility and site have been decontaminated to unrestricted release levels, the costs, waste volumes, radiation doses, and durations given in Table ES.1 reflect only the efforts necessary to achieve termination of the nuclear license. The costs of demolition of the decontaminated structures and restoration of the site to an undisturbed (green field) condition, and the costs of operating the spent fuel storage pool and/or an independent spent fuel storage installation (ISFSI), are not included when defining the amount of money the NRC requires to be placed in the plant's decommissioning fund. For this reason, the costs presented in Table ES.1 are significantly less than the amount an investor-owned utility might ask for in a rate request to its Public Service Commission to cover the total cost of plant decommissioning. Additional cost elements that might be included in the total cost of decommissioning a retired reactor facility are: structures demolition and site restoration activities, which could increase the total decommissioning cost as much as $50 million or more, depending upon the situation at the plant location; and continued operation of the spent fuel pool until the SNF inventory is reduced to zero, which is estimated to cost about $7 million per year (in 1993 dollars) and could add another $43 million or more.

The bases used in these analyses have been incorporated into a user-friendly computer program, the Cost Estimating Computer Program (CECP), to assist the NRC staff in their reviews of the reasonableness of the license termination cost estimates submitted by licensees with their decommissioning plans, as required by NRC regulations. The program can accommodate different reactor sizes and cost bases that vary from location to location, and can be used to examine the sensitivity of the cost estimate to changes in the various parameters used in the analysis, i.e., local labor rates, disposal facility charge rates, distances for waste transport, depth of contaminated concrete surface removed, length to which piping segments are cut, etc.

SENSITIVITY OF THE RESULTS TO CHANGES IN ANALYSIS ASSUMPTIONS

Examination of the major cost elements of decommissioning shows that, aside from the undistributed (overhead) costs, the cost of disposal of low-level radioactive waste is the principal contributor to the license termination costs. For comparison, the transport and disposal costs associated with disposal of LLW from DECON and SAFSTOR2 in the Chem-Nuclear facility at Barnwell, SC, are shown in Table E.2 together with the costs for transport and disposal of the LLW in the U.S. Ecology facility at Richland, WA. The sensitivity of the total decommissioning costs to transport distance (15 miles vs 500 miles) is also examined, for the case of disposal at the U.S. Ecology facility.

The license termination costs for Barnwell disposal are increased by about $148 million, or about 92% greater than for Hanford disposal. Assuming a 500-mile transport distance with Hanford disposal increases the total decommissioning cost by about $2.4 million. Similar cost differences may well

TABLE ES.2. Comparison of Costs for Transport and Disposal of LLW Resulting from DECON and SAFSTOR2 for Two Disposal Sites[(a)]

		Estimated Costs in Millions of 1993 Dollars		
		Richland	Barnwell	Difference (Barnwell - Richland)
DECON:	Transport	1.4	8.0	6.6
	Disposal	43.2	183.8	140.6
	Total	44.6	191.8	147.2
SAFSTOR2:	Transport	1.4	8.0	6.6
	Disposal	42.8	183.8	141.0
	Total	44.2	191.8	147.6

(a) All values are in constant early 1993 dollars, and include a 25% contingency.

arise for future disposal at any of the yet-to-be-developed LLW disposal facilities in the other waste compact areas.

A brief study was carried out to examine the sensitivity of DECON costs to increased base rates at the U.S. Ecology disposal facility at Richland, using the CECP. The calculations were performed for base disposal rates of $50/ft^3, $100/ft^3, $300/ft^3, $500/ft^3, and $1000/ft^3. The associated disposal facility fees, surcharges, and taxes were held constant. All other parameters of the CECP calculation were also held constant. The results of the analysis showed that the total cost for DECON increased almost linearly with increased disposal cost, from $167.68 million for the $50/ft^3 rate to $805.22 million for the $1000/ft^3 rate, all values including a 25% contingency.

The fractions of cost attributable to labor and materials (A), energy (B), and LLW disposal (C), and the adjusted DECON cost (total DECON cost minus property taxes and nuclear insurance) employed in the formula for DECON cost escalation, as discussed in Section 3.7, are illustrated in Figure ES.1 as functions of the LLW disposal charge rates.

As the disposal rates increase, the incentive for volume reduction efforts increases, and it is likely that the LLW disposal costs would not increase in direct proportion to the disposal rate increases due to the probable LLW volume reductions. However, because the disposal facilities must have sufficient revenue to cover fixed costs, it is also likely that the disposal charge rates will tend to increase as the volume-reduction efforts by the waste generators reduce the annual receipts at the disposal facilities.

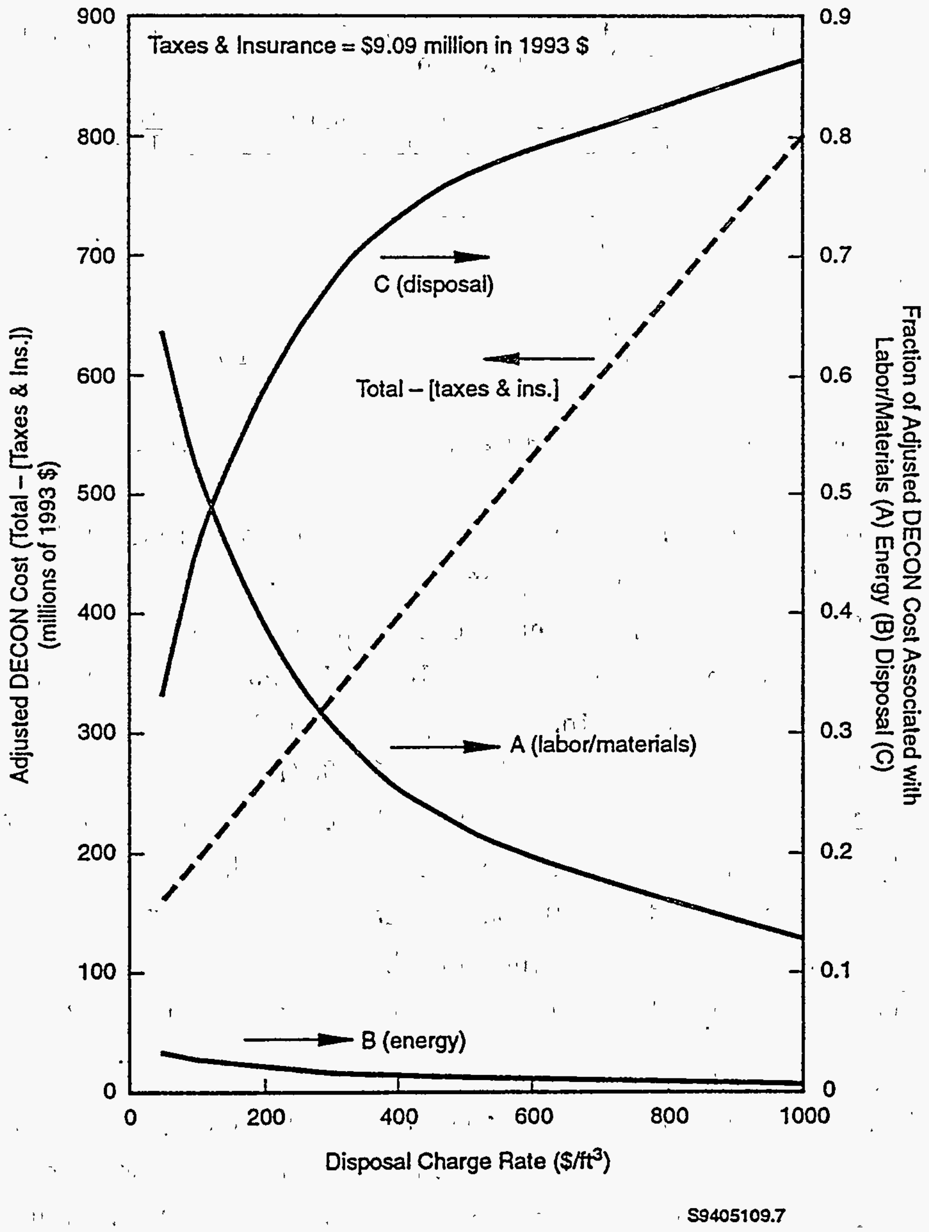

FIGURE ES.1. Variation of DECON Escalation Formula Terms as Functions of Low-Level Waste Disposal Charge Rates

The net effect of these interactions on future LLW disposal costs cannot be predicted with any great certainty, except one can be assured that disposal costs are unlikely to decrease over time.

Another factor affecting license termination cost is the amount of contaminated concrete surface removed during facility decontamination. In the original BWR study (NUREG/CR-0672), the very conservative assumption was made that a 2-inch depth of concrete surface was removed from about 21,800 ft^2 of the floors in the three potentially contaminated buildings (Reactor, Turbine Generator, and Radwaste/Control buildings). In this reevaluation study, the base assumption is to remove a 1-inch depth of surface from those same areas anticipated to require surface removal. The 1-inch depth may also be quite conservative, considering data on contaminant penetration of concrete surfaces given in NUREG/CR-4289. Thus, an analysis of the sensitivity of DECON license termination costs to a range of concrete surface removal depths was performed. The calculation assumed that the length of Period 4 was constant, i.e., constant overhead staff costs, because the concrete surface removal effort is carried out in parallel with other activities on the decontamination and dismantlement schedule.

The results are illustrated in Figure ES.2. The license termination cost is not very sensitive to the depth of concrete removed. For removal depths from 0 in. to 1.0 in., the total DECON cost increases by less than $0.8 million.

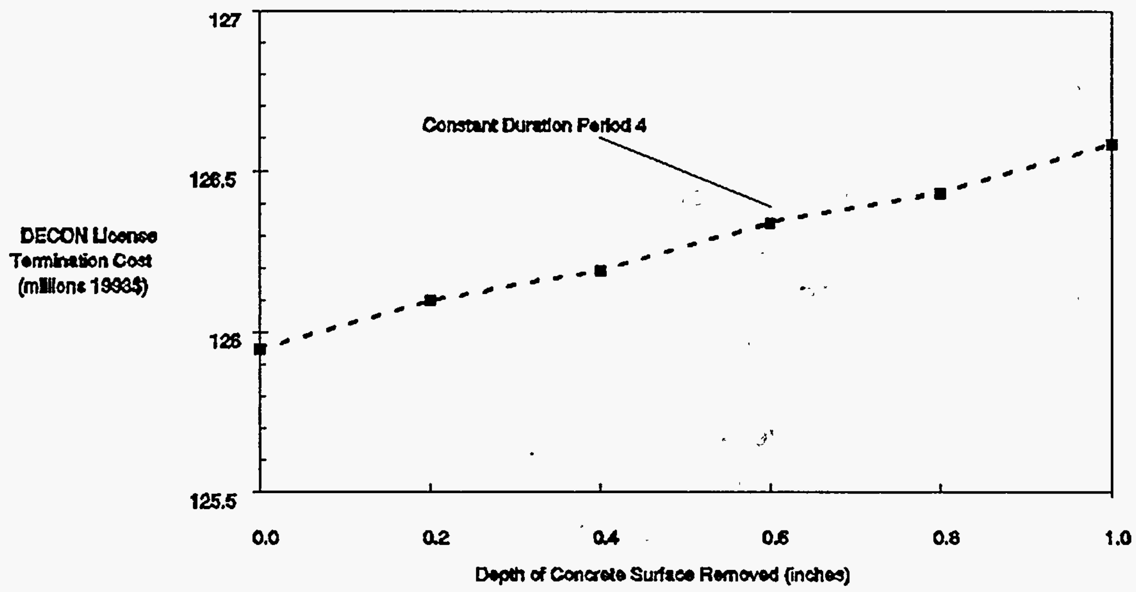

FIGURE ES.2. Sensitivity of License Termination Cost to Varying Depths of Contaminated Concrete Removal During DECON

Another sensitivity analysis was performed to examine the effect on the cost of DECON of cutting the contaminated piping into shorter (5-ft) segments, as compared with the nominal 15-ft segments postulated in this reevaluation. Only the assumed length of piping pieces after cutting was changed for this analysis. It was assumed that more cutting crews were deployed so that the duration of the decontamination and dismantlement period (Period 4) of DECON remained constant. As would be expected when tripling the number of cutting operations, the direct labor costs for pipe removal increased about $12.3 million, including contingency. Because the volume of dry active waste, the amount of laundry used, and the quantity of small tools and equipment used are factored from the direct labor hours, the costs associated with these cost elements also increased, by about $2.8 million. Thus, the increase in the total DECON cost resulting from cutting the piping into 5-ft lengths instead of the 15-ft lengths postulated in the base analysis was about $15.1 million, including a 25% contingency.

Associated with the increased number of pipe cutting operations was an increase in the worker radiation dose. Because pipe cutting tends to be performed in higher radiation fields than many other DECON activities, the cumulative radiation dose to workers more than doubled, from 963 person-rem for the base analysis (15-ft pipe lengths) to 1,561 person-rem for the sensitivity case (5-ft pipe lengths).

The license termination costs associated with each of the decommissioning alternatives (DECON, SAFSTOR, ENTOMB) can be influenced by whether the reactor being decommissioned is on a single-reactor or a multiple-reactor site. While no analyses of these possible impacts were performed during this study, a fairly exhaustive study of these effects was reported in NUREG/CR-1755, and some qualitative statements can be made. Because costs are affected, the choice of alternatives may be influenced. For example, the security staff represents a major segment of the overhead costs, especially during a period of safe storage. With another operating reactor on the site, those costs can be assigned almost entirely to the operating plant, thus greatly reducing the safe storage costs and making it a more attractive alternative. Similarly, the availability of another reactor fuel storage pool on the site may make it possible to transfer the spent fuel inventory from the shutdown reactor to the operating reactor's pool, thus releasing the facility for final decontamination and demolition earlier than would otherwise be possible. A careful analysis of all of the interacting factors would be necessary to arrive at the optimum choice of decommissioning alternative for a particular site situation.

THE EFFECT OF THE TIME-VALUE OF MONEY ON SHUTDOWN FUNDING REQUIREMENTS

All of the analyses in this reevaluation of the costs of decommissioning the reference BWR are conducted using constant dollars, i.e., a dollar spent 10 years from now is just as valuable as a dollar spent today. Because unspent money can earn interest until spent, and inflation can diminish the value of money over time, it is useful to examine the present value of future expenditures (see Section 3.5.2 for details), taking into account the net discount rate (interest rate minus inflation rate) to be applied to future expenditures when estimating the amount of money the licensee needs to have in its decommissioning fund at the time of reactor shutdown. The expenditures required to complete license termination activities for DECON, SAFSTOR, and ENTOMB are distributed over time periods ranging from about 8 years to a maximum of 300 years. The present value of those expenditures, assuming a net discount rate of 3% per year, are: $133.6 million for DECON; $121.6 million for SAFSTOR1 and $134.2 million for SAFSTOR2; and $151.9 million, $155.2 million, and $164.5 million with license termination at 60, 60, and 300 years, for ENTOMB1, ENTOMB2, and ENTOMB3, respectively. The present values of the distributed expenditures are compared in Figure ES.3.

All of the decommissioning scenarios have present values that fall in the range of $121 to $165 million, with SAFSTOR1 being the smallest and ENTOMB3 being the largest. Discount rates greater than the 3% per year assumed in these calculations would favor the delayed dismantlement scenarios. Because the differences between the present values of the alternatives in this analysis are not large, the present value cost would not be a strong discriminator for selecting a decommissioning alternative.

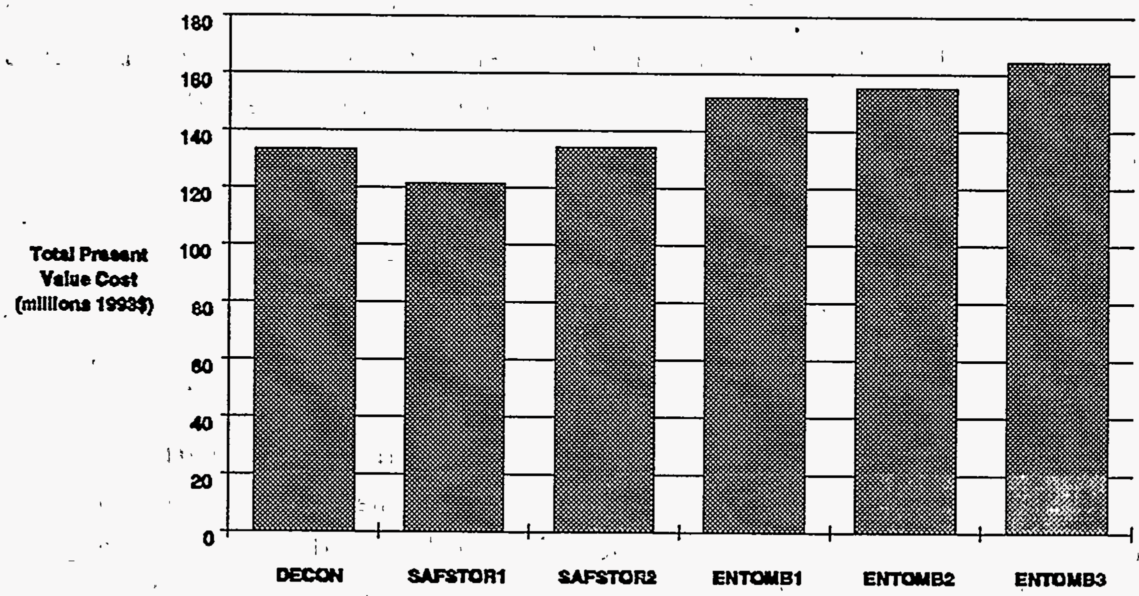

FIGURE ES.3. Comparison of Present Values of Decommissioning Alternatives

The costs associated with SNF storage on-site until acceptance into the federal waste management system are also examined using a present-value analysis. The cost for extended pool storage was compared with a 5-year pool storage followed with dry storage in casks. Because of the large capital expenditure required by purchase of the storage casks, the pool plus casks scenario does not become cost-effective (considering only SNF storage costs) until about 13 years following reactor shutdown. The results of these calculations are illustrated in Figure D.2, in Appendix D.

CONCLUSIONS

The changes in the industrial and regulatory situation in the U.S. since the late 1970s have forced revisions to the viable scenarios of the original studies decommissioning alternatives, DECON, SAFSTOR, and ENTOMB. The principal effect is the delay of major decommissioning actions for at least 5 years following reactor shutdown due to the need to store SNF in the reactor pool for that period of time, and a resulting increase in decommissioning costs accumulated during the short safe storage period while the SNF pool continues to operate.

Review of the constant dollar costs and the present value costs for the three alternatives suggests that while DECON is the least expensive choice in constant dollars, it is about equivalent to the SAFSTOR scenarios in present value. ENTOMB is also about equivalent to the DECON and SAFSTOR scenarios in both constant dollar cost and present value cost. Considering the relatively small spread of present value costs for all alternatives, it appears that present value cost would not be a strong discriminator for choosing a decommissioning alternative. Having about $140 to $150 million accumulated in the decommissioning fund at 2½ years before final shutdown would appear to be sufficient to cover any of the alternatives examined in this reevaluation study.

The radioactive wastes generated during DECON can be classified into Class A, Class B, Class C, and Greater-than-Class C (GTCC), in accordance with the criteria given in 10 CFR 61.55. The volumes of each category of LLW estimated to result from DECON are listed below.

Class A: 492,570 ft^3, 13,903 m^3 (97.35%)
Class B/C: 13,152 ft^3, 372 m^3 (2.60%)
GTCC: 242 ft^3, 6.9 m^3 (0.05%)

The LLW volumes generated during the decommissioning vary significantly between the various alternatives and within alternatives, depending upon the scenarios. For DECON, all of the radioactive materials are removed, resulting in a relatively large volume (14,282 m^3) of LLW requiring disposal.

For the SAFSTOR1 scenario, if decay of all radioactive materials (except the reactor pressure vessel and sacrificial shield) to unrestricted release levels is assumed, the SAFSTOR LLW volume is reduced from that of DECON to about 1,117 m^3. With similar assumptions, the LLW disposal volume for the ENTOMB2 scenario is smaller than that of the SAFSTOR1 scenario, or about 1,139 m^3. The LLW disposal volume for the SAFSTOR2 scenario (14,282 m^3) is approximately the same as DECON, since all of the originally radioactive materials are assumed to be removed following storage. For ENTOMB1 and ENTOMB3, the reactor pressure vessel and sacrificial shield are assumed to be left in-place until decayed to unrestricted release levels. The resulting LLW volume for disposal (490 m^3 for ENTOMB1) is much smaller than for DECON

($14,282\ m^3$). Considering the costs of LLW disposal, and the uncertainty associated with future disposal costs and availability, LLW volume reduction might be a strong discriminator favoring ENTOMB. However, the ability of SAFSTOR1 to achieve license termination within 60 years may out-weigh the reduction in LLW volume achievable with ENTOMB1, making SAFSTOR1 the more desirable alternative. On the other hand, if the facility owner could deal with maintaining institutional control of the site for 300 years following reactor shutdown, the 300-year ENTOMB3 scenario would eliminate future concerns about LLW disposal altogether.

However, the current decommissioning regulations require completion of decommissioning within 60 years unless there is a compelling reason to extend that period for the purpose of protecting the health and safety of the public. As a result, the ENTOMB3 scenario is outside the regulatory framework as it currently exists but does provide an additional reference base for informational purposes.

Although not required to satisfy the regulatory requirement for releasing a site for unrestricted use and terminating the license for decommissioning purposes, an analysis of the costs for demolition of the non-radioactive structures and for the restoration of the site to a natural state is included in the report for informational purposes. These costs are estimated to be about $48.5 million for the WNP-2 facility, including a 25% contingency. These results are very specific to the WNP-2 plant and site. Demolition and site restoration costs could be significantly different at other sites, depending upon many local factors.

FOREWORD

In 1988, the Nuclear Regulatory Commission (NRC) issued regulations related to the decommissioning of nuclear facilities. The decommissioning regulations were based in part on information gathered previously for light water reactors (LWRs) to support rulemaking activities. Since the issuance of the decommissioning regulations, more information on decommissioning has been released to warrant a reexamination of the initial study results.

This draft report for public comment contains information concerning a reevaluation of the reference boiling water reactor (BWR) decommissioning study and its addendums used to support the decommissioning regulations. It uses the latest information available on the technology, safety, and cost estimates to decommission a large reference BWR. A companion draft document reevaluating the reference pressurized water reactor (PWR) decommissioning costs was published earlier (NUREG/CR-5884 Draft for Comment). Completion of the two reports will be used to provide the NRC an information data base on decommissioning costs for LWRs. Based on the results of the studies and public input, the NRC will determine if amendments to the decommissioning regulations are warranted.

Any interested party may submit comments on this report for consideration by the staff. To be certain of consideration, comments on this report must be received by the due date published in the Federal Register Notice. Comments received after the due date will be considered to the extent practical. Comments may be submitted to the Rules Review and Directives Branch, Division of Freedom of Information and Publication Services, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Further technical information can be obtained from George J. Mencinsky, Division of Regulatory Applications, Office of Nuclear Regulatory Research, Mail Stop T-9 C24, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Telephone (301) 415-6206.

This report is not a substitute for NRC regulations, and compliance is not required. The approaches and/or methods described in this NUREG/CR are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

Cheryl Trottier for

Donald A. Cool, Chief
Radiation Protection and Health Effects Branch
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Office of Nuclear Regulatory Research

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1.0 INTRODUCTION

In the 1976 to 1980 time frame, two studies were carried out for the U.S. Nuclear Regulatory Commission (NRC) by the Pacific Northwest Laboratory[a] to examine the technology, safety, and costs of decommissioning large reference nuclear power reactor plants. Those studies, NUREG/CR-0130[1] and NUREG/CR-0672[2] for a pressurized water reactor (PWR) and a boiling water reactor (BWR), respectively, reflected the industrial and regulatory situation of the time. While the cost estimates from the BWR reports were escalated to 1987 dollars in subsequent addenda reports,[3-7] the technical and regulatory bases for the analyses remained as developed in the original studies. Many things have changed since 1980 that have a strong influence on when and how power reactors can best be decontaminated and decommissioned and on how much the effort will cost.

With the publication of the Decommissioning Rule in June 1988, owners and/or operators of licensed nuclear power plants are required to prepare and submit plans and cost estimates for decommissioning their facilities to the NRC for review. These submittals are reviewed by NRC staff for adequacy of decommissioning planning and for reasonableness of the estimated cost of decommissioning the facilities, to assure that the work will be carried out in compliance with applicable regulations and to assure that sufficient money will have been accumulated in the plant's decommissioning fund to pay the costs of decontamination and license termination activities.

The purpose of this study is to provide current bases for evaluation of the reasonableness of decommissioning cost estimates and radiation doses associated with BWR license termination activities provided to the NRC by licensees and to reassess the basis for the minimum funding amounts required in 10 CFR Part 50 for financial assurance, in light of today's conditions.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

For completeness, an estimate has also been developed for the costs of demolition of the decontaminated structures and for the restoration of the site to a natural state.

1.1 MAJOR FACTORS CONSIDERED IN THIS STUDY

The major factors considered in this reevaluation of the estimated costs and schedules for license termination at the reference BWR are:

- The demise of the spent nuclear fuel (SNF) reprocessing industry in the U.S., and the delays being encountered by the federal waste management system in its attempts to establish interim storage facilities and permanent disposal facilities for SNF, with the resultant accumulation of large inventories of SNF at the reactors by the time of shutdown.
- The requirement that the SNF must be cooled in the reactor pool for at least five years before it can be placed into dry storage, necessitating pool operation for at least five years following final reactor shutdown. Alternatively, the fuel could be left in the pool until it has been accepted into the federal waste management system. However, this latter choice would delay final decontamination and decommissioning of the reference BWR until that time. This latter alternative was not evaluated in this study.
- The difficulties being encountered by the regional waste compacts in siting regional low-level radioactive waste (LLW) disposal facilities has resulted in rapid and large increases in the costs of LLW disposal at the two remaining disposal facilities, with even higher disposal rates forecast for future LLW disposal facilities.

The above factors have combined to redefine the possible schedules and to increase the costs of the viable decommissioning alternatives examined in this report.

The major study bases and assumptions used in this reevaluation study are presented in Chapter 2. They must be carefully examined before the results can be applied to a different facility, since they can have major impacts on the issues of decommissioning safety, cost, and time.

It is important to remember that, because the NRC's responsibility for the radiological health and safety of the public ends when the facility and site have been decontaminated to unrestricted release levels, the costs, waste volumes, radiation doses, and durations given in this reevaluation <u>only</u>

address the efforts necessary to achieve termination of the nuclear license. The costs of demolition of the decontaminated structures and restoration of the site to an undisturbed (green field) condition are not presently included when defining the amount of money the NRC requires to be placed in the plant's decommissioning fund. For this reason, the decommissioning costs presented in this study are significantly less than the amount an investor-owned utility might ask for in a rate request to its Public Service Commission to cover the total cost of plant decommissioning. Structures demolition, site restoration, and removal of any excess retired large components (e.g., low-pressure turbine rotors, moisture separator reheater tube bundles, etc.) could increase the total decommissioning cost by an additional $100 million or more, depending upon the situation at the plant location. In addition, operation of the spent fuel pool during SAFSTOR would incur surveillance and maintenance costs of about $7 million per year until all SNF had been removed from the pool.

1.2 DECOMMISSIONING ALTERNATIVES

In the original BWR studies, three generic alternatives were chosen for analysis: DECON (decontamination/dismantlement as rapidly after reactor shutdown as possible, to achieve termination of the nuclear license); SAFSTOR (a period of safe storage of the stabilized and defueled facility, followed by final decontamination/dismantlement and license termination); and ENTOMB (the radioactively contaminated materials are relocated to within the reactor containment building which is then sealed). Upon sufficient passage of time, the radioactivity on the entombed materials has decayed sufficiently to permit termination of the nuclear license). In all alternatives, the highly activated reactor vessel internals are removed and packaged for storage during facility deactivation.

Because of the accumulated inventory of SNF in the reactor storage pool and the requirement for at least five years of pool storage for the SNF before transfer to dry storage, details of the original alternatives have been modified to reflect present conditions and possibilities:

- DECON is comprised of four distinct periods of effort, 1) pre-shutdown planning/engineering and regulatory reviews, 2) plant deactivation and preparation for storage, 3) a period of plant safe storage with concurrent operations in the spent fuel pool until the pool inventory is zero, and 4) decontamination and dismantlement of the radioactive portions of the plant, leading to license termination. Because of the ongoing delays in development of the federal waste management system, it may be necessary to continue operation of a dry fuel storage facility on the reactor site beyond when the reactor systems have been dismantled and the reactor nuclear license terminated. However, these latter storage costs are presently considered operations costs, and are not part of reactor decommissioning costs.

- SAFSTOR is comprised of five distinct periods of effort, with the initial three periods being identical with those of DECON. The fourth period of SAFSTOR is extended safe storage (< 60 years), with no fuel in the reactor storage pool, and the fifth period is decontamination and dismantlement of the radioactive portions of the plant.

  SAFSTOR1 assumes that all of the radioactive materials in the stored facility except the reactor pressure vessel and the concrete bioshield will have decayed to unrestricted release levels by the end of the storage period, permitting license termination after removal and disposal of the activated reactor pressure vessel and concrete bioshield.

  SAFSTOR2 assumes that all of the materials that were radioactive originally still exceed unrestricted release levels and are removed for disposal as LLW.

- ENTOMB is also comprised of five distinct periods of effort, with the initial three periods being identical with those of DECON. The fourth period is preparation for entombment, when all of the radioactive materials are consolidated within the Containment Building and entombed. The fifth period is extended entombed storage.

  ENTOMB1 assumes that the entombment period and the nuclear license continue until all of the contained radioactivity has decayed to unrestricted release levels, some time beyond 60 years after reactor shutdown. The costs for ENTOMB1 are based on license termination at 60 years after reactor shutdown.

  ENTOMB2 assumes that those radioactive materials that do not decay to unrestricted release levels by the end of the entombment period, i.e., the activated reactor pressure vessel and the concrete biological shield, are removed for disposal during the preparations period, thus assuring unrestricted release of the entombed contents by 60 years after reactor shutdown.

- ENTOMB3 differs from ENTOMB1 only in that the entombment period continues for 300 years after reactor shutdown. The costs for ENTOMB3 are based on license termination at 300 years after reactor shutdown.

Each of the above decommissioning alternatives has been evaluated for the reference BWR[b] in terms of estimated cost, schedule, waste volumes disposed, and estimated radiation dose to the decommissioning workers. The DECON, SAFSTOR, and ENTOMB alternatives are evaluated, over all periods of effort in Chapters 3, 4, and 5, respectively. In all cases except ENTOMB3, decommissioning operations are completed within 60 years following final reactor shutdown, as required by current regulations. The effects of radioactive decay on the estimated cumulative radiation dose received by workers and the potential reduction in the volumes of radioactive waste generated during the deferred decontamination and dismantlement of SAFSTOR, and the reduced volumes of radioactive waste requiring disposal resulting from ENTOMB, are quantified.

These analyses reflect the fact that the reference BWR is a single-reactor facility, with no other reactors on the site, and the assumption that the low-level radioactive wastes are transported from the reference BWR location at Richland, Washington, to the U.S. Ecology facility on the Hanford Reservation in Washington for disposal. All costs are given in constant dollars of early 1993, regardless of when the expenditures occur in time.

The sensitivities of license termination costs to: 1) transporting to and disposing of decommissioning wastes at the Chem-Nuclear facility at Barnwell, South Carolina; 2) increased disposal charge rates at an LLW disposal facility; 3) cutting contaminated piping into 5-ft lengths rather than the nominal 15-ft lengths postulated for the basic analysis; 4) removing varying depths of contaminated concrete surface throughout the plant; and 5) increased cost of transporting the LLW 500 miles instead of 15 miles, are quantified. The effect of differences between single- and multiple-reactor sites on selection of decommissioning alternatives is discussed. In addition, the effect of the time-value of money (present value analysis) on the amount of money needed in the plant's decommissioning fund at the time of reactor

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(b) The Washington Public Power Supply System's (WPPSS) Washington Nuclear Plant Two (WNP-2), at Richland, Washington, is used as the reference BWR power station for this reevaluation study, just as it was used in the earlier studies. WNP-2 is an 1155 MW(e) single-reactor power station that utilizes a nuclear steam supply system with a direct-cycle boiling water reactor manufactured by the General Electric Company. WNP-2 has a Mark II containment. The analyses contained in this report assume that the WNP-2 plant has operated for the full term of its license.

shutdown to assure fully-funded license termination efforts is examined.

1.3 ORGANIZATION OF THE REPORT

The analyses and results are contained in Volume 1 (Main Report). The detailed data supporting Volume 1 are contained in Volume 2 (Appendices). The supporting data are presented in a manner that facilitates their use for examining decommissioning actions other than those included in this study.

1.4 REFERENCES

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5. R. I. Smith, G. J. Konzek, E. S. Murphy, and H. K. Elder. 1985. Updated Costs for Decommissioning Nuclear Power Facilities. EPRI NP-4012, Electric Power Research Institute Report by Pacific Northwest Laboratory, Richland, Washington.

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7. G. J. Konzek and R. I. Smith. 1990. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station - Comparison of Two Decommissioning Cost Estimates Developed for the Same Commercial Nuclear Reactor Power Station. NUREG/CR-0672, Addendum 4, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2.0 APPROACH, BASES, AND ASSUMPTIONS

This chapter contains a description of the study approach, bases, and assumptions used in this study. It should be noted that the results are based on specific bases and assumptions, and that different approaches, bases, or assumptions could potentially lead to significantly different results.

2.1 STUDY APPROACH

The initial effort in conducting the reevaluation study is a thorough review of the earlier reference boiling water reactor (BWR) decommissioning studies, NUREG/CR-0672 and addenda.[1-5] Those studies are reexamined and reevaluated in this study to reflect current conditions.

Predecommissioning conditions for the plant and site are reviewed (and updated, as required), including residual radionuclide inventories, radiation dose rates, and radioactive contamination levels. Related regulatory guidance is reviewed, summarized, and used as an aid and basis in this reevaluation study.

Current methods for nuclear facility decommissioning are reviewed and the methods specified in this reevaluation study are selected, as was done in the original studies, on the basis of engineering judgment, while maintaining a balance of safety and cost. For each of the selected decommissioning alternatives, tasks and task schedules are developed to conceptually decommission the reference facility by using the methods specified.

A principal step in planning for decommissioning is the development of site-specific engineering cost estimates for the alternatives of decommissioning available to the facility. The basic method for determining the site-specific efforts required for the selected decommissioning alternatives developed in this study is the unit cost factor method. This method, coupled with the plant-specific inventory of components, piping, and structures, provides a demonstrable basis for establishing reliable cost estimates, resulting in a reasonable degree of confidence in the reliability of the cost estimates. The unit cost factors are developed on a unit productivity basis (e.g., labor hours per contaminated floor drain removed, etc.). By inclusion of the appropriate labor rates for the respective crafts, material costs, and equipment purchase or rental rates, this method permits rapid estimation of costs on a per unit basis. The cost per item is then multiplied by the number of items to provide an engineering cost estimate. The unit cost factors utilized in this study are presented in detail in Appendix C. They are intended to be representative of current technology.

The various safety aspects of decommissioning (e.g., accidents, accidental releases, industrial safety, transportation safety, etc.) presented in NUREG/CR-0672 were reviewed and it was concluded that the safety analyses presented in that original BWR study still encompass the spectrum of possibilities, and no additional safety analyses need be performed for this study.

The major factors considered in this reevaluation of the estimated costs and schedules for license termination at the reference BWR are the delays being encountered by the federal waste management system in its attempts to establish interim storage facilities and permanent disposal facilities for spent nuclear fuel (SNF) and other high-level radioactive wastes, the requirement that the SNF must be cooled in the reactor pools for at least 5 years before it can be placed into dry storage, and the difficulties being encountered by the regional waste compacts in siting regional low-level radioactive waste (LLW) disposal facilities. The latter issue has resulted in rapid and large increases in the costs of LLW disposal at the two remaining disposal facilities. These factors have combined to redefine the possible schedules and to increase the costs of the viable decommissioning alternatives.

The need to cool the SNF in the pool until the heat emission rate is sufficiently low to avoid cladding failures in dry storage results in a change in the decommissioning planning base. Although only considered to the extent of being a scheduling constraint, the inclusion of this issue in the estimates presented in this reevaluation study for the postulated decommissioning alternatives (DECON, SAFSTOR, and ENTOMB) results in major differences from the earlier estimates of both costs and doses. The principal effect is the delay of major decommissioning actions for at least 5 years following reactor shutdown due to the need to store SNF in the reactor pool for that period of time, and a resulting accumulation of decommissioning costs during the short safe storage period while the SNF pool continues to operate. Thus, this change in the planning time base required a reoptimization of decommissioning activity schedules and sequences, staff loadings, and shift schedules, to minimize the cost and radiation dose over the longer decommissioning period.

The question of whether the costs associated with the storage of the spent fuel after final shutdown are operating expenses or whether they are chargeable as decommissioning costs has not been resolved. For purposes of this study, however, estimates of those costs are included, based on the assumption that 90% of the total plant operations costs are assigned to the pool SNF storage operations (not included in decommissioning costs), and the remaining 10% is assigned to plant safe storage operations (included in decommissioning costs).

The decision made for this study to remove the SNF from the pool as early as possible and place it into a dry storage facility onsite was made to facilitate the earliest possible decontamination and dismantlement of the reactor facility. It should not be inferred from this study decision that continued storage of the SNF in the reactor spent fuel pool is unacceptable. In many situations, continued pool storage may be the most cost-effective approach. However, continued pool storage would permit neither early decontamination and dismantlement of the reactor facility nor early termination of the Part 50 license.

Once the reference facility is reviewed in sufficient detail (including the radiation dose rates and radionuclide inventories at final shutdown) and the radioactive material packaging and disposal requirements are defined, the analyses for DECON, SAFSTOR, and ENTOMB proceed in the following manner:

- define the decontamination and sectioning requirements for each piece of contaminated equipment or material
- determine the amenable method and resultant time of sectioning, including applicable work difficulty factors
- specify the staff required to perform the tasks
- determine the schedule and sequence of the tasks
- calculate the resultant costs and occupational radiation exposure of the tasks.

In addition, the following selected sensitivity analyses are performed in this reevaluation study:

- The effect on total decommissioning costs of transporting to and disposing of the LLW resulting from DECON at the Chem-Nuclear facility at Barnwell, South Carolina, as compared with shipping to and disposing of the LLW resulting from DECON in the U.S. Ecology facility at Richland, Washington. The sensitivity of assuming a 500-mile transport distance (instead of 15 miles) from the reference BWR (WNP-2) to the U.S. Ecology facility is also examined.
- The effect on total decommissioning costs of increased disposal charge rates at an LLW disposal facility, for charge rates ranging from $50/ft^3 to $1000/ft^3.
- The effect on total decommissioning costs of cutting the contaminated piping into 5-ft lengths versus the nominal 15-ft lengths postulated for the basic reevaluation analysis.
- The effect on total decommissioning costs of removing a range of depths of contaminated concrete surfaces.

2.2 STUDY BASES AND ASSUMPTIONS

The purpose of this study is to provide current bases for evaluation of the reasonableness of decommissioning cost estimates and radiation doses associated with BWR license termination activities provided to the NRC by licensees and to reassess the basis for the minimum funding amounts required in 10 CFR Part 50 for financial assurance, in light of today's conditions. The study bases are established for all aspects to ensure that the objective is achieved.

Applicable bases presented in NUREG/CR-0672[1] for decommissioning the reference BWR power station (WNP-2)[a] are used as the point of reference for developing decommissioning costs and occupational radiation exposure in this reevaluation study. For ease of reference, the original bases are

(a) The Washington Public Power Supply System's (WPPSS) WNP-2 nuclear plant, on the Hanford Reservation at Richland, Washington, is used as the reference BWR power station for this reevaluation study, just as it was used in the earlier studies. WNP-2 is an 1155-MW(e) single-reactor power station that utilizes a boiling water reactor manufactured by the General Electric Company in the nuclear steam supply system. The analyses contained in this report assume that the WNP-2 plant has operated for the full term of its license, in order to be representative of large BWRs in general.

presented below, together with new bases developed for this reevaluation study.

- The study must yield realistic and up-to-date results. This primary basis is a requisite to meeting the objective of the study, and provides the foundation for most of the other bases.

- The study is conducted within the framework of the existing regulations and regulatory guidance. No assumptions are made regarding what future regulatory requirements or guidance might be. It is recognized that future regulations could have significant impacts on the methods and results of this study.

- The study evaluates an existing single-reactor facility (WNP-2), with no other nuclear facilities onsite at the start of decommissioning; thus, no support from shared facilities is assumed. This is required to meet the NUREG/CR-0672 objectives and the primary basis stated earlier. (Decommissioning a multiple-reactor site may be quite different, as delineated in NUREG/CR-1755.[6, 7])

- WNP-2's current operating license expires in CY-2013, based on a 40-year license period, beginning with the start of construction. The Energy Information Administration's (EIA's) projected year of final shutdown for the WNP-2 plant is CY-2024. This license end-date used by the EIA assumes that the 40-year licensing period began at the start of commercial operation of the WNP-2 plant, not at the start of construction.[8] The EIA's shutdown date of CY-2024 is used throughout this study for the purpose of developing decommissioning schedules.

- The plant operates for 30 effective full-power years.

- The shutdown radiation dose rates used in the analyses remain essentially unchanged from those estimated in the original study, NUREG/CR-0672, which, in turn, were based on conservative estimates of the effectiveness of the chemical decontamination of the plant systems. The rate at which radiation levels diminish with time during the decommissioning efforts is assumed to be controlled by the half-life of ^{60}Co.

- The radiation dose rates assumed allowable for unrestricted release are as given in Regulatory Guide 1.86.

- The methods used to accomplish decommissioning utilize presently available technology; i.e., the results do not depend on any breakthroughs or advances in present-day technology.

- Sufficient funds are available as necessary to complete the planned activities without fiscal constraint.

- A low-level radioactive waste disposal facility is in operation. The existence of an operable disposal facility is requisite to all decommissioning alternatives. Incremental costs for disposal of Greater-than-Class C material at a Federal Deep Geological Disposal Facility are estimated, even though such a repository does not currently exist. The disposal costs associated with mixed wastes are not estimated, since a repository does not currently exist for them, and no estimates for disposal costs at some future mixed waste disposal facility are available.

- The ultimate costs of disposal of accumulated low-level wastes onsite at final shutdown are assumed to be operational costs, since they were incurred during operation of the plant. Potentially, such wastes could include old steam generators and/or other large-volume components.

- When concrete surface removal is deemed necessary because of radioactive contamination, those surfaces are removed to a depth of 1 inch.

- The waste disposal costs presented in this study were specifically developed for the reference BWR, which is located within the Northwest Compact. For reactors not located within the Northwest Compact, the waste disposal costs could be increased by as much as a factor of three or four, depending on whether or not the waste generator is located within the compact for that site.

- For decommissioning activities immediately following plant shutdown, the staff is drawn largely from the operating personnel of the station, who are very familiar with the facility and its systems. However, the staff required to decommission the reference plant are assumed to be drawn primarily from an offsite contractor, a Decommissioning Operations Contractor (DOC). The cost estimates presented in this reevaluation study assume that the utility contracts with a DOC, based on the assumption that most utilities do not have the work force available and in some instances, the expertise to manage the complete decommissioning operation.

- Decommissioning radiation protection philosophies and techniques conform to the principle of keeping occupational radiation doses As Low As is Reasonably Achievable (ALARA).

- The physical plant description and radioactive materials inventories used in this reevaluation study are identical, insofar as possible, to those used in the previous BWR decommissioning study and addenda.

- It is assumed that only insignificant amounts of asbestos (block insulation and asbestos cement) are present in the reference plant itself, although the exact quantity is not known. It is further assumed that programs are in place at the reference plant to replace asbestos insulation with non-asbestos insulation in the course of normal system and equipment modification work, such that any significant amount of asbestos in the radioactively contaminated areas of the facility will have been removed by the time of decommissioning.

- The demolition and site restoration costs given in NUREG/CR-0672 were not reevaluated, because these actions are <u>not</u> required for license termination.

- Per 10 CFR Part 961, Appendix E,[9] SNF is broadly classified into three categories - standard fuel, nonstandard fuel, and failed fuel. Most, if not all, SNF from the reference BWR is assumed to fall into the standard fuel category. Standard fuel requires a minimum cooling time of 5 years before acceptance by DOE, to avoid potential cladding failure during dry storage. However, depending on the irradiation history and characteristics of a given fuel assembly (i.e., burnup, cooling time, initial enrichment), pool cooling for more than 5 years may be necessary before long-term dry storage can be permitted,

- A licensed system is available for dry transfer of SNF and packaged GTCC from the onsite dry storage facility into transport casks.

- All costs are given in constant dollars of early 1993.

In addition, the bases used in these analyses have been incorporated into a user-friendly, cost-estimating computer program (CECP),[b] to assist the NRC staff in their reviews of the reasonableness of the license termination cost estimates submitted by licensees with their decommissioning plans, as required by the Decommissioning Rule. The program can accommodate different reactor sizes, cost bases that vary from location to location, and can be used to examine the sensitivity of the cost estimate to changes in the various parameters used in the analysis.

The study bases have major impacts on the issues of decommissioning safety, cost, and time. Many aspects of decommissioning may change from plant

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(b) This computer program, designed for use on an IBM personal computer or equivalent, was developed for estimating the cost of decommissioning light-water reactor power stations to the point of license termination. Such costs include component, piping and equipment removal costs; packaging costs; decontamination costs; transportation costs; burial volumes and costs; and manpower staffing costs. Using equipment and consumables costs and inventory data supplied by the user, the program calculates unit cost factors and then combines these factors with transportation and burial cost algorithms to produce a complete report of decommissioning costs. In addition to costs, the program also calculates person-hours, crew-hours and exposure person-hours associated with decommissioning. Data for the reference BWR were used to develop and test the program. (See Appendix C for details.)

to plant, depending on each specific facility design, shutdown conditions, and residual contamination levels. The bases used in this reevaluation study must therefore be carefully examined before the results can be applied to a different facility. For example, the license termination costs associated with each of the decommissioning alternatives (DECON, SAFSTOR, ENTOMB) can be influenced by whether or not the reactor being decommissioned is on a single-reactor or a multiple-reactor site. While no analyses of these possible impacts were performed during this study, a fairly exhaustive study of these effects was reported in NUREG/CR-1755, and some qualitative statements can be made. Because costs are affected, the choice of alternatives may be influenced. For example, the security staff represents a major segment of the overhead costs, especially during a period of safe storage. However, with the SNF removed from the pool and moved to an onsite ISFSI, the security requirements for the reactor facility are greatly reduced and a significant reduction in security costs attributable to decommissioning might be realized.

With another operating reactor onsite, the security costs can be assigned almost entirely to the operating plant, thus greatly reducing the safe storage costs and making it a more attractive alternative. Similarly, the availability of another reactor fuel storage pool onsite may make it possible to transfer the spent fuel inventory from the shutdown reactor to the operating reactor's pool, thus releasing the facility for final decontamination and demolition earlier than would otherwise be possible. A careful analysis of all of the interacting factors would be necessary to arrive at the optimum choice of decommissioning alternative for a particular site situation.

From the aforementioned major study bases and assumptions, more specific bases and assumptions are derived for specific study areas. These specific bases and assumptions are presented in their respective report sections.

2.3 REFERENCES

1. H. D. Oak, G. M. Holter, W. E. Kennedy, Jr., and G. J. Konzek. 1980. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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9. Code of Federal Regulations, Title 10, Part 961, "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste," Superintendent of Documents, GPO, Washington, D.C., 20402, January 1, 1989.

3.0 DECON FOR THE REFERENCE BWR POWER STATION

The principal alternative considered in this reevaluation of the cost and radiation dose resulting from decommissioning of the reference boiling water reactor (BWR) is DECON. For these analyses, a decommissioning operations contractor (DOC) is assumed to be contracted approximately 2½ years prior to reactor shutdown to develop the plans and procedures to be carried out during decommissioning. The reactor and associated systems are postulated to be shut down and deactivated for a period of safe storage, which continues only until all of the spent nuclear fuel (SNF) has been removed from the spent fuel storage pool. Fuel from the last core is postulated to have to remain in the pool for almost 5 years after shutdown until it is sufficiently cooled to permit dry storage, at which time the fuel remaining in the pool is transferred into an existing dry fuel storage facility onsite. The spent fuel pool and the transport cask handling facilities required to support the spent fuel pool operations are maintained in service, since acceptance of SNF by the U.S. Department of Energy's Office of Civilian Radioactive Waste Management (DOE-OCRWM) is expected to continue during that period. Once the pool has been emptied, the pool-related systems are deactivated and active dismantlement begins, continuing until the total reactor facility has been decontaminated to unrestricted release levels.

The many activities required to arrive at the condition permitting unrestricted release of the facility and termination of the Part 50 possession-only license (POL) are discussed in this chapter, approximately in their order of occurrence, together with estimates of cost and occupational radiation dose associated with those activities. These decommissioning activities are postulated to occur within four designated periods of time, as illustrated by the schedule shown in Figure 3.1. The estimated costs and radiation doses accumulated during these periods are summarized briefly in Table 3.1, with more details in subsequent sections of this chapter. The pre-decommissioning engineering and planning operations that occur in Period 1 are discussed in Section 3.1. The Period 2 activities associated with plant deactivation, chemical decontamination, reactor pressure vessel internals removal, and

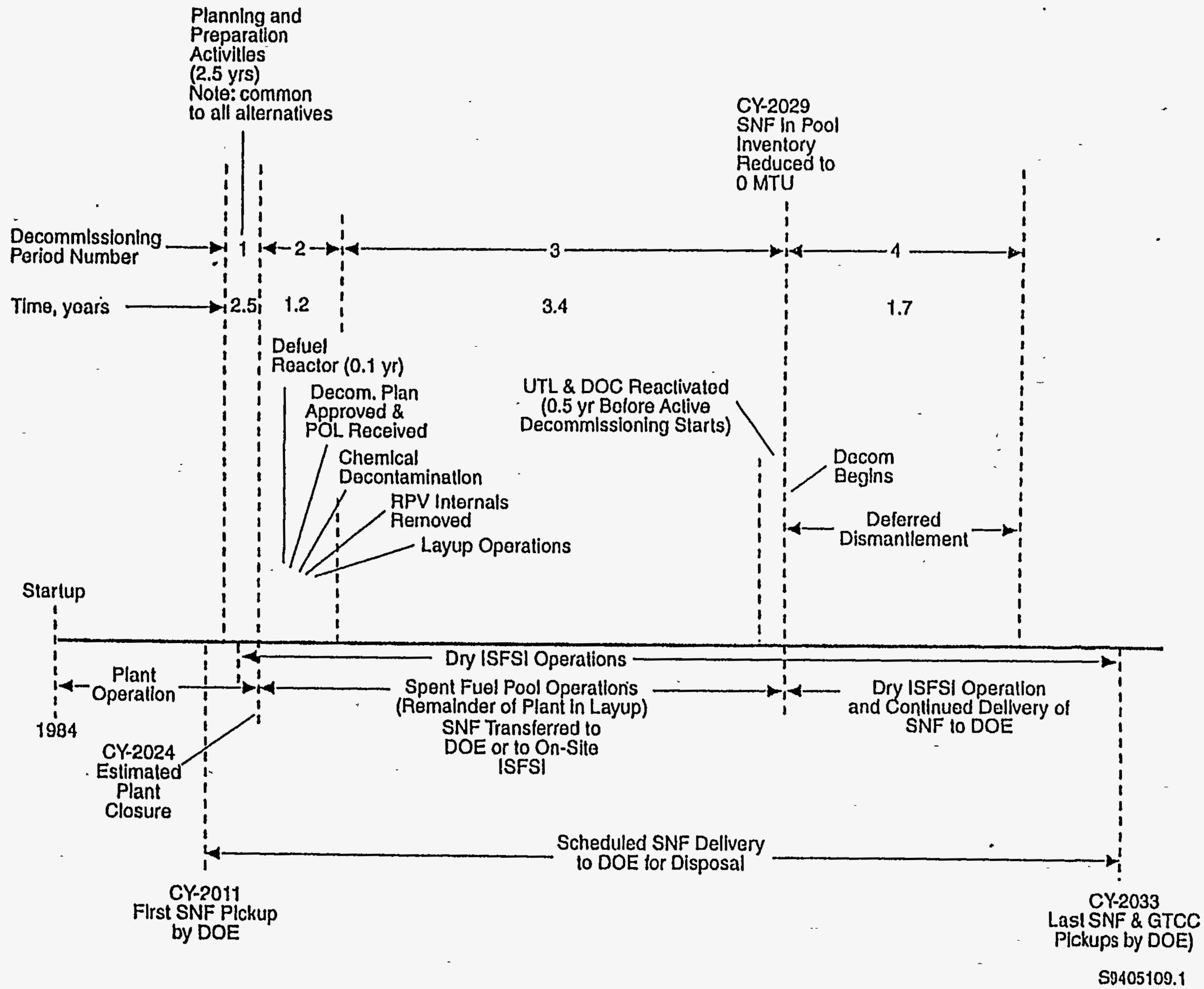

FIGURE 3.1. Schedule of Activities During the Four Periods of DECON

TABLE 3.1. Summary of Estimated Costs and Radiation Doses During the Four Periods of DECON

Period Number	Duration (years)	Estimated Cost (Millions 1993 $) Decon[a]	Remove[b]	Package[c]	Transport[d]	Disposal[e]	Undistributed[f]	Total	Estimated Radiation Dose (person-rem)
1	2.5	--	--	--	--	--	9,459,241	9,459,241	--
2	1.2	13,256,628	890,902	139,631	789,697	3,450,631	22,301,563	40,829,051	424.61
3	3.4	--	--	--	--	--	4,594,011	4,594,011	10.27
4	1.7	782,266	10,810,527	3,140,987	306,635	31,132,967	25,531,428	71,704,809	527.60
Subtotal	8.8	14,038,894	11,701,429	3,280,618	1,096,332	34,583,597	61,886,243	126,587,112	962.48
							25% Contingency	31,646,778	
							Total	158,233,890	

(a) Includes direct decommissioning labor and materials for chemical decontamination of systems, cleaning of surfaces, and waste water treatment.
(b) Includes direct labor and materials costs for removal of systems and components.
(c) Includes direct costs of waste disposal packages.
(d) Includes cask rental costs and transportation costs.
(e) Includes all costs for disposal at the LLW disposal facility.
(f) Includes all costs that are period-dependent, e.g., DOC mobilization/demobilization, utility and DOC overhead staff, nuclear insurance, regulatory costs, plant power usage, taxes, laundry services, environmental monitoring.

systems layup are discussed in Section 3.2. The Period 3 activities, comprised of safe storage of the laid-up plant, SNF pool storage operations, and subsequent ramp-up of DOC activities prior to the start of active decommissioning operations, are discussed in Section 3.3. The many activities associated with dismantlement that occur in Period 4 are discussed in Section 3.4. The estimated utility staffing and costs for the four decommissioning periods and for the concurrent three SNF storage periods are summarized in Table 3.2. Similarly, the estimated DOC staffing and costs for the 1st, 3rd and 4th decommissioning periods are summarized in Table 3.3. Sensitivity of the decommissioning costs to the location of the disposal facility and to the time-value of money is discussed in Section 3.5, and the quantities of low-level waste (LLW) generated are classified into Classes A, B, C, and greater than Class C in Section 3.6. The total cost of DECON is reorganized into groupings comprised of Labor and Materials, Energy, and Waste Disposal, and the resulting coefficients for the decommissioning cost escalation formula of 10 CFR 50.75(c) are presented in Section 3.7. Overlaying all four periods is the operation of the existing onsite independent spent fuel storage installation (ISFSI), assumed to be initiated about 2 years prior to reactor shutdown, and continuing for just over 3 years following DECON. References for this chapter are given in Section 3.8.

3.1 PRE-DECOMMISSIONING ENGINEERING AND PLANNING--PERIOD 1

The assumption was made in the original BWR study (NUREG/CR-0672[1]) that the pre-decommissioning engineering and planning was performed by the utility's in-house staff, and no specific cost was assigned to that activity. In this study, these activities are carried out by a decommissioning operations contractor (DOC). The postulated Utility and DOC staffing structures are shown in Figure 3.2. The labor costs for the utility and the DOC during the initial pre-shutdown period, based on annual salaries presented in Appendix B, are presented in Tables 3.2 and 3.3. These costs are estimated to be about $4.8 million for the DOC and about $0.8 million for the utility, in 1993 dollars, without contingency, over the 2½-year period.

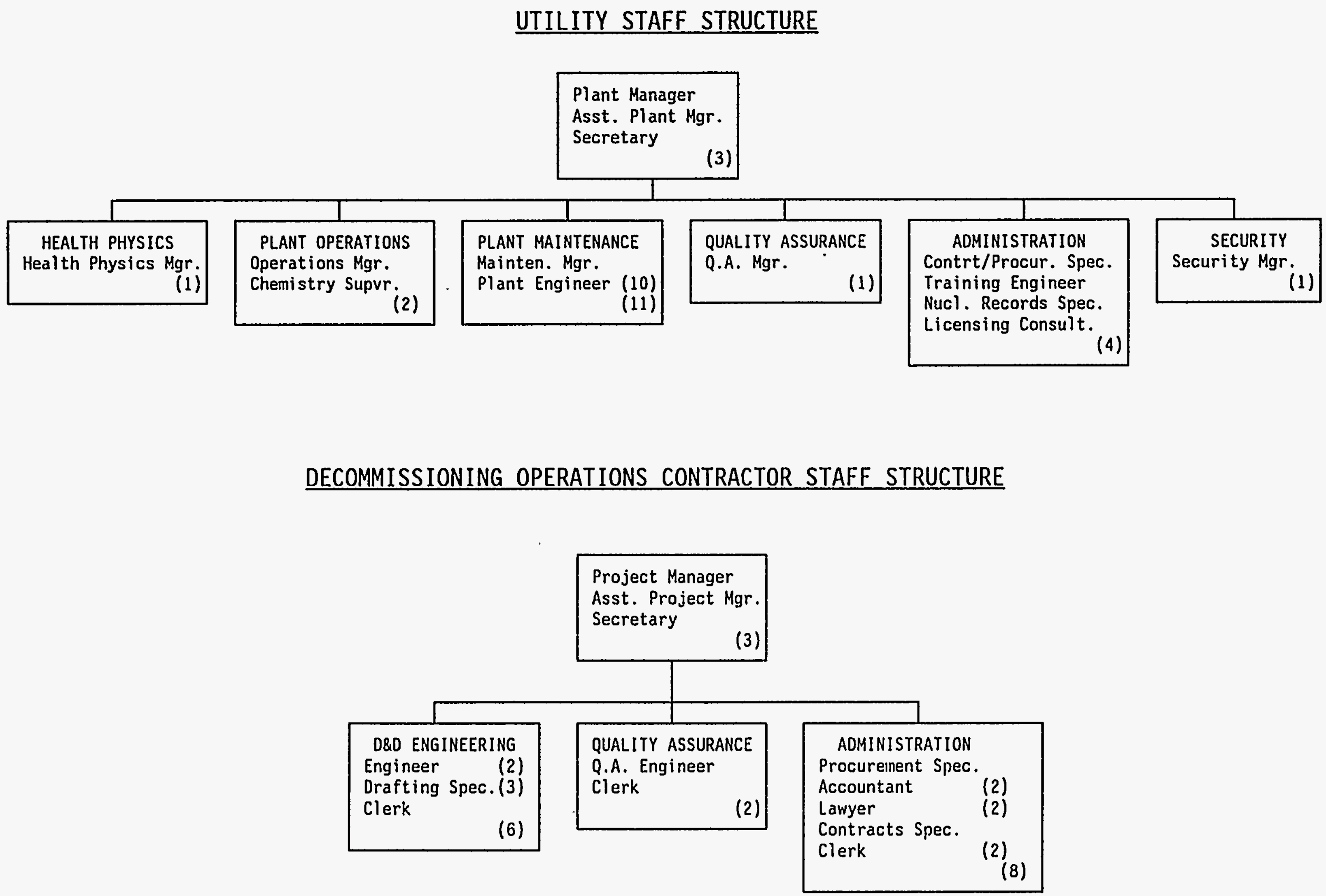

FIGURE 3.2. Utility and DOC Staff Structure and Staffing Level During Pre-Decommissioning: Period 1

TABLE 3.2. Estimated Utility Staffing and Costs for DECON

Positions	Annual Salary[a]	Period 1		Period 2		Period 3[b]		Period 4		Pool Opn.(P3)[b]		ISFSI Opn.(P4)		ISFSI Opn.(P5)	
		Person-years per Period and Period Costs in 1993 Dollars													
Plant Manager	129,518	0.125	16,190	0.62	80,301	0.63	81,596	1.7	220,181	5.67	734,367	--	--	--	--
Asst. Plant Manager	104,824	0.125	13,103	0.62	64,991	0.63	66,039	--	--	5.67	594,352	1.7	178,201	5.3	555,567
Secretary	29,110	0.125	3,639	3.69	107,416	0.63	18,339	1.7	49,487	5.67	165,054	--	--	--	--
Clerk	27,150	--	--	9.85	267,428	3.15	85,523	6.8	184,620	28.35	769,703	1.7	46,155	5.3	143,895
Chemistry Supervisor	74,735	0.250	18,684	0.62	46,336	--	--	--	--	--	--	--	--	--	--
Chemistry Tech.	43,012	--	--	2.46	105,810	0.63	27,098	0.4	17,205	5.67	243,878	--	--	--	--
Quality Assurance Manager	86,819	0.625	54,262	0.62	53,828	--	--	--	--	--	--	--	--	--	--
Quality Assurance Engineer	49,288	--	--	2.46	121,248	--	--	1.7	83,790	--	--	--	--	--	--
Quality Assurance Tech.	43,012	--	--	4.92	211,619	0.63	27,098	--	--	5.67	243,878	--	--	--	--
Health Physics Manager	79,449	0.125	9,931	0.62	49,258	0.63	50,053	--	--	5.67	450,476	--	--	--	--
H. P. ALARA Planner	73,045	--	--	0.62	45,288	--	--	1.7	124,177	--	--	--	--	--	--
Sr. Health Physics Tech.	73,045	--	--	2.46	179,691	1.89	138,055	--	--	17.01	1,242,495	1.7	124,177	5.3	387,139
Health Physics Tech.	45,028	--	--	9.85	443,526	--	--	--	--	--	--	--	--	--	--
Plant Operations Manager	97,440	0.125	12,180	0.62	60,413	0.63	61,387	--	--	5.67	552,485	--	--	--	--
Planner/Schedule Engineer	74,735	--	--	0.62	46,336	--	--	--	--	--	--	--	--	--	--
Operations Supervisor	86,819	--	--	2.46	213,575	0.63	54,696	3.0	260,457	5.67	492,264	1.7	147,592	5.3	460,141
Control Operator	72,988	--	--	9.85	718,932	2.52	183,930	4.5	328,446	22.68	1,655,368	1.7	124,080	5.3	386,836
Equipment Operator	51,787	--	--	9.85	510,102	3.78	195,755	4.5	233,042	34.02	1,761,794	1.7	88,038	5.3	274,471
Maintenance Supervisor	95,410	0.125	11,926	0.62	59,154	--	--	--	--	--	--	--	--	--	--
Plant Engineer	72,619	5.000	363,095	2.46	178,643	0.63	45,750	6.0	435,714	5.67	411,750	--	--	--	--
Maintenance Supervisor	87,231	--	--	2.46	214,588	0.63	54,956	1.5	130,847	5.67	494,600	--	--	--	--
Craftsman	60,790	--	--	9.85	598,782	2.52	153,191	5.3	322,187	22.68	1,378,717	1.7	103,343	10.6	644,374
Administration Manager	86,819	--	--	0.62	53,828	0.63	54,696	--	--	5.67	492,264	--	--	--	--
Contracts/Procure. Spec.	69,026	0.625	43,141	1.85	127,698	0.63	43,486	1.7	117,344	5.67	391,377	--	--	--	--
Licensing Consultant	72,264	0.125	9,033	1.85	133,688	0.63	45,526	1.7	122,849	5.67	409,737	--	--	0.5	382,999
Accountant	69,026	--	--	1.23	84,902	0.63	43,486	1.7	117,344	5.67	391,377	--	--	--	--
Industrial Safety Spec.	67,592	--	--	1.85	125,045	0.63	42,583	1.5	101,388	5.67	383,247	--	--	--	--
Radioactive Shipment Spec.	79,449	--	--	1.85	146,981	0.63	50,053	1.5	119,174	5.67	450,476	--	--	5.3	421,080
Training Engineer	74,735	0.250	18,684	0.62	46,336	--	--	1.5	112,103	--	--	--	--	--	--
Nuclear Records Specialist	61,429	0.250	15,357	0.62	38,086	0.63	38,700	1.7	104,429	5.67	348,302	0.5	30,715	5.3	325,574
Custodian	32,248	--	--	1.23	39,665	1.26	40,632	3.4	109,643	11.34	365,692	--	--	5.3	170,914
Security Manager	86,819	0.125	10,852	0.62	53,828	0.63	54,696	0.2	17,364[c]	5.67	492,264	1.5	130,229[c]	5.3	460,141
Security Shift Supervisor	38,439	--	--	2.46	94,560	1.89	72,650	0.6	23,063[c]	17.01	653,847	4.5	172,976[c]	15.9	611,180
Security Patrolman	34,875	--	--	19.69	686,689	5.04	175,770	1.6	55,800[c]	45.36	1,581,930	12.0	418,50[c]	42.4	1,478,700
Utility Overhead Totals		7.90	600,077	112.0	6,008,571	33.39	1,905,744	55.9	3,390,654	300.51	17,151,693	30.4	1,564,006	122.4	6,702,811

(a) Salary rates include 42% overhead on utility salaries.
(b) Costs are allocated 10% to Safe Storage and 90% to SNF storage.
(c) Costs are allocated 12% to Dismantlement and 88% to SNF storage.

TABLE 3.3. Estimated DOC Staffing and Costs for DECON

Position	Annual Salary[(a)]	Person-years per Period and Period Costs in 1993 Dollars — Decontamination and Decommissioning Operations							
		Period 1		Period 2		Period 3[(b)]		Period 4	
Project Manager	220,272	2.5	550,680	--	--	0.5	110,136	1.7	374,462
Asst. Project Manager	178,275	2.5	445,688	--	--	0.5	89,138	1.7	303,068
Secretary/Clerk	47,829	12.5	597,863	--	--	2.5	119,573	13.6	650,474
Planner/Schedule Engineer	127,101	--	--	--	--	--	--	5.1	648,215
Quality Assurance Supvr.	147,653	--	--	--	--	--	--	1.7	251,010
Quality Assurance Engineer	83,825	2.5	209,563	--	--	0.5	41,913	1.7	142,503
Quality Assurance Tech.	76,580	--	--	--	--	--	--	6.0	459,480
Health Physics Supvr.	148,643	--	--	--	--	--	--	1.7	252,693
H. P. ALARA Planner	124,228	--	--	--	--	--	--	1.7	211,188
Sr. Health Physics Tech.	124,228	--	--	--	--	--	--	5.1	633,563
Health Physics Tech.	76,580	--	--	--	--	--	--	21.0	1,608,180
D&D Operations Supervisor	147,653	--	--	--	--	--	--	4.5	664,439
Crew Leader (matl. handling)	114,060	--	--	--	--	--	--	1.5	171,090
Utility Operator (matl. hand.)	88,075	--	--	--	--	--	--	3.0	264,225
Craftsman (matl. handling)	103,386	--	--	--	--	--	--	3.0	310,158
Tool Crib Attendant	76,725	--	--	--	--	--	--	3.0	230,175
Protective Clothing Attendant	76,725	--	--	--	--	--	--	3.0	230,175
Industrial Safety Spec.	114,954	--	--	--	--	--	--	4.5	517,293
Enginering Supvr.	147,653	--	--	--	--	--	--	1.5	221,480
Engineer	122,899	5.0	614,495	--	--	1.0	122,899	12.0	1,474,788
Drafting Spec.	67,813	7.5	508,598	--	--	1.5	101,720	4.5	305,159
Safety Consultant	242,200	--	--	--	--	--	--	0.5	121,100
Lawyer	150,744	5.0	753,720	--	--	1.0	150,744	0.8	120,595
Contracts/Account. Supvr.	150,744	--	--	--	--	--	--	1.7	256,265
Accountant	117,369	5.0	586,845	--	--	1.0	117,369	1.7	199,527
Procurement Spec.	106,743	2.5	266,858	--	--	0.5	53,372	1.5	160,115
Contracts Spec.	117,369	2.5	293,423	--	--	0.5	58,685	1.7	199,527
Licensing Engineer	122,899	--	--	--	--	--	--	1.7	208,928
Radioactive Shipment Spec.	135,119	--	--	--	--	--	--	1.5	202,679
DOC Overhead Totals		47.5	4,827,733	--	--	9.5	965,549	112.6	11,271,449

(a) Salary rates include 110% overhead, plus 15% profit on DOC salaries.
(b) Based on 6 months of effort for the staff from Period 1.

3.2 REACTOR DEACTIVATION FOR SAFE STORAGE--PERIOD 2

Following final reactor shutdown, the last fuel core is removed to the spent fuel pool. Utility staffing costs are assigned to plant operations until permission is received from the NRC for a general relaxation of the plant operating specifications, thus permitting a marked reduction in required staffing levels. At that time, a general cleanup of the plant is initiated, with decontamination and/or fixing of surfaces with smearable contamination to avoid contamination spread during the deactivation and safe storage periods.

In addition to the general cleanup, three major decommissioning actions take place during the deactivation period:

- the reactor coolant piping systems are chemically decontaminated to reduce the radiation dose rates throughout the plant
- the highly irradiated reactor vessel internals are removed, segmented, and packaged in canisters for storage in the pool/on-site ISFSI, pending shipment of the Greater-Than-Class-C materials to a geologic repository and shipment of the materials that are Class C and less to an LLW disposal facility
- systems and services not necessary for the SNF storage operations are drained, dried, deactivated, and decontaminated, including the Dryer/Separator Pool, RPV, and RCS.

The postulated schedule for the activities occurring during Period 2 is illustrated in Figure 3.3. When defueling of the reactor has been completed, the staffing level at the facility is reduced in steps to the minimum level appropriate to support the planned decommissioning activities and spent fuel pool operations. The utility staffing structure during the deactivation period, following receipt of relief from many of the Technical Specifications associated with plant operations, is illustrated in Figure 3.4, predicated in part upon an analysis of the plant deactivation activities considered for the Rancho Seco plant.[2] The estimated staff costs are compiled in Table 3.2. The chemical decontamination operations and the internals segmentation operations are performed by specialty contractors, with utility operations support. This same level of utility staffing is maintained until decontaminated systems have been drained and dried, the solutions from the piping systems decontamination have been purified and the water released, the smearable contamination

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS		ELAPSED TIME - WEEKS															
				0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
			DEACTIVATION : PERIOD 2																
			DOC ACTIVATED 30 MONTHS PRIOR TO SHUTDOWN																
			DEFUEL REACTOR AND OBTAIN POSSESSION ONLY LICENSE																
1920	10	4		[========]		RAD SURVEY FOR CHEM DECON BASELINE													
				1920															
7920	10	16			[=======	=======	=======	========]		CHEM DECON RCS SYSTEMS									
					1980	1980	1980	1980											
5760	10	12		DEACTIVATE SUPPORT SYSTEMS				[=======	=======	========]									
								1920	1920	1920									
26640	10	37		CUT, REMOVE RPV INTERNALS				[=======	=======	=======	=======	=======	=======	=======	=======	=======	==]		
								2880	2880	2880	2880	2880	2880	2880	2880	2880	720		
2016	21	2									DRAIN, DECON DRYER SEPARATOR POOL					[==]			
																2016			
4032	21	4							TREAT, RELEASE RPV, DRYER SEPARATOR POOL WATER								[========]		
																	4032		
10080	5	36					RAD WASTE PACKAGING			[=======	=======	=======	=======	=======	=======	=======	=======	========]	
										1120	1120	1120	1120	1120	1120	1120	1120	1120	
58368	TOTAL	LABOR	HRS	1920	1980	1980	1980	6780	4800	5920	4000	4000	4000	4000	4000	6016	5872	1120	

FIGURE 3.3. Schedule of Activities During Deactivation (Period 2)

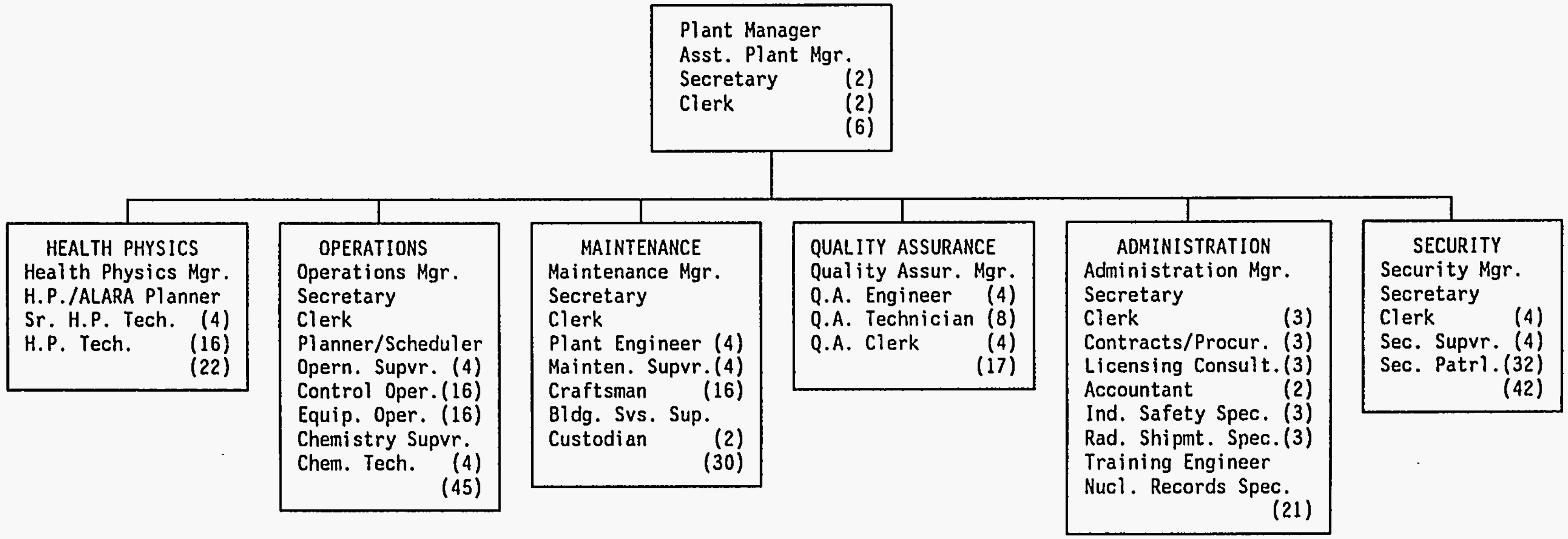

FIGURE 3.4. Utility Staffing Structure and Levels Following Receipt of Possession-Only License: Period 2

has been removed or fixed in place, and the systems and services that are not essential to continued operation of the spent fuel pool have been deactivated. After the activated reactor vessel internals are removed and packaged, the dryer separator storage pool and the RPV are drained and dried, and the pool is decontaminated, the facility is ready to enter Period 3 (concurrent safe storage and spent fuel storage activities).

The estimated costs and radiation doses accumulated during deactivation (Period 2) are summarized in Table 3.4, including the chemical decontamination operations (from Appendix G), vessel internals segmentation and packaging operations (from Appendix E), and the utility support staff costs, based on Figure 3.4 and staff labor costs given in Table 3.2.

TABLE 3.4. Estimated Costs and Radiation Doses During Deactivation: Period 2

Cost Element	Cost (millions) (1993 $)[a]	Radiation Dose (person-rem)
Chemical Decontamination (Appendix G)	13.716	45.70
RFC & D/S Pool Decontamination	0.007	0.10
RPV Internals Removal (Appendix E)	4.677	209.09
Subtotal	18.400	254.89
Undistributed Costs		
Utility Support Staff	16.660	169.73
Regulatory Costs	0.431	--
Plant Power Usage	1.135	--
Environmental Monitoring	0.058	--
Dry Active Wastes	0.136	--
Small Tools	0.018	--
Laundry Services	0.565	--
Energy (chem. decon)	0.238	--
Nuclear Insurance (Appendix B)	3.195	--
Subtotal	22.436	169.73
Total	40.836	424.61

(a) Costs shown do not include contingency.

3.3 SAFE STORAGE AND SPENT FUEL MANAGEMENT--PERIOD 3

With all plant operations shut down except for the storage and shipping of spent fuel from the spent fuel pool and the continuing storage activities at the onsite ISFSI, the utility staffing levels are reduced further, to the structure and levels shown in Figure 3.5. The safe storage of the laid-up plant and the SNF pool storage operations of Period 3 continue until the

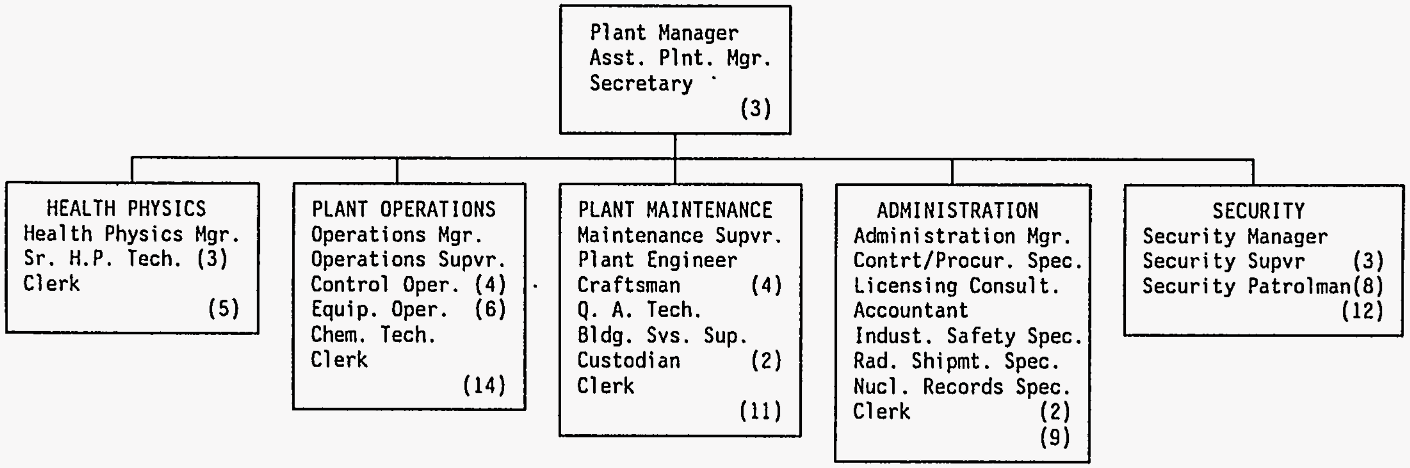

FIGURE 3.5. Staffing Structure and Levels during Safe Storage and SNF Pool Operation: Period 3

pool has been emptied, which is determined by the time at which the hottest fuel has cooled sufficiently to permit storage in dry, shielded containers outside of the pool. A discussion of the analysis that led to the selection of 4.6 years following shutdown for the duration of pool storage of the hottest fuel is given in Appendix D.

The utility staff costs during Period 3 (safe storage with spent fuel pool operations) are given in Table 3.2. The estimated costs associated with the ramp-up of the DOC staff, which is postulated to occur during the 6 months prior to the start of deferred dismantlement, are presented in Table 3.3. The total costs by cost element, and the radiation doses associated with the safe storage and spent fuel management operations during Period 3, are given in Table 3.5, based on Table 3.2 and the authors' assumption that 90% of the total plant operations costs is assigned to SNF storage operations (not charged to decommissioning) and the remaining 10% is assigned to plant safe storage operations (charged to decommissioning).

TABLE 3.5. Estimated Costs and Radiation Doses During Safe Storage: Period 3

Cost Element	Cost[a] (millions 1993 $)	Radiation Dose (person-rem)
Undistributed Costs		
Environmental Monitoring	0.017[b]	--
Regulatory Costs	0.087[b]	--
Utility Support Staff	1.474[c]	10.27
DOC Ramp-up Staff	0.966[d]	--
Plant Power Usage	0.018[b]	--
Laundry Services	0.032[b]	--
Nuclear Insurance	2.040[e]	--
Property Taxes	N.A.	--
Total	4.633	10.27

(a) Costs shown do not include a contingency.
(b) Cost allocated to SNF storage (90%); to safe storage (10%), from Table D.4
(c) Cost allocated to SNF storage (90%); to safe storage (10%), from Tables 3.2 and D.4.
(d) Six months for DOC staff, from Table 3.3.
(e) Costs distributed between SNF storage operations and plant safe storage, from Table D.4.

3.4 DISMANTLEMENT--PERIOD 4

The principal buildings requiring decontamination and dismantlement in order to obtain license termination at the reference BWR power station are the Reactor Building, the Turbine Generator Building, and the Radwaste and Control Building. These three buildings contain essentially all of the activated or radioactively contaminated material and equipment within the plant. The activities to decontaminate and dismantle these buildings begin in the Reactor Building and proceed sequentially through the Turbine Generator and Radwaste and Control Buildings, with a number of activities occurring within several buildings simultaneously.

Upon removal of all SNF from the spent fuel storage pool, the systems supporting the pool are deactivated and decontamination and dismantlement of the contaminated systems and structures can begin. At this point in time, the DOC planning staff has been back onboard for 6 months, reviewing the original planning documents and procedures, and making any necessary adjustments to reflect the actual situation at about 5 years after reactor shutdown. The DOC operations staff has been mobilized, and additional utility staff have been returned to the site to support the active decontamination and dismantlement operations. DOC subcontractors have been identified and placed under contract to perform selected operations.

The structure and staffing levels for the utility and the DOC are illustrated in Figure 3.6, with the salary costs associated with those staffs given in Tables 3.2 and 3.3. The numbers of direct decommissioning workers vary with time during the Period 4 operations, and are indicated in Figures 3.7, 3.8, and 3.9, which also contain the postulated schedules for operations in the Reactor, Turbine Generator, and Radwaste and Control Buildings during the decontamination and dismantlement effort.

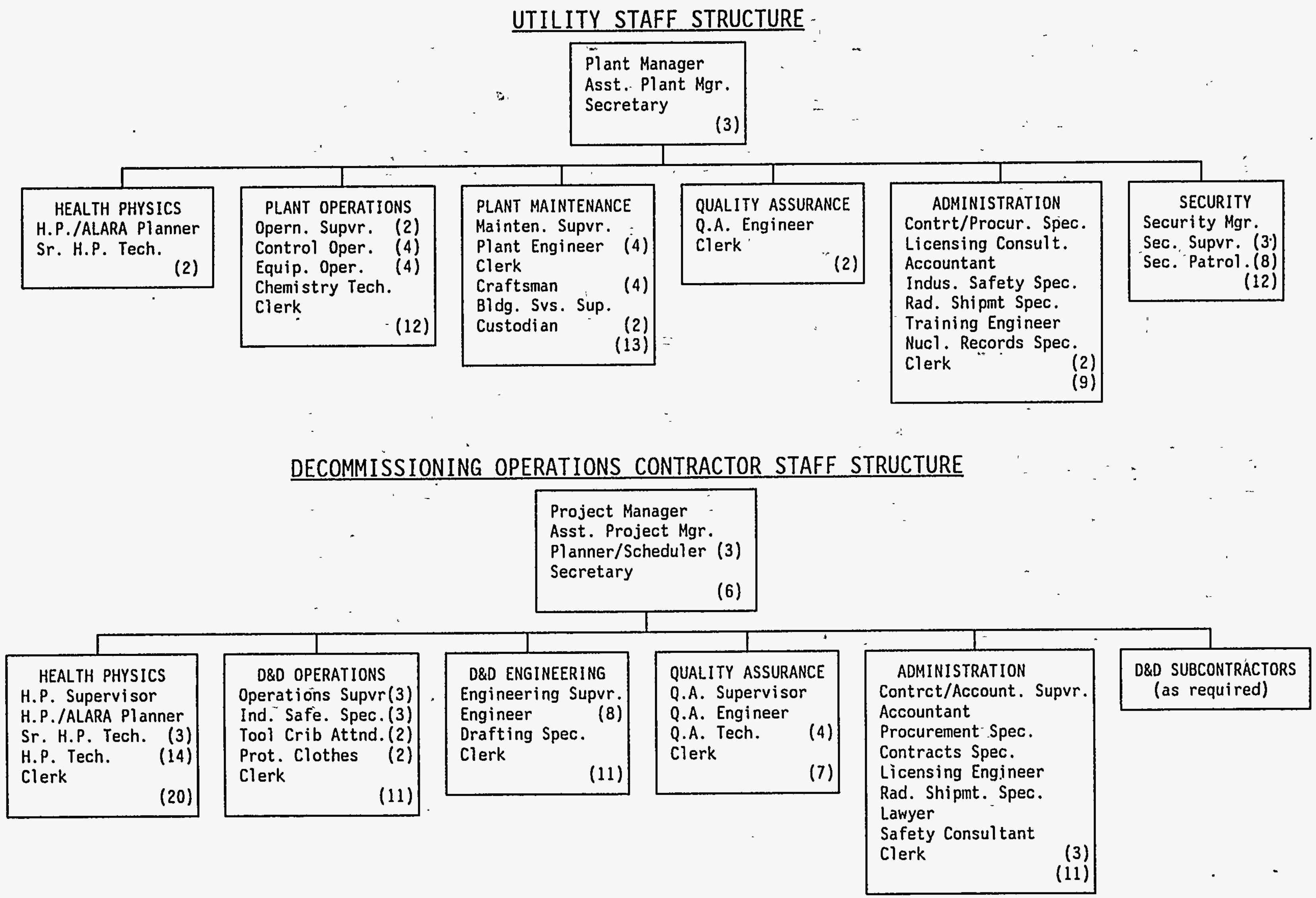

FIGURE 3.6. Utility and DOC Staff Structure and Staffing Levels during Deferred Dismantlement: Period 4

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS	ACTIVITY	0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76
			DECONTAMINATION/DECOMMISSIONING: PERIOD 4																				
1920	10	6	RAD SURVEY ALL FACILITIES	1280	640																		
			REACTOR BUILDING																				
4000	10	5	DECON, REMOVE, PACK FUEL RACKS		3200	800																	
4320	21	4	DRAIN, PROCESS POOL WATER			2160	2160																
1800	10	5	REMOVE SFP COOLING SYSTEM				360	1440															
60	10	1	REMOVE REFUELING CRANE					60															
1860	10	2	DECON, REMOVE, PACK POOL LINERS						1860														
29920	10	34	REMOVE RCS PIPING, PUMPS AND EQUIPMENT		1760	3520	3520	3520	3520	3520	3520	3520	3520										
12220	10	13	REMOVE CONTROL ROD DRIVE SYSTEM				3760	3760	3760	940													
	10	6	CUT AND PACK RPV							3640	1820												
3600	10	9	REMOVE SACRIFICIAL SHIELD								800	1600	1200										
42720	10	48	REMOVE OTHER SYSTEM PIPING				1780	3560	3560	3560	3560	3560	3560	3560	3560	3560	3560	3560	1780				
12750	10	15	REMOVE DRYWELL CONTAMINATED STRUCTURES										3400	3400	3400	2550							
7700	10	7	REMOVE OTHER SYSTEMS IN REACTOR BLDG													4400	3300						
13910	10	13	DECON, REMOVE VENTS, DRAINS														4280	4280	4280	1070			
1460	10	4	VACUUM, WASH, ALL SURFACES																	1460			
6600	10	6	REMOVE CONTAMINATED CONCRETE																	2200	4400		
1375	10	4	REMOVE, DECON BRIDGE CRANE																			1375	
2880	10	4	REMOVE HVAC EQUIPMENT, DUCTS																				2880
149095	TOTAL	LABOR	HRS	1280	5600	6480	11580	12340	12700	11660	9700	8680	11680	6960	6960	10510	11140	7840	6060	4730	4400	1375	2880

FIGURE 3.7. Schedule of Activities During Dismantlement (Reactor Building)

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS							ELAPSED TIME - WEEKS										
				0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
			TURBINE GENERATOR BUILDING																
7040	10	8			[=======	========]		REMOVE STEAM TURBINE											
					3520	3520													
31680	10	36				[=======	=======	=======	=======	=======	=======	=======	=======	========]	REMOVE OTHER SYSTEM PIPING				
						3520	3520	3520	3520	3520	3520	3520	3520	3520					
12600	10	12					[=======	=======	========]		REMOVE CONDENSER								
							4200	4200	4200										
3460	10	4								[========]		REMOVE MOISTURE SEPARATOR REHEATERS							
										3460									
1920	10	4									[========]		REMOVE FEEDWATER HEATERS						
											1920								
1800	10	4										[========]		REMOVE FEEDWATER CONDENSATE SYSTEM					
												·1800							
400	10	2											[====]	REMOVE FEEDWATER PUMPS/TURBINE DRIVES					
													400						
800	10	2								DECON CRANE IN SITU			[====]						
													800						
2940	10	6									DECON, REMOVE DRAINS			[=======	====]				
														1960	980				
160	10	1										VACUUM, WASH SURFACES			[==]				
															160				
640	10	2									REMOVE CONTAMINATED CONCRETE					[====]			
																640			
3610	10	4										REMOVE HVAC DUCTS, EQUIPMENT				[====	====]		
																1645	1965		
67050	TOTAL	LABOR	HRS		3520	7040	7720	7720	7720	6980	5440	5320	4720	5480	1140	2285	1965		

FIGURE 3.8. Schedule of Activities During Dismantlement (Turbine Building)

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS	ELAPSED TIME - WEEKS	0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88
			RADWASTE AND CONTROL BUILDING																							
2160	21	6	PROCESS CHEMICAL RADWASTE					1440	720																	
3150	10	7	REMOVE CONDENSATE DEMINERALIZER SYS						1800	1350																
2340	10	5	REMOVE OFFGAS AND STANDBY GAS TREATMENT SYS							1404	936															
3680	10	10	REMOVE MAIN STEAM AND LEAKAGE CONTROL SYSTEMS								1472	1472	736													
31860	10	36	REMOVE OTHER SYSTEM PIPING						3540	3540	3540	3540	3540	3540	3540	3540	3540									
1560	10	6	REMOVE CONTAMINATED DRAINS													1040	520									
580	10	2	REMOVE, DECON FILTER/DEMIN CRANE														580									
320	10	1	DECON IN SITU, TRUCK LOADING, RADWASTE STORAGE CRANES														320									
390	10	1															390									
1955	10	2	REMOVE CONTAMINATED CONCRETE SURFACES														1955									
6190	10	8	REMOVE HVAC EQUIPMENT, DUCTS															3095	3095							
54185	TOTAL	LABOR	HRS			0	0	1440	6060	6294	5948	5012	4276	3540	3540	4580	7305	3095	3095							
			LICENSING TERMINATION SURVEY																							
3270	10	6	OTHER STRUCTURES																1090	2180						
3270	10	6	RADWASTE AND CONTROL BLDG																		2180	1090				
6600	10	11	TURBINE GENERATOR BLDG																			1800	2400	2400		
3100	10	5	REACTOR BLDG																					620	2480	
16240	TOTAL	LABOR	HRS																1090	2180	2180	2890	2400	3020	2480	
292030	TOTAL	LABOR	HRS	1280	9120	13520	19300	21500	26480	24934	21088	19012	20676	15980	11640	17375	20410	10935	10245	6910	6580	4265	5280	3020	2480	

FIGURE 3.9. Schedule of Activities During Dismantlement (Radwaste Building)

Inventories of process system components and the inventory of stainless steel piping that will have to be removed during decommissioning are compiled and presented in Appendix C, together with appropriate unit cost factors and algorithms, to estimate the costs of removal, packaging, transport, and disposal for these materials. For the analyses presented in this report, it is postulated that all waste disposal containers are filled to either their weight capacity or their volume capacity. Thus, for a given system or set of components, it is likely that the number of containers required to contain that material will be some decimal value, e.g., 4.75. In the detailed tabular presentations of costs in this report, each line item will display the cost of containers, transport, handling, and burial based on the appropriate decimal number of containers required for that line item. This approach may be slightly non-conservative compared to actual field practice, but the total error should not be significant. A brief discussion of the basic analysis approach for removal of process systems and piping, and a summary of the analysis results, are presented in Section 3.4.1.

Removal of the reactor pressure vessel (RPV) and the sacrificial shield is discussed in detail in Appendix E and summarized briefly in Sections 3.4.2 and 3.4.6, respectively. Removal of the steam turbine, the turbine condenser, and associated moisture separator reheaters and feedwater heaters is discussed in detail in Appendix F and summarized briefly in Section 3.4.3. The reactor coolant system, because of its complexity and large physical size, is treated in detailed analyses, with removal of RCS piping discussed in Section 3.4.4. Removal of the racks from the spent fuel pool is discussed in Section 3.4.5. Removal of the contaminated HVAC ductwork and associated equipment is discussed in Section 3.4.7. Decontamination of remaining contaminated surfaces throughout the Reactor, Turbine Generator, and Radwaste and Control Buildings is discussed in Section 3.4.8. Removal of the cranes from these buildings is discussed in Section 3.4.9. Environmental monitoring during dismantlement is discussed in Section 3.4.10. The regulatory costs during dismantlement are discussed in Section 3.4.11, and the final site radiation survey and the confirmation survey necessary to obtain license termination are discussed in detail in Appendix B and summarized briefly in Section 3.4.12.

A summary of the estimated costs and radiation doses resulting from the dismantlement (Period 4) activities is given in Table 3.6.

TABLE 3.6. Summary of Estimated Costs and Radiation Doses Resulting from Dismantlement Activities: Period 4

Element	Cost (millions 1993 $)	Radiation Dose (person-rem)
Contaminated Systems	14.921	110.28
Reactor Pressure Vessel	1.381	39.57
Steam Turbine/ Condenser/ Reheaters, Feed Pumps	12.930	8.74
Recirculation Piping /Components	5.095	263.46
SNF Pool Racks	1.643	1.13
Sacrificial Shield	1.936	24.95
HVAC System	2.366	7.19
Contaminated Surfaces	1.382	10.34
Facility Cranes	0.437	0.16
Containment Structural Steel & Cable Trays	1.462	4.42
Termination Survey	1.058	0.00
Dry Active Waste	1.348	0.00
Floor Drains	0.489	1.66
Waste Water Treatment	0.784	1.52
Undistributed Costs	24.473	54.18
Totals (w/o contingency)	71.705	527.60

3.4.1 Removal of Process Systems and Piping

The estimated costs and radiation doses associated with the removal of the contaminated systems and piping are summarized in Table 3.7, calculated using the Cost Estimating Computer Program (CECP) and the detailed inventories of system components and valves for each system and the piping inventories that are presented in Appendix C.

The weights and volumes of the components and piping are derived from construction drawings, handbooks, and similar sources. The weights of the valves listed are from construction data or are based on typical 600 psig service-rated gate valves. On the average, the estimated weights should be conservative. The valve volumes are estimated using a conservative approximation to the space occupied by the valve body/valve stem/valve operator.

TABLE 3.7. Estimated Costs and Radiation Doses for Removal, Packaging, Transport, and Disposal of Contaminated Systems During Dismantlement: Period 4

Contaminated System	Cost (1993 $)	Radiation Dose (person-rem)
Control Rod Drive	1,067,013	8.49
Feedwater and Condensate	1,783,578	0.24
Chemical Waste Processing	230,706	5.30
Containment Instrument Air	30,522	0.02
Fuel Pool Cooling and Cleanup	148,756	1.51
Condensate Demineralizers	371,515	0.22
Equipment Drain Processing	223,341	3.51
Extraction Steam	365,729	0.07
High/Low Pressure Core Spray	209,258	0.08
Miscellaneous Drains	31,610	0.05
Main Steam and MS Leakage Control	860,904	2.94
Radioactive Floor Drain Processing	151,136	3.04
Turbine and Radwaste Bldg. Drains	45,038	0.07
Offgas System	257,079	3.10
Reactor Bldg. Closed Cooling Water	159,857	0.31
Reactor Core Isolation Cooling	83,542	0.11
Residual Heat Removal	959,382	0.32
Recirculation Water	98,890	0.20
Reactor Water Cleanup	187,815	40.26
Reactor Bldg. Equipment and Floor Drains	53,992	0.14
Sample System	14,973	0.01
Standby Gas Treatment	127,263	0.02
Heater Vents and Drains	694,252	0.50
Miscellaneous Items	543,294	2.26
Other Systems Piping	6,221,156	36.86
Totals (w/o contingency)	14,920,599	110.28

The numbers of valves of each size are also given. Valves 3 in. in diameter and smaller will probably be removed while attached to a length of piping and packaged together with their piping. Because of their size and weight, most of the larger and heavier valves will be removed and packaged separate from their associated piping. No effort is made to identify and quantify the number and characteristics of pipe hangers, under the assumption that most of the pipe hangers are sufficiently small that they can be placed in the piping containers without further consideration.

Other Systems Piping

The quantities of piping associated with each system are, in most cases, not known sufficiently well to attempt to assign lengths of piping to individual systems. Rather, the total inventory of piping purchased for construction of the plant is listed, excluding the RCS piping, and is segregated according to size and material, a conservative approach. This piping is identified as Other Systems Piping. The removal activities include removal and packaging of insulation, cutting the piping free from the systems components, cutting the piping into sections nominally 15 - 18 ft in length, and placing the segments into modified maritime containers for transport to the LLW disposal facility. Additional cuts may be required to accommodate pipe bends and valves.

The activities necessary to remove the Other Systems piping and place it in modified maritime containers are estimated to require about 19,314 crew-hours and 36.86 person-rem. The total estimated cost for removing and preparing the Other Systems piping for shipment is $3,719,826. Cost of the modified maritime containers is estimated to be $233,902. Transport by truck to the LLW disposal facility is estimated to cost $8,537, and the disposal fee is estimated to be $2,258,891. Thus, the total estimated cost for removal and disposal of the Other Systems piping is $6,221,156, without contingency.

The basic approach in this analysis is that only those systems likely to be contaminated, or which must be removed to facilitate removal of contaminated systems, are removed to satisfy the requirements for license termination. The remaining piping systems which serve uncontaminated systems, e.g., potable water, sanitary sewer, etc., are assumed to be uncontaminated, and do not need to be removed to satisfy the requirements for license termination, and they remain in place for a demolition contractor to remove, should the owner choose to demolish the clean structures.

3.4.2 Removal of the Reactor Pressure Vessel

Removal of the activated RPV from the Reactor Building (the RPV internals are removed during Period 2) requires sectioning of the components, and packaging of those components for transport to a licensed disposal site. The RPV is postulated to be segmented and packaged during Period 4, and the packaged material is transported to a licensed LLW disposal facility. The sectioning and packaging operations, which are estimated to require about 7 weeks, are described in detail in Appendix E. The estimated costs and radiation doses associated with RPV removal, packaging, transport, and disposal are summarized below:

- Estimated Cost (without contingency) $1,380,823
- Estimated Worker Radiation Dose 39.57 person-rem

3.4.3 Removal of the Steam Turbine, Turbine Condenser, Moisture Separator Reheaters, Feedwater Reheaters, and Feedwater Pumps and Turbine Drives

Disassembly and packaging of the steam turbine, turbine condenser, moisture separator reheaters, feedwater reheaters, and the feedwater pump and turbine drive assemblies and the transport and disposal of these large massive components as LLW is a major task during dismantlement. A detailed analysis of this effort is presented in Appendix F, with the results summarized in this section. The components are disassembled and segmented for packaging prior to transport to the U.S. Ecology LLW disposal facility on the Hanford Reservation. A summary of the estimated direct labor hours, effort duration, costs, and radiation doses associated with the disassembly and packaging of these large components is given in Table 3.8.

TABLE 3.8. Estimated Crew-hours, Calendar Days, Costs, and Radiation Doses for Removal of the Steam Turbine, Condenser, Moisture Separator Reheaters, Feedwater Pumps and Turbine Drives, and Feedwater Reheaters

Component	Crew-hours	Calendar Days	Cost (1993 $)	Radiation Dose (person-rem)
Turbine	1,280	40	4,743,613	2.37
Condenser	2,315	71	5,590,848	4.36
Moisture Sep. Rehtr.	635	20	707,266	1.20
Feedwater Pumps/Turb.	80	8	296,359	0.14
Feedwater Reheaters	384	18	1,592,191	0.67
Totals	4,694		12,930,277	8.74

The total cost for removal, transport, and disposal of these materials is estimated to be $12,930,277, without contingency.

3.4.4 Removal of RCS Piping, Pumps, and Associated Components

The components considered in this section comprise the balance of the reactor coolant system (RCS) after removal of the reactor pressure vessel, the steam turbine, condenser/moisture separator reheaters, feedwater pumps and turbines, and feedwater reheaters, which are discussed individually in Appendices E and F. The detailed discussions of the sectioning, packaging, transport, and disposal, which are presented later in this section, are summarized briefly as follows:

- Estimated Cost (without contingency) $5,094,615
- Estimated Worker Radiation Dose 263.46 person-rem

Specifically included are: the recirculation pumps, the large piping connecting the coolant recirculation pumps with the RPV, and the piping of various sizes that interconnect the RCS with the RPV and other plant systems. Brief descriptions of the activities postulated to be carried out are presented, together with the results of the analyses to develop estimates of staff labor requirements, staff exposure hours and cumulative radiation exposure, and estimated costs for labor and materials for removing and packaging these components for transport and disposal.

Removal of contaminated reactor coolant system piping and components requires sectioning of the piping and components, packaging, and transport of the packaged segments to an LLW disposal facility. The assumptions listed below are made to facilitate the analysis.

- The time, cost, and exposure for cutting the RCS piping are all accounted for in this chapter, including severing the piping from the RPV, and the associated coolant recirculation pumps, and from the steam turbine, turbine condenser, and reheaters.
- The piping is cut to fit within modified maritime containers, into segments nominally 15 to 18 feet in length, thereby reducing the number of cuts needed to remove the piping. Additional cuts are made where necessary to accommodate bends and valves.
- Scaffolding was required for all piping cuts, to provide appropriate access to the work.
- Piping is cut using plasma arc equipment, with cutting rates ranging from 8 in./minute for the thick-walled primary piping to 30

in./minute for the smaller-diameter (14 in. dia. to 3/4 in. dia.) piping, based on the Decommissioning Handbook.[3]

- Respiratory protection is required during these cutting operations.
- The coolant recirculation pumps are removed and shipped to the LLW disposal site at Hanford in one piece.
- The turbine, turbine condenser, moisture separator reheaters, and feedwater reheaters are segmented and packaged into modified maritime containers for transport and disposal.
- The RCS piping is packaged in modified maritime containers, and the insulation is packaged in standard maritime containers for transport to the LLW disposal facility.

The composition of the piping and components removal crews is given in Table 3.9, together with their labor rates, rates/crew-hour, and radiation dose rates/crew-hour.

Following separation of the RPV, steam turbine and condenser, recirculation pumps, and the reheaters from their piping connections, those components are removed sequentially from their respective buildings. Subsequently, the RCS piping is cut and packaged for disposal. The insulation associated with these components is packaged as a part of the component removal operations.

TABLE 3.9. Composition of RCS Piping and Components Removal Crews

Person-hrs/crew-hr	Category	Labor Rate ($/person-hr)	Cost[a] ($/crew-hr)	Dose Rate[b] (mrem/crew-hr)
3.0	Laborer	26.37	79.11	36
1.5	Craftsman	49.70	74.55	18
0.5	H.P. Tech.	36.82	--[c]	6
0.5	Foreman	54.84	27.42	6
5.5			181.08	66
Average cost per crew-hour, including shift differential[d]			$190.13	

(a) Includes 110% overhead, 15% DOC profit.
(b) Nominal dose-rate during Period 4.
(c) Part of DOC Overhead staff, labor costs appear in undistributed cost.
(d) 10% shift differential for second shift.

Recirculation Pumps

The insulation enclosing the pump bowls is removed and packaged for disposal. The pumps are separated from the piping, cooling and drain lines, and associated sensor and control lines, and are rigged for lifting. Plates are welded over the inlet and outlet ports of the pump bowl. The load is taken up by the reactor hall crane,and the pump support and seismic constraints are removed. The pump and motor are lifted as a single unit to the refueling floor and placed horizontally in a shipping cradle, preparatory to removal from the Reactor Building for transport to the licensed LLW disposal facility.

The activities necessary to remove each pump and place it on the refueling floor in its shipping cradle are estimated to require about 16 crew-hours, 57 exposure hours and 0.94 person-rem, $3,112 in labor costs, and $5,000 in material costs (shipping cradle). Thus, the total estimated cost for removing and preparing two recirculation pumps with motors for shipment is $16,224. The total estimated crew labor hours is about 33, the total estimated exposure hours is about 115, and the total estimated radiation dose is 1.87 person-rem.

The cost of transporting the pumps from WNP-2 to the U.S Ecology disposal facility at Hanford is estimated to be about $600 for the two pumps. The total estimated cost for removal and disposal of the recirculation pumps is $269,676, without contingency.

Recirculation Piping

The insulation is removed from the remaining portions of the piping and packaged for disposal. Each piping segment is cut into a manageable length and individually rigged for lifting. The Reactor Building crane is used to lift the piping segments to the refueling floor where they are placed into modified maritime containers for transport to the LLW disposal facility.

The activities necessary to remove and package the recirculation system piping for disposal are estimated to require about 5,397 crew-hrs, a radiation dose of 261.59 person-rem, and $1,041,231 in labor costs. Maritime container costs are $475,837. The estimated cost to transport the containers to the LLW disposal facility at Hanford is $18,744. The fee for disposal of the packaged materials is $2,846,048. Thus, the total estimated cost for removal and disposal of the recirculation system piping is $4,381,861, without contingency.

RCS Insulation

The insulation removed from the various RCS components is packaged in maritime containers. The labor costs for insulation removal and packaging are included in the activities of removal of the various components. The container costs are $23,175. Transport of the containers to the LLW disposal facility at Hanford is estimated to cost $1,151. The disposal fee is estimated to be $418,753. Thus, the total estimated cost for disposal of the removed insulation is $443,078, without contingency.

RCS Piping and Components Summary

The estimated numbers of packages, weight per package, volume per package, number of shipments, and the disposal volume per component are summarized in Table 3.10. The estimated costs for staff labor, packages, transport, site support services, and disposal are summarized in Table 3.11, together with the estimated number of exposure hours associated with each component removal and packaging activity.

TABLE 3.10. Summary of RCS Component Information

Component	No. of Packages	Weight per Package (lb)	Volume per Package (ft^3)	No. of Shipments	Disposal Volume (ft^3)
Recirculation Pumps	2[(a)]	96,000	2,607	2	5,214
Recirculation Piping	104[(b)]	40,000	320	104	33,102
RCS Insulation	7[(c)]	9,000	1360	4	8,635

(a) Packaged as own container, openings welded closed, placed in shipping cradle.
(b) Packaged in modified maritime containers, 20 ft x 8 ft x 2 ft, 2,500 lb empty.
(c) Packaged in standard maritime containers, 20 ft x 8 ft x 8½ ft, 4,180 lb empty.

TABLE 3.11. Estimated Costs in 1993 Dollars for Removal and Disposal of RCS Components

Component	Labor Cost	Package Cost	Transport Cost	Disposal Cost	Total Cost	Exposure Hours	Radiation Dose (Person-rem)[d]
Recirculation Pumps	$16,224	--[a]	$600	$252,852	$269,676	114	1.87
Recirculation Piping	1,041,231	475,837[b]	$18,744	$2,846,048	$4,381,861	18,858	261.59
RCS Insulation	--[c]	$23,175[d]	$1,151	$418,753	$443,078	--	0.0[f]
Totals	$1,057,455	$499,012	$ 20,495	$3,517,653	$5,094,615	18,972	263.46

(a) Packaged as own container, openings welded closed, placed in shipping cradle.
(b) Packaged in a modified maritime container, 20 ft x 8 ft x 2 ft, 2500 lb empty.
(c) Insulation removal cost included in piping removal cost.
(d) Packaged in standard maritime containers, 20 ft x 8 ft x 8½ ft, 4180 lb empty.
(e) Assumed radiation dose rate to dedicated workers is 55 mrem/crew-hour.
(f) Radiation dose included with RCS piping removal.

Sensitivity to Length of Pipe Cuts

A sensitivity analysis was performed to examine the effect of cutting the contaminated piping into 5-ft lengths, rather than the nominal 15-ft lengths postulated for this reevaluation study. Only the assumed length of piping pieces after cutting was changed for this sensitivity analysis. It was assumed that more cutting crews were deployed so that the duration of the decontamination and dismantlement period (Period 4) of DECON remained constant. As would be expected when tripling the number of cutting operations, the direct labor costs for pipe removal approximately tripled, an increase of about $12.320 million, not including contingency. Because the volume of dry active waste, the amount of laundry used, and the quantity of small tools and equipment used are factored from the direct labor hours, the costs associated with these cost elements also increased, by about $2.740 million. Thus, the increase in the total DECON cost resulting from cutting the piping into 5-ft lengths instead of the 15-ft lengths postulated in the base analysis was about $15.060 million, including contingency.

Associated with the increased number of pipe cutting operations was an increase in the worker radiation dose. Because pipe cutting tends to be performed in higher radiation fields than many other DECON activities, the total radiation dose to workers nearly doubled, from 962 person-rem for the base analysis (15-ft pipe lengths) to 1,561 person-rem for the sensitivity case (5-ft pipe lengths).

3.4.5 Removal of Racks from Spent Fuel Storage Pool

The storage racks in the spent fuel pool that are used to hold the accumulated spent fuel become contaminated during the reactor's lifetime and subsequently have to be removed during decommissioning. The assumptions made and the methodology used for this analysis, brief descriptions of the spent fuel racks and the postulated removal and disposal activities, the results of a reevaluation of the anticipated occupational radiation dose, and the estimated costs and schedule for removing, packaging, transporting and disposing of the contaminated spent fuel racks are presented in the following subsections.

Assumptions

In developing the spent fuel racks removal scenario and the subsequent analyses, the following assumptions were used:

- The removal of the reference plant's spent fuel racks is based, in part, upon a reassessment of cost and dose estimates for removal of spent fuel racks during decommissioning presented in Reference 1 and upon discussion with an industry expert in reracking spent fuel pools.

- Spent fuel racks removal, decontamination, and packaging are handled by an experienced contractor, who is well established in spent fuel racks changeout and associated integrated outage activities.

- One-piece rack removal is postulated, based upon two of the most important considerations -- reduced radiation exposure and a shorter overall schedule duration.

- Spent fuel racks exterior surfaces will be decontaminated using hydrolasers, and interior surfaces will be decontaminated using pads on long-handled tools.

- The lifting frame for the spent fuel racks is onsite and available for use by the contractor when needed.

Methodology

Two removal scenarios were considered: 1) sectioning each spent fuel rack into two or more pieces for packaging in 8-ft x 8.5-ft x 20-ft maritime containers for subsequent legal weight truck transport, and 2) disengaging the spent fuel racks from above the water surface of the SFP with appropriate long-handled tools, decontaminating the whole intact units as they are raised from the water, and bagging them in a nearby laydown area before packaging them in specially designed metal containers for subsequent transport by oversize truck shipments to the LLW disposal facility. This latter scenario was identified as having the greatest estimated potential for minimizing cost and occupational radiation exposure and was analyzed in this study.

Description of Spent Fuel Racks (15 each)

The reference SFP accommodates ten racks with 12 x 16 cells (6.6 ft x 8.8 ft, 43,973 lb), two racks with 11 x 16 cells (6 ft x 8.8 ft, 40,309 lb), and one each rack with 8 x 13 cells (4.4 ft x 7.2 ft, 23,819 lb), 12 x 13 cells (6.6 ft x 7.2 ft, 35,728 lb), and 7 x 18 cells (3.9 ft x 9.9 ft, 28,857 lb), for a total of 15 racks to be removed during decommissioning. The racks are about 14 ft high. Sixty-four turnbuckles attach the racks to the spent fuel pool walls (average weight about 204 lb ea.).

Removal and Disposal of Spent Fuel Racks

The spent fuel racks are disengaged from above the water surface of the pool using appropriate long-handled tools. The racks are decontaminated (using pads on long-handled tools for the interior cells and using hydrolasers provided by the utility for the exterior surfaces) as they are raised from the water. The racks are moved to a nearby laydown area, enclosed in large plastic bags, and placed in specially designed metal containers that have wall thicknesses of about 1/8 in. and weights ranging from 2000 lb to 3000 lb, since the intact racks do not fit efficiently in regular-size maritime containers. The turnbuckles are placed within the smallest of the fuel racks for disposal. The total weight of all shipments is about 661,504 lb, and the total disposal volume for the boxed racks and turnbuckles is about 11,575 ft^3. Subsequent transport is by truck (one container per truck, 12 OWT and 3 LWT shipments) to the U.S. Ecology LLW disposal facility at Hanford, Washington. In addition, compressible dry active waste (DAW) is generated during the rack decontamination effort. The DAW is also postulated to be packaged and shipped to the U.S. Ecology LLW disposal facility at Hanford. The breakdown of estimated costs for packaging, transport, and disposal of the racks and the associated DAW is given in Table 3.12.

TABLE 3.12. Breakdown of Transport and Disposal Costs for Spent Fuel Racks

Component	No. of Disposal Containers	Container Costs ($)[a]	No. of Shipments	Transport Costs ($)	Disposal Volume (ft^3)	Disposal Cost ($)[b]	Total Cost($)
SFP Racks	15[c]	79,067[d]	15[e]	3,196	11,575	721,077	1,630,215
DAW, Compressible	19[f]	512	0.25	45	140.6	6,911	7,468
Totals	34	79,579	15.25	3,241	11,715.6	727,988	1,637,683

(a) Based on information in Table B.3 of Appendix B.
(b) Based on information in Table B.4 of Appendix B; includes all applicable surcharges, taxes, and fees.
(c) Specially designed containers, see text and Table B.3 in Appendix B for details.
(d) Includes specially designed large plastic bags at $1,103 apiece.
(e) Oversize/overweight truck shipments, see text for details.
(f) Drums; see Table B.3 of Appendix B.

Occupational Radiation Dose

The removal of the spent fuel racks will mostly involve work above and at the edge of the SFP. It is estimated that two dedicated 9-person specialty contractor crews, working one crew on each of two shifts, will be required to complete this contract in six weeks. In addition, the DOC is postulated to provide one health physics technician per crew. Based upon the crew makeup described above, it is estimated that the removal of the spent fuel racks will require about 4,000 person-hours, with about half of that time spent working in areas having dose rates of up to about 1 mrem/hr, and the remaining spent time working in areas having dose rates essentially at background levels. The estimated occupational radiation dose associated with the spent fuel rack removal and packaging operations is about 1.09 person-rem.

Estimated Costs and Schedule

The major contributors to the estimated total cost of the SFP racks removal and disposal are summarized in Table 3.13. The total cost for this activity is estimated at about $1.64 million, not including contingency.

TABLE 3.13. Summary of Estimated Costs for Spent Fuel Pool Racks Removal and Disposal Activities

	Estimated Costs (1993 $)		
Cost Element	Spent Fuel Racks	Dry Active Waste	Total
Rack Decon and Removal	826,875	--	826,875
Packaging	79,067	512	79,579
Transport	3,196	45	3,241
Disposal	721,077	6,911	727,988
Totals	1,630,215	7,468	1,637,683
Laundry Services[a]	7,560		

(a) Protective Clothing/Equipment for contractor staff @ $21/day/person, included in Undistributed Costs.

A specialty contractor who is experienced in spent fuel racks changeout and associated integrated outage activities is hired for this task. The contract for these services is estimated to cost about $826,875. The contract period of 5 weeks includes 1 week of indoctrination training provided by the utility, with facility-specific crane qualification training for the contractor staff.

3.4.6 Removal of the Sacrificial Shield

The concrete and steel sacrificial shield, which surrounds the RPV within the containment vessel, becomes activated to varying degrees during the operating lifetime of the reactor. Because of the design of the shield, which is comprised of a steel-clad, steel-reinforced cylindrical annulus, the entire shield must be removed during dismantlement. Operations necessary for removal of the sacrificial shield are discussed in Appendix E, and summarized below.

The shield is sawn into 60 segments approximately 93 in. x 114 in. x 25 in. thick, using a diamond rope saw, and packaged in form-fitting, thin-walled containers for transport to the LLW disposal site, one segment per LWT shipment. The estimated costs are: for removal, $750,000; for containers, $63,000; for transport, $10,872; and for disposal, $1,112,261, for an estimated total cost for removal and disposal of the sacrifical shield of $1,936,133.

3.4.7 Removal of Contaminated HVAC Systems

The heating and ventilation (HVAC) systems ductwork and equipment within the Reactor, Turbine Generator, and Radwaste/Control Buildings are among the last items removed, since the HVAC systems need to be in service until essentially all of the contaminated materials have been removed. It is assumed that the facility has suffered no major contamination dispersal accidents and that the ductwork and the equipment are only mildly contaminated, with very small radiation dose rates (1 mrem/hr) associated with the removal activities. Because the ducts are likely to have accumulations of dust on the outer surfaces which may be contaminated, as well as some accumulations of contaminants on the inner surfaces of the exhaust ducts, the workers removing the ducts wear masks to prevent inhalation of any of the contaminants, and to wear anti-contamination clothing during the operations.

Removal of Ductwork

The rates of duct removal used in these analyses are based on information presented in R.S. Means,[5] modified to reflect the situation in the reference BWR, and are developed in the Unit Cost Factor for Duct Removal (see Appendix C). The Means information is for non-contaminated ducts. Thus, the rates are modified to reflect the efficiency penalties associated with wearing masks, changing clothing 4 times per shift, and for ALARA considerations. The crew size postulated for these analyses is larger than that of Means, who assumed that a single laborer comprised a crew. For work in a contaminated environment, additional crew members are postulated, as shown in Table 3.14.

TABLE 3.14. Composition of Duct Removal Crew

Man-hrs/crew-hr	Category	Labor Rate ($/hr)	$/crew-hr[a]
2.0	Laborer	26.37	52.74
0.5	H.P. Tech.	36.82	--[b]
0.5	Foreman	54.84	27.42
3.0			80.16
Average cost per crew-hour, including shift differential[c]			84.17

(a) Includes 110% overhead, 15% DOC profit.
(b) Part of DOC overhead staff, labor costs are in undistributed costs.
(c) 10% shift differential for second shift.

The quantity of ductwork within the Reactor, Turbine Generator, and Radwaste/Control Buildings was determined by scaling the actual construction drawings for the facility, including the sizes of the ducts. The duct walls are postulated to be 16-gauge galvanized steel, on the average. The weight of the duct material is postulated to be 2.656 lb/ft^2 for the 16-gauge materials.

For packaging, it is postulated that the rectangular ductwork is flattened, resulting in a slab whose dimensions are (height + width) x length of the section x an effective thickness of 2 in. for the flattened section. Similarly, the round ductwork is postulated to be flattened, resulting in a slab whose dimensions for the flattened section are $\pi D/2$ x length x an effective thickness of 2 in. The flattened volumes are used in the analyses of packaging and disposal costs. The estimated weights and volumes of compacted ductwork from the Reactor, Turbine Generator, and Radwaste/Control Buildings are given in Table 3.15.

The flattened ductwork is placed into 11 standard maritime containers. The detailed information on the ductwork in the Reactor, Turbine Generator, and Radwaste/Control Buildings was reduced to average values for use in the subsequent analyses of cost and schedule. Given the total length of duct,

TABLE 3.15. Summary of Estimated Weights and Volumes of Ductwork from the Reactor, Turbine Generator, and Radwaste/Control Buildings

Parameter	Reactor Building	Turbine/Gen. Building	Radwaste/Control	Totals
Duct Weight (lb)	66,025	106,895	120,674	293,594
Duct Length (ft)	2,498	3,292	6,537	12,327
Uncompacted Volume (ft^3)	38,649	35,402	23,530	97,581
Compacted Volume (ft^3)	2,706	3,361	3,795	9,862

(2,498 ft + 3,292 ft + 6,537 ft) = 12,327 ft, and the removal rate of 0.279 hours/ft of average duct, 3,443 crew-hours are estimated to be required to remove the ductwork, at an estimated cost of about $289,831, and an estimated radiation dose of 4.38 person-rem. Assuming 3 crews per shift, and a 2-shift operation (i.e., 6 crew-shifts per day), the duration of the ductwork removal is estimated to be about 72 days, or about 14 weeks.

Removal of HVAC Equipment Items

There are about 58 components associated with the ductwork. The crews utilized for these removal activities are larger than the ductwork removal crews, as shown in Table 3.16. The items are separated into eight groups for analysis, depending upon their locations, functions, and exposure rates.

TABLE 3.16. Composition of HVAC Equipment Removal Crew

Pers-hrs/crew-hr	Category	Labor Rate ($/hr)	$/crew-hr[a]
2.0	Craftsman	49.70	99.40
2.0	Laborer	26.37	52.74
0.5	H. P. Tech.	36.82	--[b]
0.5	Foreman	54.84	27.42
5.0			179.56
Average cost per crew-hour, including shift differential[c]			188.54

(a) Includes 110% overhead, 15% DOC profit.
(b) Part of DOC overhead staff, labor costs are in undistributed costs.
(c) 10% shift differential for second shift.

Larger items are sectioned and placed into standard maritime containers for transport and disposal. A total of about 45½ crew-shifts are estimated to be required to remove these components, at a total cost of about $68,351. The estimated total radiation dose to workers is about 2.81 person-rem. The eight groups, the numbers of containers, shipment weights, disposal volumes, removal costs, and radiation doses are summarized in Table 3.17.

TABLE 3.17. Summary of Weights and Volumes of Contaminated HVAC Equipment

Component Group	No. of Items	No. of Containers[a]	Transport Wt. per Container (lb)	Disposal Vol. per Group (ft^3)	Removal Cost ($)	Radiation Dose (per-rem)
Emerg. Fan Coil units	17	1	39,930	1,360	13,115	0.22
Contain. Fan Coil units	5	2	12,430	2,720	8,679	0.44
Contain. Recirc. Fans	7	7[b]	1,800	336	4,050	0.21
Radwaste Air Handlers	11	1	36,339	1,360	8,486	0.14
Radwaste Filter units	3	3	28,680	4,080	12,497	1.05
Turbine Gen. Bldg. Exhausts	4	4	14,970	5,440	8,023	0.14
React. & Turbine Fans and Filter units	10	1	22,435	1,360	7,715	0.13
Standby Gas Treatment	1	4	9,055	5,440	5,786	0.49
Totals	58			22,096	68,351	2.82

(a) Unless otherwise noted, standard maritime container, empty wt. 4,180 lb, disposal volume 1,360 ft^3, cost $3,650.
(b) Special steel box, 4 ft x 4 ft x 3 ft, empty wt. 400 lb, disposal volume 48 ft^3, cost $430.

Removal of Containment Recirculation Fans

The reactor containment vessel contains 7 recirculation fan units. Each unit weighs 1,400 lb, with dimensions of 3.5 ft dia. and 3.25 ft long. The fans are disconnected, openings capped, and lifted out of containment into seven special steel boxes, 4 ft x 4 ft x 3 ft, for a total disposal volume of 336 ft^3. The actual removal time is estimated to be 1.5 crew-hrs for each fan, for a total of 10.5 crew-hrs. Applying a work-difficulty factor of 1.3 and a non-productive time adjustment of 1.574 results in a total of 21.5 crew-hours. Using the HVAC equipment removal crew defined in Table 3.16, the removal cost is $4,050. With an assumed radiation dose rate of 3 mrem/hr, the total occupational dose is estimated to be about 0.21 person-rem for these removal operations.

Containment Fan Coil Units

The reactor containment vessel contains five fan coil units. Each unit weighs 3,300 lb and has dimensions of 10.4 ft x 5.9 ft x 6.9 ft. The units are disconnected from the supporting structure and disassembled by removing the steel skin and sectioning the support frame. The materials are packaged in two standard maritime containers, with average transport weights of 12,430 lb. The actual time to remove and dismantle each unit is estimated to be about 4.5 hrs, for a total of 22.5 crew-hrs. Applying a work-difficulty factor of 1.3 and the non-productive time factor of 1.574, the total duration becomes 46.0 crew-hrs. The labor cost for removal is $8,679. Assuming the radiation dose rate to workers is 3 mrem/hr, the radiation dose to workers is estimated to be 0.44 person-rem.

Emergency Fan Coil Units

The Reactor Building contains 17 emergency fan coil units, having average weights of 2,103 lb, and a total volume of 1,620 ft^3. The units are disassembled by removing the discharge sections and sectioning the support frame. The actual time for removal and packaging is estimated to be about 2 hrs per unit, for a total of 34 crew-hrs. Assuming a work-difficulty factor of 1.3, and a non-productive time factor of 1.574, the total duration of the activity is estimated to be 70 crew-hrs, at a labor cost of $13,115. All 17 units are placed in a single standard maritime container, with a transport weight of 39,930 lb, and a disposal volume of 1360 ft^3. Assuming a radiation dose rate to workers of 1 mrem/hr, the radiation dose to workers is estimated to be about 0.22 person-rem.

Radwaste/Control Building Filter Units and Fans

The Radwaste/Control Building contains three filter units. Each unit weighs 24,500 lb, and has the dimensions 18.5 ft x 16 ft x 13.5 ft. The units are disassembled by removing the access covers, access platforms, and guard rails, removing the pre-filters and HEPA filters, and sectioning the support frame. The actual time to dismantle each unit is estimated to be 10.8 crew-hrs, for a total of 32.4 crew-hrs. Using a work-difficulty factor of 1.3 and a non-productive time adjustment of 1.574, the total time for removal is estimated to be 66.3 crew-hrs, with a crew as defined in Table 3.16, for an estimated removal cost of $12,497. The materials are packaged in three standard maritime containers, each weighing about 28,680 lb, with a total disposal volume of 4,080 ft^3. With an assumed radiation dose rate of 5 mrem/hr, the total occupational dose is estimated to be about 1.05 person-rem.

Radwaste/Control Building Air Handlers

The Radwaste/Control Building contains 11 air handling units, with average weights of 2,924 lb, and average volumes of 176 ft^3. The units are disassembled by removing the grates, handrails, and access panels, and are placed into one standard maritime container. The transport weight is estimated to be 36,339 lb, and the disposal volume is 1,360 ft^3. The actual time for removal and packaging is estimated to be about 2 crew-hrs per unit, for a total of 22 crew-hrs. Assuming a work-difficulty factor of 1.3, and a non-productive time factor of 1.574, the total work duration is about 45 crew-hrs, with a total labor cost of $8,486. Assuming a radiation dose rate of 1 mrem/hr, the estimated radiation dose to workers is 0.14 person-rem.

Reactor and Turbine Building Fans and Filter Units

The Reactor and Turbine Generator Buildings contain 10 air handling and filter units, having average weights of 1,826 lb and average volumes of 104 ft^3. The filters are removed and packaged for disposal, and the support frame is sectioned. The units are placed into one standard maritime container, having a transport weight of 22,435 lb, and a disposal volume of 1360 ft^3. The actual time to remove and package these units is estimated to be about 2 hrs per unit, for a total of 20 crew-hrs. Assuming a work-difficulty factor of 1.3 and a non-productive time factor of 1.574, the total work duration is about 41 crew-hrs, for a total labor cost of $7,715. Assuming a radiation dose rate of 1 mrem/hr, the radiation dose to workers is estimated to be 0.13 person-rem.

Turbine Generator Building Exhaust Air Units

The Turbine Generator Building has four exhaust fans located on the roof of the structure and connected to the building exhaust plenum. Each fan unit is 9.12 ft x 10.3 ft x 17.5 ft in dimension and weighs about 10,790 lb. The units are disassembled by removing the top half of the housing, the damper transition piece, and damper head assembly, and cutting into four sections, each 7 ft high and 4.1 ft on the quarter-radius. The fan housing is cut into four quarter-sections. Each unit is packaged in a single standard maritime container, having a transport weight of 14,970 lb per container, and a total disposal volume of 5,440 ft^3. The actual duration of the removal time for the four units is estimated to be 20.8 crew-hrs. Assuming a work-difficulty factor of 1.3 and a non-productive time factor of 1.574, the total work duration time becomes 42.6 crew-hrs, for a total labor cost of $8,023. Assuming a radiation dose rate of 1 mrem/hr, the total radiation dose to workers is estimated to be 0.14 person-rem.

Standby Gas Treatment System

The standby gas treatment system includes a filter but no cryogenic storage units. The filter unit has the dimensions of 46.3 ft x 7.33 ft x 6.36 ft, weighs about 19,500 lb, and includes a pre-filter, two HEPA filters, and two activated carbon filters. The unit is sectioned into four segments, whose lengths vary from 6 ft to 11.5 ft, to 11.9 ft, to 17 ft, and are packaged in four standard maritime containers, for a total disposal volume of 5,440 ft^3. Each container weighs about 9,055 lb, on the average. The removal and disassembly effort is estimated to require about 15 crew-hrs. Assuming a work-difficulty factor of 1.3 and a non-productive time factor of 1.574, the total activity duration becomes 30.7 crew-hrs, for a total labor cost of $5,786. Assuming a radiation dose rate of 5 mrem/hr, the radiation dose to workers is estimated to be about 0.02 person-rem.

Summary of Estimated Costs and Radiation Doses for HVAC System Removal

The radiation dose accumulated by the HVAC ductwork and equipment removal crews is based on the assumed dose rates for each operation (specified above for the individual tasks) and is estimated to be approximately 7.19 person-rem.

The HVAC ductwork and supporting equipment is packaged for disposal in standard maritime containers and special steel boxes. The compacted ductwork occupies about 11 maritime containers, and the HVAC equipment occupies an additional 16 maritime containers and 7 special steel boxes. The numbers of containers, average transport weights, and disposal volumes for the removal of these materials are summarized in Table 3.18 The costs for removal, packaging, transport, and disposal of these materials are summarized in Table 3.19.

TABLE 3.18. Numbers of Containers, Transport Weights, and Disposal Volumes for HVAC Ductwork and Equipment

Component	Number of Containers[a]	Average Wt. of Loaded Containers	Disposal Volume (ft^3)
Ductwork	11[a]	30,870 lb	14,960
Equipment	16[a]	19,107 lb	21,760
	7[b]	1,800 lb	336

(a) Standard maritime containers, 8 ft x 8½ ft x 20 ft, 4,180 lb empty.
(b) Special steel boxes, 4 ft x 4 ft x 3 ft, empty wt. 400 lb, disposal volume 48 ft^3, cost $430.

TABLE 3.19. Estimated Costs for HVAC Removal and Disposal

Cost Element	Estimated Cost (1993 $)				
	Labor	Packaging	Transport	Disposal	Total
Ductwork	289,831	40,150	1,993	761,531	1,093,505
Equipment	68,351	61,410	4,143	1,138,636	1,272,540
Total	358,182	101,560	6,136	1,200,167	2,366,045

3.4.8 Decontamination and Removal of Contaminated Surfaces

The principal buildings requiring decontamination and dismantlement in order to obtain license termination at the reference BWR power station are the Reactor, Turbine Generator, and Radwaste/Control Buildings. The activities necessary to remove the piping and equipment from the Reactor and Turbine Generator Buildings are described in some detail in separate appendices, because of the size and complexity of those efforts. Removal of piping and equipment from the Radwaste/Control Building is relatively straightforward, complicated primarily by the need to cut openings through a number of shielding enclosures to obtain access for dismantlement and egress for removal of the various tanks, pumps, heat exchangers, etc. Once the piping and equipment have been removed, the structures are vacuumed to collect any loose debris and/or radioactive materials. Following the vacuuming, the structures are surveyed to identify areas of significant radioactive contamination, which are then washed using high-pressure water/vacuum cleaning systems. The resulting waste water is collected and treated for disposal. After the surfaces have again dried, another survey is conducted to identify areas that are still contaminated. Additional high-pressure water/vacuum cleaning and/or surface removal using scabblers is used to remove the remaining contamination on the surfaces, with the waste water treated and the removed concrete collected and packaged for disposal. When surface removal is necessary, the concrete surfaces are assumed to be removed to a depth of 1 inch, based on data gathered in an experimental measurement program conducted at several reactor power stations.[6] Removal of concrete to greater depths may be necessary in selected locations where the radioactive contamination has penetrated more deeply. The surface cleaning, surface removal, and clean concrete cutting activities are estimated using Unit Cost Factors developed for those efforts.

Cleansing of Contaminated Surfaces

The areas requiring vacuuming and washing are estimated by inspection of the building drawings and using engineering judgment as to which specific areas may need treatment. For example, essentially all surfaces within all of the buildings are postulated to be vacuumed and washed, including the inner surface of the containment vessel itself. Those areas that contained tanks, pumps, valves, and other equipment that might leak radioactively contaminated liquids on the floor are postulated to require surface removal in addition to high-pressure water/vacuum cleaning. It is postulated that all surfaces requiring concrete removal are horizontal surfaces. The areas of concrete surfaces expected to require vacuuming and washing, and to require surface removal, are listed in Table 3.20.

There are several large areas in the Reactor Building that are covered with stainless steel lining (spent fuel pool and gate, and cask loading pit and gate) and several lined sumps in the Radwaste/Control and the Turbine Generator Buildings. The dryer/separator storage pool and gate and the refueling cavity above the reactor containment vessel were washed during Period 2. Those areas are washed, sectioned, packaged, and transported to an LLW disposal facility for disposition. The areas involved are listed in Table 3.22. The concrete behind or beneath these stainless steel linings is postulated to be uncontaminated, even though some small areas might have been contaminated by leakage through the lining. The cost of washing these surfaces is estimated to be $24,251. The radiation dose to workers doing the washing is estimated to be 0.23 person-rem. The cutting of the liners is described in detail in the Unit Cost Factor for removal and packaging of

TABLE 3.20. Surface Cleaning, Concrete and Metal Surface Removal in Contaminated Buildings

Building	Contaminated Surfaces Treated: Vacuum/Wash (ft^2)	Contaminated Surfaces Treated: Removed (ft^2)	Volume[a] (ft^3)
Concrete Surfaces[b]			
Reactor Bldg.	30,537	15,653	2,317
Turbine Gen. Bldg.	8,042	1,481	219
Radwaste/Control Bldg.	21,711	4,655	689
Subtotals	69,290	21,789	3,225
Metal Surfaces[c]			
Reactor Bldg.	33,906[d]	51,926	9,616
Turbine Gen. Bldg.	1,526	1,526	283
Radwaste/Control Bldg.	1,526	1,526	283
Subtotals	36,958	54,978	10,182
	97,248	76,767	13,407

(a) Volume shown is packaged disposal volume.
(b) Average depth of removal is 1 in.
(c) Average thickness of metal is 1/4 in.
(d) Refueling cavity and dryer/separator pools washed during Period 2.

contaminated pool liners in Appendix C. The labor costs for removing the metal liners in all buildings is estimated to be $36,173, andthe radiation dose to cutting workers is estimated to be 0.80 person-rem. The total pckaged volume of plate material removed from all buildings is estimated to be about 10,182 ft^3, with a weight of about 572,686 lb. This material is placed into 16 modified maritime containers (cost $79,440) and transported to the LLW disposal facility (cost $2,883). The disposal cost is $663,148, including the handling surcharge. The total cost of removing, packaging, transporting, and disposing of the liner material is $781,187, without contingency.

Vacuuming and washing of the concrete surfaces is estimated to cost $34,673. The radiation dose to workers doing the vacuuming/washing is estimated to be 0.41 person-rem.

Removing the contaminated concrete surfaces (about 21,800 ft^2) is estimated to be $372,288, and the radiation dose to workers doing the surface removal is estimated to be 6.32 person-rem. The contaminated concrete surface material is postulated to be packaged in 436 55-gallon drums, resulting in a disposal volume of 3,226 ft^3, and a packaging cost estimated to be $11,744. Transport and disposal of the removed concrete surface material are estimated to cost $1,283 and $156,383, respectively.

The estimated costs and radiation doses for cleaning, removal, transport, and disposal of the contaminated surface materials are summarized in Table 3.21, together with the costs for treating and disposing of the contaminated wash water. The total volume of water resulting from the washing operations which requires treatment, packaging, and disposal is about 13,280 gallons. The cost of treating and disposing of the water and its contained solids is estimated to be $247,141* with the radiation dose to workers about 0.32 person-rem.

TABLE 3.21. Estimated Costs and Radiation Doses for Cleaning, Removing Packaging, Transporting, and Disposing of Contaminated Surfaces

Operations	Costs (1993 $)	Radiation Doses (person-rem)
Concrete Surfaces		
Vacuum/Wash	34,673	0.41
Surface Removal	372,288	8.55
Packaging	11,744	
Transport	1,283	
Disposal	156,383	
Metal Surfaces		
Wash	24,251	0.29
Segment	36,173	1.09
Package	78,983	
Transport	2,883	
Disposal	663,148	
Totals	1,381,812	10.34
Undistributed		
Wash Water Treat/Dispose[a]	247,141*	0.32

(a) Based on an estimated volume of waste water of 12,156 gallons.

Another factor affecting total license termination cost is the amount of contaminated concrete surface removed during facility decontamination. In the original BWR study (NUREG/CR-0672), the conservative assumption was made that a 2-inch depth of concrete surface was removed from all contaminated floors in the three potentially contaminated buildings (Reactor, Turbine Generator, and Radwaste/Control Buildings). In this reevaluation study, the assumption is to remove a 1-inch depth of surface from only those areas anticipated to require further decontamination following surface washing, a significantly smaller area than in the previous study. The 1-inch depth may also be quite conservative, considering data on contaminant penetration of concrete surfaces given in NUREG/CR-4289.[7] Thus, an analysis of the sensitivity of DECON license termination costs to a range of concrete surface removal depths was performed.

The calculation assumed that the length of Period 4 was constant, i.e., constant overhead staff costs, because the concrete surface removal effort is carried out in parallel with other activities on the schedule. The results are illustrated in Figure 3.10. The total DECON cost is not very sensitive to the depth of concrete removed. For removal depths ranging from 0 in. to 1.0 in., the total DECON cost increases by less than $0.7 million.

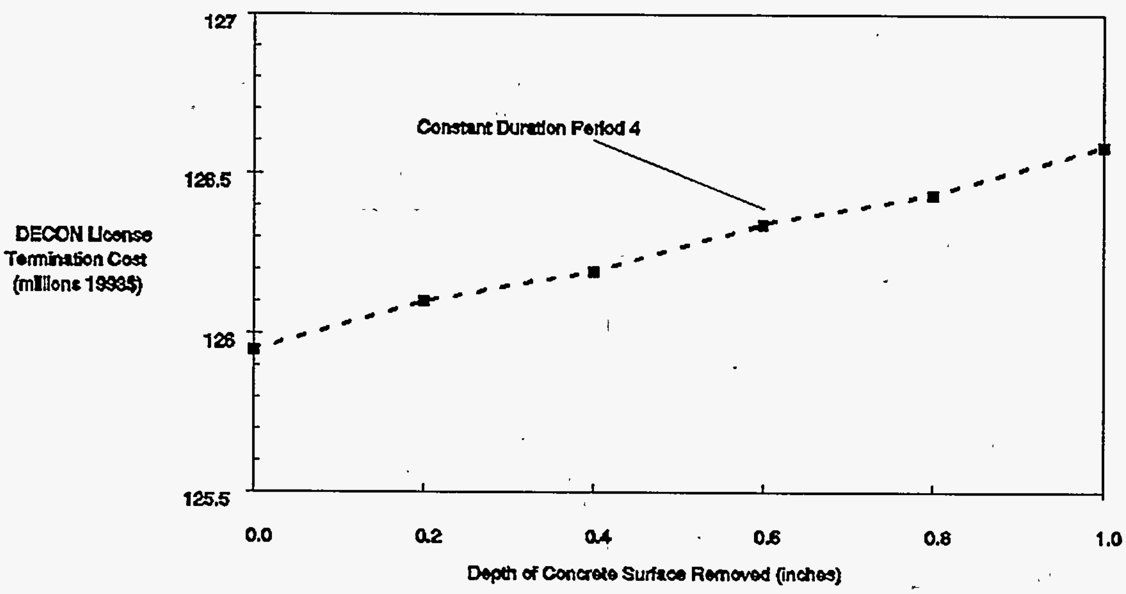

FIGURE 3.10. Sensitivity of License Termination Cost to Varying Depths of Contaminated Concrete Removal During DECON

3.4.9 Decontamination and/or Removal of Building Cranes

There are six cranes within the facility that must be removed or decontaminated: the Reactor Building bridge crane and the Refueling Pool bridge crane in the Reactor Building, the Turbine Generator Building bridge crane, the Filter/Demineralizer bridge crane, the Truck Loading bridge crane, and the Radwaste Storage bridge crane in the Radwaste/Control Building. The estimated number of containers, transport weights, total costs, and radiation doses associated with decontamination and/or removal of these cranes are summarized in Table 3.22.

TABLE 3.22. Estimated Costs and Doses for Crane Removal

Item	No. of Containers[a]	Transport Wt. (lb)	Estimated Cost (1993 $)	Estimated Dose (person-rem)
Reactor Building Bridge	1	39,180	171,197	0.0
Turbine Gen. Bldg. Bridge	0	0	30,166[b]	0.0
Refueling Bridge	1	18,820	74,709	0.16
Filter/Demin. Bridge	1	27,450	149,197	0.0
Truck Loading Bridge	0	0	6,034[b]	0.0
Radwaste Storage Bridge	0	0	6,033[b]	0.0
Totals	3		437,336	0.16

(a) Standard maritime containers, empty wt. 4180 lb, disposal volume 1360 ft^3, cost $3,650.
(b) Costs for decontamination of bridge, trolleys, and cables only. No dismantlement or disposal.

The Reactor Building crane is anticipated to be disengaged from its moorings by a vendor, lowered to the operating floor, decontaminated, surveyed, and, except for the trolley drums and associated cables, abandoned in place. The trolley drums and associated cables are packaged and shipped to the LLW disposal site at Hanford. The Turbine Generator Building crane is decontaminated and left in place. These are the final decommissioning activities before the license termination survey commences.

The principal cost elements of removal of the Reactor Building bridge crane are summarized in Table 3.23. These activities are estimated to cost about $171,197, not including a 25% contingency. The estimated costs, staffing, and schedule for the removal of the Reactor Building crane are given in Table 3.24.

After removal of the trolley drums and associated cables, the decontamination process is estimated to require one week for the Reactor Building crane. Two additional weeks are estimated to be required for the in situ decontamination of the Turbine Generator Building crane. It is estimated that two dedicated 5-person crews, as defined in Table 3.25, working one crew on each of two shifts, will be required to complete these activities, at a total cost of $45,250. Very little occupational radiation exposure is anticipated from these activities.

TABLE 3.23. Summary of Estimated Costs for Reactor Building Bridge Crane Dismantlement and Disposal Activities

Cost Element	Estimated Cost (1993 $)[a]
Removal of Reactor Building Crane	75,680[b]
Decontamination/Survey of Cranes[c]	15,083
Disposal of Drum and Cable:	
Maritime Containers (1)	3,650[d]
Transportation (1 OWT shipment)	181
Disposal	76,603[e]
Total	171,197

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) See Table 3.24 for details.
(c) Based on crew defined in Table 3.25.
(d) Based on Table B.3 in Appendix B.
(e) For disposal at the U.S. Ecology facility at Hanford.

TABLE 3.24. Estimated Contractor Costs, Manpower, and Schedule for Removal of the Reactor Building Crane[a]

Component	Staffing[b]	Estimated Cost (1993 $)[c]	Estimated Time, days
Equipment	-	22,000	-
Mobilization & Demobilization	5 people	22,000	10
Rigging Operations	8 people	14,080	4
Drum/Cable Removal[d]	5 people	17,600	8
Totals		75,680	22

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, reference plant decommissioning cost projections, dated July 21, 1992.
(b) Specialty Contractor staff.
(c) $55/person-hour is used in the calculations to estimate built-up job cost.
(d) Includes removal and packaging of the trolley drum and cable (~40,000 lb) in a maritime container.

TABLE 3.25. Crew Composition and Exposure Rates Postulated for Crane Cleanup

Man-hrs/crew-hr	Category	($/hr)	Labor Rate $/crew-hr[a]	Dose Rate (mrem/crew-hr)
2.0	Laborer	26.37	52.74	0
2.0	Craftsman	49.70	99.40	0
0.5	H.P. Tech.	36.82	-[b]	0
0.5	Foreman	54.84	27.42	0
5.0			179.56	0

Average cost per crew-hour, including shift differential[c] $188.54

(a) Includes 110% overhead, 15% DOC profit.
(b) Included for completeness; costs are accounted for in undistributed staff costs.
(c) 10% shift differential for second shift.

The Refueling Bridge crane is about 46 ft in length, with a nominal width of 6 ft. For purposes of estimating the weight of the bridges, it is assumed that it is constructed using two 24-in. I-beams, covered with 1/8-in. steel diamond plate. Each bridge has mounted on it a telescoping mast assembly with a fuel assembly grapple. Each bridge has safety railings along both edges of the bridge, made from 1½-in.-dia. steel pipe. The total weight of the bridge and accessories is estimated to be 14,640 lb, plus the 4,180-lb container, for a shipment weight of about 18,820 lb.

The manipulator assembly and the railings are removed from the bridge, and the bridge is lifted from across the pool/cavity to the operating floor, where it is cut into sections to fit within one standard maritime container.

The operations to remove the refueling bridge are estimated to require about 6 crew-hours, which when multiplied by the respiratory protection factor (1.2) and the non-productive time factor (1.574) results in about 12 crew-hours to complete the tasks. Costs for labor, packaging, transport, and disposal are estimated to be $2,262, $3,650, $181 and $68,616, respectively, for a total of about $74,709. The associated radiation dose is estimated to be about 0.16 person-rem.

Decontamination and removal of the Filter/Demineralizer bridge crane, while somewhat shorter in span, is nearly identical with those operations for the Reactor Building bridge crane, in that the drum and cables are removed and packaged for disposal and the bridge is lowered to the operating floor and decontaminated and abandoned in place. It is estimated that the removal, decontamination, transport, and disposal costs, and disposal volumes are essentially identical with the Reactor Building bridge crane, without the mobilization/demobilization costs, i.e., $149,197 and one standard maritime container of 1360 ft^3.

The Truck Loading bridge crane and the Radwaste Storage bridge crane are postulated to be decontaminated and left in place. The decontamination effort is estimated to require about 4 crew-shifts per crane, for a total of 8 crew-shifts, or about $12,067.

3.4.10 Environmental Monitoring During Dismantlement

Environmental monitoring of nuclear facility sites is a continuing activity, from before the facility is constructed, through construction and operation, through shutdown and layup, through safe storage with the fuel stored in the pool, and finally during dismantlement, until the nuclear license is terminated. For development of cost estimates for environmental monitoring, it is assumed that a specialty contractor is contracted to provide this service. It is also assumed that the monitoring costs are allocated 90% to reactor/pool operations and 10% to decommissioning until the spent fuel has been removed from the pool. Thereafter, environmental monitoring costs are 100% applicable to decommissioning, beginning at the start of Period 4, Dismantlement.

The estimated annual costs for environmental monitoring are presented in Table 3.26. Since these activities are not particularly dependent upon exactly what is happening at the reactor site, the same annual costs are assumed to apply to the dismantlement period of DECON, to the extended safe storage period of SAFSTOR, and to the entombment decay period of ENTOMB.

3.4.11 Regulatory Costs During Dismantlement: Period 4

There are a number of costs that arise because of regulatory requirements. The exact nature and magnitude of these costs are somewhat dependent upon in which state the facility is located. The regulatory costs given in Table 3.27 are developed for the WNP-2 reactor in the state of Washington. Actual costs at a site in another state could be significantly different.

TABLE 3.26. Estimated Annual Costs for Environmental Monitoring

Cost Element	Activities	Annual Cost (1993 $)
Health Physicist (0.05 person-years/yr)	Collect data, archive samples and data	6,211
H.P. Supervisor (0.10 person-years/yr)	Data analysis, prepare reports.	14,864
Chemist (0.10 person-years/yr)	Sample preparation/analysis	12,710
Craftsman (0.10 person-years/yr)	Maintain/calibrate instruments	10,339
Q.A. Engineer (0.02 person-years/yr)	Provide Q.A. audits	1,677
Utilities and Services		1,133
Supplies and Equipment		1,669
Total		48,603

TABLE 3.27. Estimated Regulatory Costs During Dismantlement: Period 4

Regulatory Agency	Estimated Cost (1993 $)[a]
Washington State Compliance Monitoring	244,000/yr[b]
NRC (during periods of active decommissioning)	115,300/yr[c]
NRC (during Safe Storage)	15,184/yr[b]
Total Regulatory Costs	374,484/yr
Certification Survey[d]	159,155[d]

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) See Table B.16.
(c) Based upon discussions with the NRC, 1/2 FTE, with roughly 1/3 time actually spent onsite during periods of active decommissioning, would be a reasonable value to use for this cost element.
(d) Listed for completeness. Included in total termination survey costs, not included in the total regulatory costs.

3.4.12 License Termination and Confirmation Surveys

The operations necessary to perform the license termination survey of the decontaminated buildings are discussed in detail in Appendix B. The costs associated with the termination survey by the licensee and confirmation survey by the NRC are estimated to be $1,058,344, and the radiation dose to workers doing the surveys is essentially zero.

3.5 SENSITIVITY OF RESULTS TO DISPOSAL FACILITY LOCATION AND TO THE TIME-VALUE OF MONEY

The cost of disposing of LLW at an alternative disposal facility, and the impact of the time-value of money on the amount of funding needed in a utility's decommissioning fund prior to reactor shutdown, are discussed in this section.

3.5.1 Cost Impact of Using Alternative Disposal Facilities

The reference BWR is located within the area of the Northwest Compact for purposes of LLW disposal. Thus, the transportation and disposal costs presented in the preceding text have reflected the distance between the WNP-2 site and U.S. Ecology's Washington Nuclear Center in Richland, Washington (a distance of about 15 miles) and the disposal rates at that facility. Most of the power reactors in the U.S. are located outside of the areas of the Northwest and Rocky Mountain Compacts, and must send their LLW to Chem-Nuclear's disposal facility in Barnwell, South Carolina, with a resulting increased cost. However, effective July 1, 1994, the Barnwell facility will no longer accept waste from generators located outside of the Southeast Compact region, and those waste generators must store their wastes locally until a disposal facility becomes available in their region.

To determine the sensitivity of the total license termination cost to disposal facility location, two additional calculations were made using the Cost Estimating Computer Program (Appendix C): 1) the LLW from the reference BWR was transported to and disposed of in the Barnwell facility; and 2) the LLW was transported a distance of 500 miles to the U.S. Ecology facility. The Greater-Than-Class C radioactive wastes were postulated to be disposed of in DOE's geologic repository in both analyses. The disposal rate schedule for the Barnwell facility was used to calculate the LLW disposal costs for the first scenario. Estimates developed within the DOE's Office of Civilian Radioactive Waste Management were utilized to estimate the costs of GTCC material disposal.

The resulting total license termination cost for the situation where the LLW from the reference BWR was transported to and disposed of in the Barnwell facility was $244,373,941, without contingency. This cost is comprised of the decontamination, removal, and packaging costs (which remain the same for both situations), the transport costs (which increased from $1,096,332 to $6,436,540) and the disposal costs (which increased from $34,583,597 to $147,030,218), without contingency. These results are expected to represent a likely upper bound for those transport/disposal costs because of the distance between the reference BWR and the Barnwell facility. The impact of transporting the LLW from WNP-2 a distance of 500 miles to the U.S. Ecology facility, as in the second scenario, was simply an increase in transport costs of about $1,933,557.

An additional brief study of the cost impact of increased base rates at the U.S. Ecology disposal facility at Hanford was carried out using the CECP. The calculations were performed for base disposal rates of $50/ft^3$, $100/ft^3$,

$300/ft^3, $500/ft^3, and $1000/ft^3. The associated disposal facility fees, surcharges, and taxes were held constant. All other parameters of the CECP calculation were also held constant. The results of the analysis showed that the total cost for DECON increased almost linearly with increased disposal cost, from $167.68 million for the $50/ft^3 rate to $805.22 million for the $1000/ft^3 rate, all values including a 25% contingency. The results of the calculations are listed in Table 3.28. The fractions of cost attributable to labor and materials (A), energy (B), and LLW disposal (C), and the adjusted DECON cost (total DECON cost minus property taxes and nuclear insurance) employed in the formula for DECON cost escalation, as discussed in Section 3.8, are also listed in the table and are illustrated in Figure 3.11 as functions of the LLW disposal charge rates.

TABLE 3.28. Sensitivity of DECON Cost to LLW Disposal Charge Rates[(a)]

Disposal Charge Rate ($/ft^3)	Costs, With Contingency[(b)] (millions of 1993 $) Burial	Total DECON	Terms for LLW Disposal Cost Escalation Formula[(c)] Labor/Matls. (A)	Energy (B)	Disposal (C)	Total - [Taxes & Ins.][(d)] (millions of 1993 $)
50	52.68	167.68	0.636	0.032	0.332	158.59
100	86.23	201.23	0.525	0.027	0.449	192.14
300	220.45	335.45	0.309	0.016	0.675	326.36
500	354.67	469.67	0.219	0.011	0.770	460.58
1000	690.22	805.22	0.127	0.006	0.867	796.13

(a) All other calculation parameters are held constant.
(b) Costs include a 25% contingency.
(c) These terms are discussed in Section 3.7.
(d) Taxes & Insurance costs for 1993 = $9.09 million.

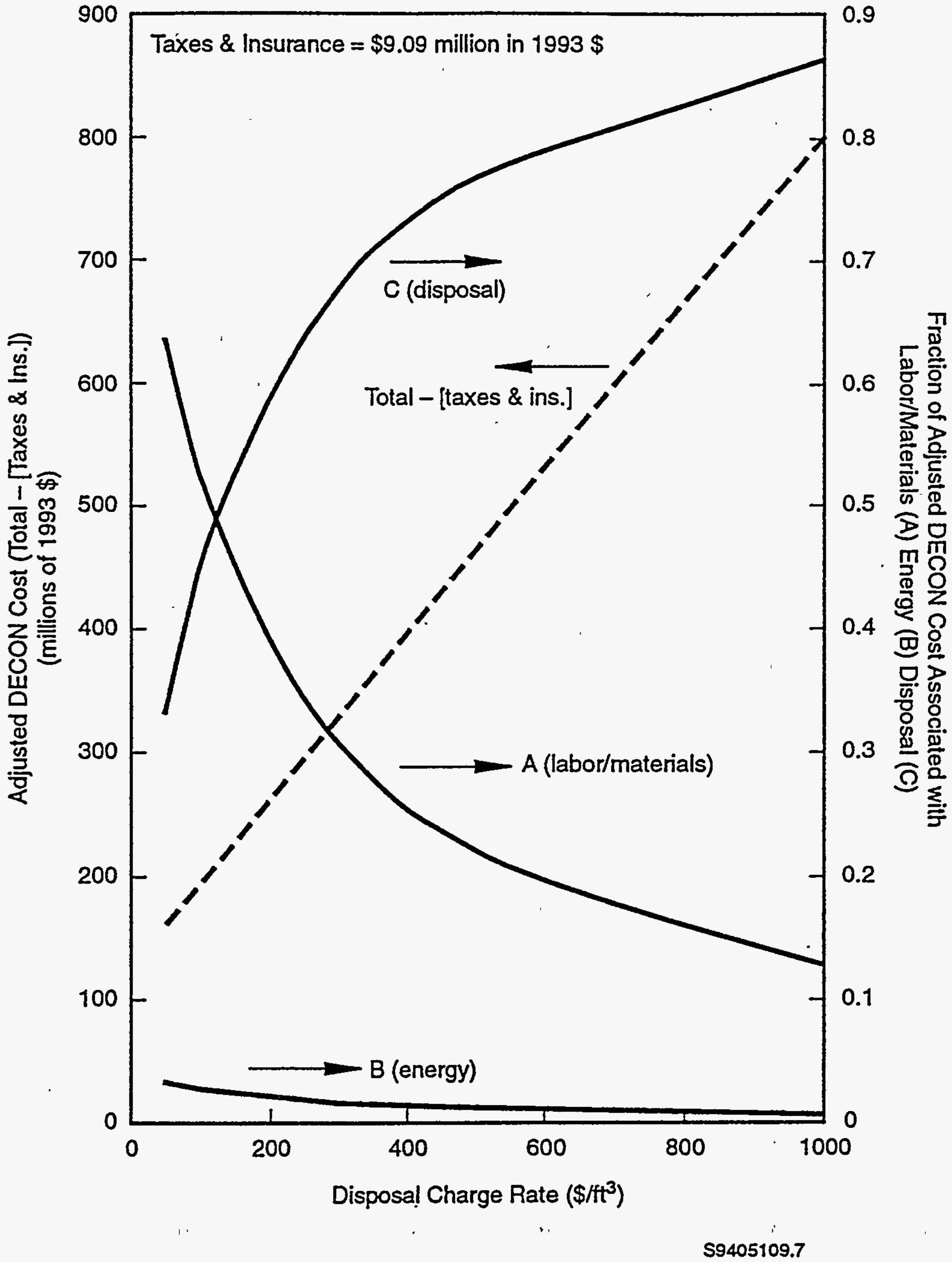

FIGURE 3.11. Variation of DECON Escalation Formula Terms as Functions of Low-Level Waste Disposal Charge Rates

As the disposal rates increase, the incentive for volume-reduction efforts increases, and it is likely that the LLW disposal costs would not increase in direct proportion to the disposal rate increases due to the probable LLW volume reductions. However, because the disposal facilities must have sufficient revenue to cover fixed costs, it is also likely that the disposal charge rates will tend to increase as the volume-reduction efforts by the waste generators reduce the annual receipts at the disposal facilities. The net effect of these interactions on future LLW disposal costs cannot be predicted with any great certainty, except to be assured that disposal costs are unlikely to decrease over time.

3.5.2 Impact of the Time-Value of Money on DECON Funding Requirements

The amount of money that must be in a utility's decommissioning fund prior to reactor shutdown is a function of the time-value of money. Because the money in the fund continues to earn interest until expended, the funding needed for expenditures made in the future is less than the funding needed for immediate expenditures. For the DECON alternative, expenditures are made during five successive time periods: 1) during initial planning and engineering; 2) during deactivation and plant lay-up; 3) during safe storage of the plant; 4) during the pre-dismantlement ramp-up of the DOC staff; and 5) during the decontamination and dismantlement of the plant. These expenditures are distributed over 8.8 years, with the largest fraction of the total expenditures occurring during the last several years. The present value of these distributed expenditures can be calculated using the following expression:

$$PV(DECON) = \sum_{i}^{k} \frac{(\text{Pre-Engineering})_i}{(1+x)^i} + \sum_{k}^{m} \frac{(\text{Deactivation})_i}{(1+x)^i} + \sum_{m}^{n} \frac{(\text{SafeStorage})_i}{(1+x)^i} + \sum_{n}^{n} \frac{(\text{DOCRamp-up})_i}{(1+x)^i} + \sum_{n}^{p} \frac{(\text{Decon/Dismantle})_i}{(1+x)^i}$$

where x is the net (interest rate minus inflation rate) discount rate, assumed to be constant at 3% per year over the total time period and i is the number of years since 2-1/2 years before reactor shutdown. The expenditures during each of the indicated periods are assumed to be evenly distributed over the period, permitting average expenditures per unit time to be used in the expression.

Using the values from Table 3.1 of this chapter in the above expression results in the present value of the total license termination cost at 2.5 years prior to reactor shutdown being $106.6 million, as compared with the constant dollar value of $126.2 million, neither values including a 25% contingency. Thus, requiring the funding needs to be calculated in constant dollars prior to reactor shutdown results in about a 18% overestimate of the funding needs for DECON, and will provide a significant safety margin to cover unforeseen events.

3.6 LLW CLASSIFICATION

The LLW generated during DECON at the reference BWR can be classified into the four categories defined in 10 CFR 61.55. The approach used was to examine the nature and magnitude of the radioactivity content of the wastes, based on the contamination levels and activation levels originally developed in NUREG/CR-0672.[1] The highly activated portions of the reactor vessel internals are sorted into Greater-Than-Class C, and/or Class B/Class C. A limited amount of waste resulting from waste water treatment is classified as Class B/C. The balance of the LLW is classified as Class A. The quantities of waste contained in each classification are estimated to be 1) Class A: 492,570 ft^3 [13,948.0 m^3] (97.35%); 2) Class B/C: 13,152 ft^3 [372.4 m^3] (2.60%); and 3) GTCC 242 ft^3 [6.85 m^3] (0.05%). Estimates based on measurements made at a number of reactor facilities by Abel, et al.[6] generally agree with these estimates.

3.7 COEFFICIENTS FOR THE COST ESCALATION FORMULA

The cost elements for DECON at the reference BWR, summarized in Table 3.1, are organized in Tables C.1 and C.2 of Appendix C into the categories of Labor and Materials, Energy, and Disposal, to provide the cost terms in the decommissioning cost escalation formula presented in 10 CFR 50.75(c). That formula has been modified to exclude property taxes and nuclear insurance

(T & I) costs from the total decommissioning cost used in the escalation calculation, since T & I costs do not necessarily follow the general inflation trends. The T & I costs in Year X dollars are added to the decommissioning cost after escalation to Year X. The revised formula has the following form:

$$\text{Estimated Cost}_{(\text{Year X \$})} = [\text{Total Cost} - (\text{T \& I})]_{(1993\ \$)}\ [A\ L_x + B\ E_x + C\ B_x] + [\text{T \& I}]_{(\text{Year X \$})}$$

where the values of the factors in the equation for the reference BWR are:

$[\text{Total Cost} - (\text{T \& I Cost})]_{(1993\ \$)}$ = \$149 million

A (labor/materials) = 0.676
B (energy) = 0.034
C (disposal) = 0.290
[T & I](1993 $) = $9.1 million

all values including a 25% contingency. L_x and E_x are the escalation factors for Labor and Energy from the base year (1993) until the year of the estimate (Year X), and their values can be derived from U.S. Department of Labor statistical data, as discussed in NUREG-1307 Revision 4, Report on Waste Burial Charges.[8]

The factor for waste disposal escalation, B_x, is given by:

Disposal Cost (Year X, at Site J)/Disposal Cost (Year 0, at Hanford site).

This factor is derived in Reference 8 for disposal at the Hanford and Barnwell facilities, based on the inventory of decommissioning wastes developed in the original BWR study,[1] i.e., Year 0 is 1986. Subsequent revisions to NUREG-1307 will utilize the waste inventory from the current PWR and BWR reevaluation studies as the baseline inventories upon which to develop the waste disposal escalation factor, B_x for the reference PWR and BWR. Thus, for Hanford disposal in 1993, B_x will have a value of 1.00. For disposal at Barnwell in 1993, B_x will have a value of 4.251, based on the estimated total burial costs at Hanford ($34.6 M) and at Barnwell ($147.0 M), from Tables C.1 and C.2 in Appendix C.

3.8 REFERENCES

1. H.D. Oak, G. M. Holter, W. E. Kennedy, Jr., and G. J. Konzek. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington, June 1980.

2. SAFSTOR REPORTS, No. 1 through No. 95. Planning documents for deactivating plant systems during the initial period of SAFSTOR, prepared by the staff of the Rancho Seco Nuclear Power Station, Sacramento Municipal Utility District, Sacramento, California. 1991.

3. W. J. Manion and T. S. LaGuardia. Decommissioning Handbook, DOE/EV/10128-1, U.S. Department of Energy, Washington, D.C., November 1980.

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

5. "Means Estimating Handbook 1991," Robert Snow Means Company, Inc., Kingston, Massachusetts.

6. K. H. Abel, et al. Residual Radionuclide Contamination Within and Around Commercial Nuclear Power Plants, NUREG/CR-4289, U. S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington. February 1986.

7. Report on Waste Burial Charges - Escalation of Decommissioning Waste Disposal Costs at Low-Level Waste Burial Facilities. NUREG-1307, Revision 4, U.S. Nuclear Regulatory Commission, Washington, D.C. April 1994.

4.0 SAFSTOR FOR THE REFERENCE BWR POWER STATION

The second alternative considered in this reevaluation of decommissioning of the reference boiling water reactor (BWR) is SAFSTOR. Two possible scenarios are evaluated. In Scenario 1 (SAFSTOR1), it is postulated that all of the radioactivity on materials remaining within the facility following initial cleanout (except the reactor pressure vessel [RPV], insulation, and sacrificial shield) will decay to unrestricted release levels within 60 years following reactor shutdown. The RPV, insulation, and sacrificial shield are removed for disposal as low-level radioactive waste (LLW) within the 60-year period following reactor shutdown, thus permitting license termination without removing all of the initially contaminated systems and equipment for disposal as LLW. In Scenario 2 (SAFSTOR2), it is postulated that the nature of the radioactive contaminants (i.e., significant fractions of longer-lived isotopes such as ^{137}Cs may be present) will not allow the radioactivity to decay to unrestricted release levels within 60 years following reactor shutdown. In this latter situation, essentially all of the decontamination/removal/packaging/transport/disposal activities performed during Period 4 of DECON will be required during Period 5 of SAFSTOR2 to achieve unrestricted release levels within the facility, and license termination.

For these analyses, a decommissioning operations contractor (DOC) is assumed to be contracted approximately 2½ years prior to reactor shutdown to develop the plans and procedures to be carried out during decommissioning. The reactor and associated systems are postulated to be shut down and deactivated for an initial safe storage period, which continues only until all of the spent nuclear fuel (SNF) has been removed from the spent fuel pool (SFP). Fuel from the last core is postulated to remain in the SFP for about 4.6 years after shutdown until it is sufficiently cooled to permit dry storage, at which time the fuel remaining in the SFP is transferred into a dry fuel storage facility onsite. During the period of pool storage, the SFP and the transport cask handling facilities required to support the SFP operations are maintained in service, since acceptance of SNF by the U.S. Department of Energy's Office of Civilian Radioactive Waste Management (DOE-OCRWM) is expected to continue during that period.

The choice made for this study to empty the SFP as quickly as possible and place the remaining SNF into a dry storage facility onsite was made to facilitate the earliest possible completion of DECON. For consistency in the analyses, this same approach was utilized in the SAFSTOR and ENTOMB alternatives. It should not be inferred from this study decision that continued storage of the SNF in the SFP is unacceptable. For shorter storage periods (less than 13 years for WNP-2), continued pool storage may be the most cost-effective approach, as discussed in Appendix D.4.3, avoiding the cost of purchasing sufficient additional dry storage units to store the remaining in-pool SNF onsite during the safe storage period.

Once the SFP is empty, the pool-related systems are deactivated, and the facility is put into safe storage for about 53.7 years, during which time the levels of radioactive contamination on materials (not activated materials) are postulated to decay to levels that satisfy the criteria for unrestricted use (see Regulatory Guide 1.86[1]), for SAFSTOR1, and selected active dismantlement activities are carried out upon termination of the extended safe storage period. For SAFSTOR2, all of the contaminated systems and materials are postulated to still be contaminated to levels above unrestricted release at the end of the safe storage period and must be disassembled and removed. Upon completion of these activities, the license termination survey is conducted, resulting in release of the total reactor facility for unrestricted use. Summaries of the estimated costs and radiation doses accumulated during the five periods of SAFSTOR1 and SAFSTOR2 are presented in Table 4.1.

The various activities required to arrive at the condition permitting unrestricted release of the facility and termination of the Title 10 Part 50 possession-only license (POL) within 60 years following shutdown[a] and the associated estimates of cost and occupational radiation dose are discussed and summarized in this chapter. The decommissioning activities are postulated to occur within five designated periods of time, as illustrated by the schedules shown in Figures 4.1 and 4.2 for SAFSTOR1 and SAFSTOR2, respectively. Layup of the SFP occurs at the beginning of Period 4 and reactivation of the utility

(a) Based on Title 10 CFR 50.82 (b)(1)(i), which states that a decommissioning alternative, as delineated in the licensee's Decommissioning Plan, is acceptable if it provides for decommissioning within 60 years.[2]

TABLE 4.1. Summary of Estimated Costs and Radiation Doses During the Five Periods of SAFSTOR1 and SAFSTOR2

Period Number	Duration[b] (years)	Estimated Cost (Millions 1993 $)[a] Decon[c]	Remove[d]	Package[e]	Transport[f]	Disposal[g]	Undistributed[h]	Total	Estimated Radiation Dose (person-rem)
1	2.5	--	--	--	--	--	9,459,241	9,459,241	--
2	1.2	13,256,628	890,902	139,631	789,697	3,450,631	22,301,563	40,829,051	424.61
3	3.4	--	--	--	--	--	3,628,466	3,628,466	10.27
4 (SAFSTOR1)	53.7	455,539	--	24,270	19,059	51,288	114,688,427	115,238,583	123.23
4 (SAFSTOR2)	53.7	455,539	--	24,270	19,059	51,288	116,284,561	116,834,717	123.23
5 (SAFSTOR1)	0.31	--	881,385	243,470	129,870	2,054,654	6,996,844	10,306,223	0.06
5 (SAFSTOR2)	1.7	326,727	10,810,527	3,116,717	287,576	30,750,983	26,468,261	71,760,791	9.77
Total SAFSTOR1	58.61	13,712,167	1,772,287	407,371	938,625	5,556,573	157,074,540	179,461,564	558.17
Total SAFSTOR2	60.00	14,038,894	11,701,429	3,280,618	1,092,582	34,252,902	178,142,091	242,508,516	567.88
					Total Cost for SAFSTOR1 with 25% contingency			224,726,955	
					Total Cost for SAFSTOR2 with 25% contingency			303,180,332	

(a) *Costs shown do not include contingency* except where explicitly labeled.
(b) Pre-shutdown period not included in SAFSTOR time duration totals.
(c) Includes direct decommissioning labor and materials for chemical decontamination of systems, cleaning of surfaces, and waste water treatment.
(d) Includes direct labor and materials costs for removal of systems and components.
(e) *Includes direct costs of waste disposal packages*
(f) Includes cask rental costs and transportation costs.
(g) Includes all costs for disposal at the LLW disposal facility.
(h) Includes all costs that are period-dependent, e.g., DOC mobilization/demobilization, utility and DOC overhead staff, nuclear insurance, regulatory costs, plant power usage, taxes, laundry services, environmental monitoring.

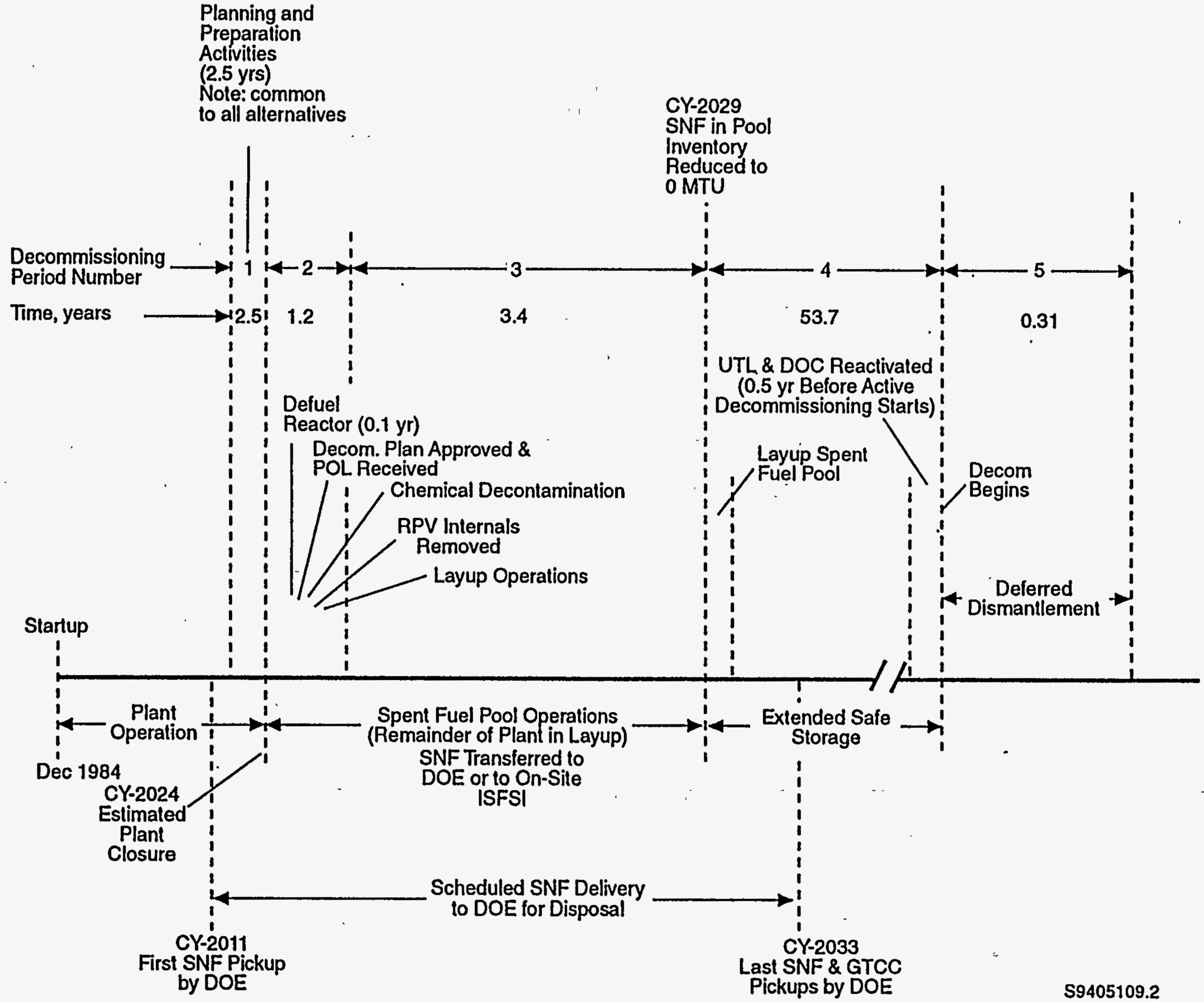

FIGURE 4.1. Schedule of Activities During the Five Decommissioning Periods of SAFSTOR1

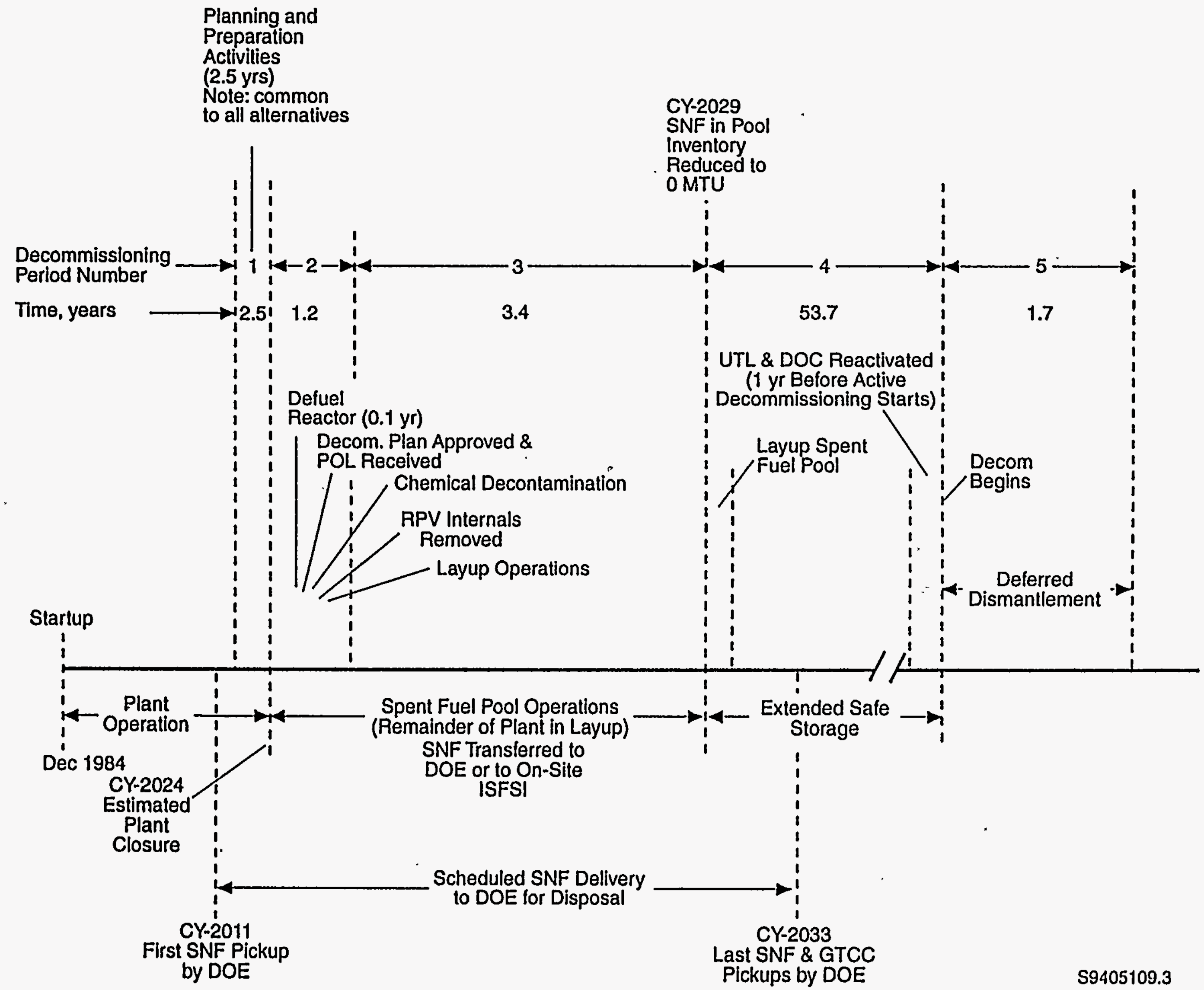

FIGURE 4.2. Schedule of Activities During the Five Decommissioning Periods of SAFSTOR2

and DOC staffs occurs 0.5 or 1 year prior to the end of Period 4 for SAFSTOR1 and SAFSTOR2, respectively. The costs and occupational radiation doses associated with these two activities are described below, together with the extended safe storage costs over a period of about 53.7 years.

The decommissioning activities performed during Periods 1, 2, and 3 are nearly identical with those of DECON, and are not discussed further in this chapter, except to note that the estimated costs associated with the ramp-up of the DOC staff, which is postulated to occur during the 6 months prior to the start of dismantlement for DECON, are not incurred during Period 3 for the SAFSTOR alternative, but appear much later at the end of the extended safe storage period (Period 4), and extend over a 0.5- or 1-year period for SAFSTOR1 AND SAFSTOR2, respectively. The Period 4 activities, comprised of preparations for safe storage, extended safe storage, and subsequent ramp-up of utility and DOC activities prior to the start of active decommissioning operations, are discussed in Sections 4.1 and 4.2. The activities associated with deferred dismantlement that occur in Period 5 are discussed in Section 4.3. The present values of the estimated costs for the two SAFSTOR scenarios are presented in Section 4.4, and the references for this chapter are given in Section 4.5.

4.1 PREPARATIONS FOR SAFE STORAGE--SAFSTOR PERIOD 4

Upon reduction of the spent fuel inventory in the SFP to zero, approximately 4.6 years after final shutdown (see Appendix D for details), the SFP water will be treated by batch process by a specialty contractor (i.e., sampled, analyzed and treated again, as necessary until release criteria are met) and released according to applicable release standards. The SFP liner surfaces will be decontaminated using high-pressure water washing and the pool and associated systems will be left dry.

Discussions with a qualified vendor have suggested that the estimated vendor's cost for treatment and transport of the SFP water would be about $750,000. Subsequent transportation costs for the resultant radioactive wastes are included in this cost estimate, but radwaste burial costs are the responsibility of the utility. It is further estimated to take 30 consecutive days, working 21 shifts per week (6 people per shift). Providing protective clothing and equipment for the vendor's staff is expected to cost the utility about $11,340.

Since the concentration of radioactivity in the SFP water is not well known at this point, it is difficult to predict with confidence either the occupational radiation exposure or the volume of waste that will result from the water cleanup activities. However, for this study, a radiation dose of approximately 2 person-rem is assumed for these activities, and it is estimated that about three of the 5.72-m^3 high-integrity containers (HICs) could be required to contain the residues of the treatment process.

Based on information contained in Appendix B, the cost of three HICs is estimated at $27,464, including the transportation cost for the HICs from the manufacturer to the plant site. Cask rental charges for 12 days are estimated to cost $15,000. Burial costs are estimated to be $40,554, based on the assumption that each HIC contains less than 100 curies of activity and has a surface dose rate of less than 5 R/hr. A summary of the total estimated cost and radiation dose for this activity is presented in Table 4.2.

TABLE 4.2. Summary of Estimated Costs and Radiation Dose for Spent Fuel Pool Water Treatment and Subsequent Waste Disposal

Cost Item	Estimated Cost (1993 $)[a]	Estimated Dose (person-rem)
Fixed-cost Specialty Contractor[b]	450,000	~1.2
Transportation of HICs from Mfgr. to Plant Site[c]	3,989	--[d]
High-Integrity Containers[e]	23,475	--
Cask Rental[f]	15,000	--
Transportation	--[g]	--
Burial[h]	40,554	--
Totals	533,018	~1.2
Protective Clothing and Equipment Services (vendor only)	11,340[i]	--

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) See text for details.
(c) Based on quote from Tri-State Motor Transport Company.
(d) Dashes mean no dose associated with this item.
(e) Based on Table B.3, cost per HIC.
(f) Based on Table B.2, 16 cask-days of rental.
(g) Included in $450,000 Fixed-Cost Contract.
(h) Derived from information provided by Pacific Nuclear Services.
(i) Included in Period undistributed costs.

Once drained, the pool surfaces (about 8,268 ft^2) are washed using high-pressure water wash/vacuuming, at a cost of about $5,548. At the calculated generation rate of 0.125 gallons per ft^2 (see Section C.2.12 for details), it is estimated that approximately 1,034 gallons of low-activity waste water will result from the surface cleansing tasks associated with the spent fuel pool. This volume of water is included with the SFP water volume for treatment.

4.2 EXTENDED SAFE STORAGE--SAFSTOR PERIOD 4

The various cost elements of the estimated annual costs during extended safe storage operations are given in Table 4.3. Based on the estimated annual cost of $2,108,402 given in the table, the total basic costs during the 53.7-year safe storage period are $115,238,583 and $116,834,717 for SAFSTOR1 and SAFSTOR2, respectively. These costs include the ramp-up of the utility and DOC staffs during the final 0.5 years (SAFSTOR1) or 1 year (SAFSTOR2) of safe storage, which are presented in Table 4.4. The estimated cumulative occupational radiation dose during this period of safe storage is less than 123.23 person-rem, based on information for similar activities previously calculated in NUREG/CR-0672.[3]

The study assumptions regarding the size and need for the security staff are predicated upon the idea that the owner will wish to limit his liability by maintaining a manned security force at the secured facility. NRC regulations do not require such a force at a facility that does not contain any special nuclear materials, and a reasonable level of industrial security could be provided using strongly secured structures and electronic surveillance systems. Thus, security costs could possibly be reduced from the currently estimated $747,566 per year to something more in the range of $100,000 per year, making a significant reduction in the annual safe storage costs.

TABLE 4.3. Estimated Extended Safe Storage Costs at the Reference BWR[a,b]

Utility Staff Required	Annual Cost (1993 $)[c]
Asst. Plant Manager	152,465
Clerk	40,058
Sr. Health Physics Tech.	92,745
Control Operator	76,342
Custodian	47,035
Security Manager	119,229
Security Shift Supervisor (3)	201,561
Security Patrolman (8)	426,776
Subtotal, Personnel Costs	1,156,211
Operation & Maintenance Allowance	17,379
Laundry Services	11,055
Electric Power (330,000 kWh/yr @ $0.027/kWh)	8,910
Environmental Monitoring	48,603[d]
Washington State Compliance Surveillance	244,000[e]
NRC Regional Inspections during safe storage:	
• Two Inspections/yr; 1-wk/inspection by 1 person	11,652[f]
• One Security Inspection/yr; 3-days by 1 person	3,532[f]
Third Party Safety Inspection	4,660[g]
Property Taxes	NA
Nuclear Liability & Property Insurance	600,000[h]
Subtotal, Non-Personnel Costs	949,791
Total, Annual Operating Cost	2,106,002

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) The values given in the table do not contain a contingency allowance.
(c) Based on positions given in Table B.1; salary rates include the appropriate overhead on utility salaries.
(d) See Table 3.26, Chapter 3.
(e) Study estimate (see Appendix B, Table B.16 for details).
(f) Includes Federal Travel Rates of $91/day/person.
(g) Third party inspection costs are based on an assumed cost of $932 per person-day.
(h) Study estimate based on discussions with nuclear industry insurance broker.

4.3 DEFERRED DISMANTLEMENT--SAFSTOR PERIOD 5

It is postulated that about 58 years after the reference BWR is shut down the owner will proceed to decontaminate the facility to unrestricted release levels, thereby allowing termination of the license. At this point in time, the utility staff and the DOC planning staff have been back on-board, reviewing the original planning documents and procedures, and making any necessary adjustments to reflect the actual situation nearly 60 years after reactor shutdown. The DOC operations staff have been mobilized, and additional utility staff have been returned to the site to support the active decontamination and dismantlement operations. DOC subcontractors have been identified and placed under contract to perform selected operations.

TABLE 4.4. Estimated Pre-Decommissioning/Planning Costs: Period 4

Staff Positions	Annual Salary (1993 $)[a]	Person-yrs per Period SAFSTOR1	SAFSTOR2	Period Cost (1993 $) SAFSTOR1	SAFSTOR2
Utility Overhead Staff					
Plant Manager	180,592	0.5	1.00	90,296	180,592
Secretary	50,407	0.5	1.00	25,204	50,407
Contracts/Procurement Spec.	92,382	0.5	1.00	46,191	92,382
Quality Assurance Manager	136,368	0.5	1.00	68,184	136,368
Health Physics Manager	99,357	0.5	1.00	49,679	99,357
Nuclear Records Spec.	89,758	0.5	1.00	44,879	89,758
Plant Operations Manager	138,699	0.5	1.00	69,485	138,969
Training Manager	153,382	0.5	1.00	76,691	153,382
Plant Engineers[b]	98,115	1.0	2.00	98,115	196,230
Maintenance Manager	123,739	0.5	1.00	61,870	123,739
Utility Overhead Totals		5.5	11.00	630,594	1,261,184
DOC Overhead Staff					
Project Manager	220,272	0.5	1.00	110,136	220,272
Assistant Project Manager	178,275	0.5	1.00	89,138	178,275
Secretary/Clerk	47,829	2.5	5.00	119,573	239,145
Accountant	117,369	1.0	2.00	117,369	234,738
Engineers	122,899	1.0	2.00	122,899	245,798
Drafting Specialist	67,813	1.5	3.00	101,720	203,439
Contracts Specialist	117,369	0.5	1.00	58,685	117,369
Procurement Specialist	106,743	0.5	1.00	53,372	106,743
Lawyer	150,744	1.0	2.00	150,744	301,488
QA Engineer	83,825	0.5	1.00	41,913	83,825
DOC Overhead Total		9.5	19.00	965,549	1,931,092
Total Ramp-up Overhead Staff Costs (w/o contingency)				1,596,143	3,192,276

(a) Salary rates include the appropriate overhead on utility salaries; 110% overhead plus 15% profit on DOC salaries.
(b) Includes an estimated equal level of effort of 0.20 FTE for each of 10 engineers (civil, cost, electrical, environmental, licensing, mechanical, nuclear, planning and scheduling, quality assurance, and radiological assessment).

Based on the available data on activation and contamination levels in operating reactor stations,[4] it appears that only the reactor vessel, vessel insulation, and reactor sacrificial shield will still be too radioactive to satisfy the unrestricted use levels derived from Regulatory Guide 1.86. The radioactivity on the rest of the plant systems and equipment will have decayed sufficiently by that time to comply with the current unrestricted release limits, thereby negating the need to remove these materials. This assumption is made for SAFSTOR1, providing a lower-bound estimate of decommissioning cost. For SAFSTOR2, all of the activated and contaminated materials are assumed to still exceed unrestricted release levels and must be removed for disposal, as was done for DECON, providing an upper-bound estimate of decommissioning cost.

As can be seen in Table 4.1, Period 5 is much shorter in duration for SAFSTOR1 (0.31 years) than for SAFSTOR2 (1.7 years). This is because in SAFSTOR1 only the RPV, vessel insulation, and the sacrificial shield are removed for disposal, while in SAFSTOR2 all of the originally radioactive material is removed for disposal as was done in DECON. As a result of the greatly reduced dismantlement effort, the amount of LLW generated during those efforts is also much-reduced, and because of the shorter period duration, the undistributed costs (mostly overhead staff costs) are greatly reduced, about $7 million for SAFSTOR1, compared with about $26 million for SAFSTOR2. The total decommissioning cost for SAFSTOR1 is estimated to be $179.5 million, and the total decommissioning cost for SAFSTOR2 is estimated to be $242.5 million, without contingency.

The viability of SAFSTOR1 depends on the premise that the contaminated materials (not activated) will decay to levels of radioactivity that satisfy the criteria for unrestricted use (see Regulatory Guide 1.86[1]) by the end of the 60-year period following reactor shutdown. Based on the measurements and calculations presented in Appendix E of NUREG/CR-0672[3] for surface radiation dose rates and inferred contamination levels on the insides of piping, it appears certain that the residual contamination would decay to less than the levels inferred from Regulatory Guide 1.86 by the end of the 60-year period. Supporting evidence is given in NUREG/CR-4289,[4] wherein actual piping samples taken from several operating BWRs yielded contamination levels that were about a factor of 2 less than the levels used in NUREG/CR-0130. In addition, chemical decontamination of the RCS and associated coolant piping and components would provide another factor of 3 to 10 reduction in the residual contamination levels within the systems. Thus, it appears that the residual levels of radioactivity within the plant systems at the end of the extended safe storage period may be as much as a factor of 10 beneath the limits for unrestricted use, and termination of the license could be accomplished without further efforts. However, should it be determined at the end of the extended safe storage period that the radioactivity on the contaminated materials had not decayed to levels permitting unrestricted use, then all of the removal and disposal activities of DECON Period 4 would be necessary, and the cost would be increased by about $63 million, without contingency.

4.4 IMPACT OF THE TIME-VALUE OF MONEY ON SAFSTOR FUNDING REQUIREMENTS

The present value of the distributed decommissioning costs for SAFSTOR has been calculated, using the same methodology developed in Section 3.5.2 of Chapter 3. Using the costs estimates from Table 4.1 with an assumed net discount rate of 3% per year, the present value of SAFSTOR decommissioning costs at 2.5 years prior to reactor shutdown is calculated to be $121.6 million for SAFSTOR1 and $134.2 million for SAFSTOR2.

4.5 REFERENCES

1. Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors." U.S. Nuclear Regulatory Commission, Washington, D.C. June 1974.

2. U.S. Code of Federal Regulations. Title 10, Part 50. Superintendent of Documents, Government Printing Office, Washington, D.C.

3. H. D. Oak, G. M. Holter, W. E. Kennedy, Jr., and G. J. Konzek. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, U.S. Nuclear Regulatory Commission report by Pacific Northwest Laboratory, Richland, Washington. June 1980.

4. K. S. Abel, et al. Residual Radionuclide Contamination Within and Around Commercial Nuclear Power Plants. NUREG/CR-4289, U.S. Nuclear Regulatory Commission report by Pacific Northwest Laboratory, Richland, Washington. February 1986.

5.0 ENTOMB FOR THE REFERENCE BWR POWER STATION

ENTOMB is the third and least likely alternative for decommissioning of nuclear power stations. The definition of decommissioning as given in 10 CFR 50.2[1] states "Decommission means to remove (as a facility) safely from service and reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of license." 10 CFR 50.82(b)(i) additionally states "...an alternative is acceptable if it provides for completion of decommissioning within 60 years. Consideration will be given to an alternative which provides for completion of decommissioning beyond 60 years only when necessary to protect the public health and safety." 10 CFR 82(b)(iii) identifies the unavailability of waste disposal capacity, the presence of other nuclear facilities on the site, and other site-specific factors, as bases to justify delaying decommissioning beyond the 60-year limit. Thus, for a nuclear power station comprised of a single reactor, only the unavailability of waste disposal capacity appears to be an acceptable reason for extending the entombment period beyond 60 years.

However, the concept of entombment is based on confining the radioactive materials in a sealed environment until the contained materials have decayed sufficiently to no longer pose any threat to the environment or the public. Because some of the activated and/or contaminated materials at the reference boiling water reactor (BWR) could still have levels of radioactivity that exceed the unrestricted release levels even after 60 years of decay, it may be necessary to continue the ongoing surveillance and maintenance programs and the nuclear license beyond the 60-year limit specified in the Decommissioning Rule. Acceptability of such an extended ENTOMB period is expected to be determined by the NRC on a case-by-case basis.

Three scenarios have been evaluated for the ENTOMB alternative. In the ENTOMB1 scenario, essentially all of the radioactive materials (except the highly activated reactor pressure vessel [RPV] internals) present in the facility after termination of spent fuel pool operations are consolidated, packaged, and stored in the lower portion of the Reactor Building, which is then entombed. For purposes of cost estimation, ENTOMB1 is costed until 60 years following reactor shutdown.

In the ENTOMB2 scenario, it is postulated that the activated RPV, RPV insulation, and sacrificial shield are removed for disposal during preparations for entombment, to assure that the entombed materials will decay to unrestricted release levels within 60 years following reactor shutdown, thus increasing the volume of low-level waste (LLW) for disposal and increasing the occupational radiation dose, relative to the ENTOMB1 scenario..

Because it is expected that the surveillance and maintenance costs for ENTOMB1 could continue beyond 60 years for as long as was necessary for the contained materials to decay to unrestricted release levels, an extended entombment period scenario (ENTOMB3) is also evaluated. This latter scenario is identical with ENTOMB1 except for the 300-year entombment period and for the deletion of the detailed radiation survey before license termination after 300 years of decay.

It is possible that some type of entry into the entombment enclosure at the end of the entombment period would be necessary to verify that the material therein is releasable before the license could be terminated. This consideration suggests that entombment is not a particularly viable decommissioning alternative. However, for completeness in consideration of alternatives, the ENTOMB alternative is evaluated in this chapter.

The scenarios postulated for the ENTOMB analyses are very similar to the scenario postulated for DECON in Chapter 3, as illustrated in Figure 5.1. The activities described for Periods 1, 2, and 3 are identical with the DECON scenario. Period 4 becomes the preparations for entombment, and a new Period 5 is added for the entombment period. The principal differences are that most (not all) of the contaminated materials within the plant are packaged and placed within the Reactor Building, which is eventually sealed as an entombment structure, rather than being shipped offsite to a licensed LLW disposal facility, and that most of the systems and equipment within the Reactor Building remain in place, without disassembly. These differences result in a reduced duration for the decontamination/dismantlement activities that take place during Period 4.

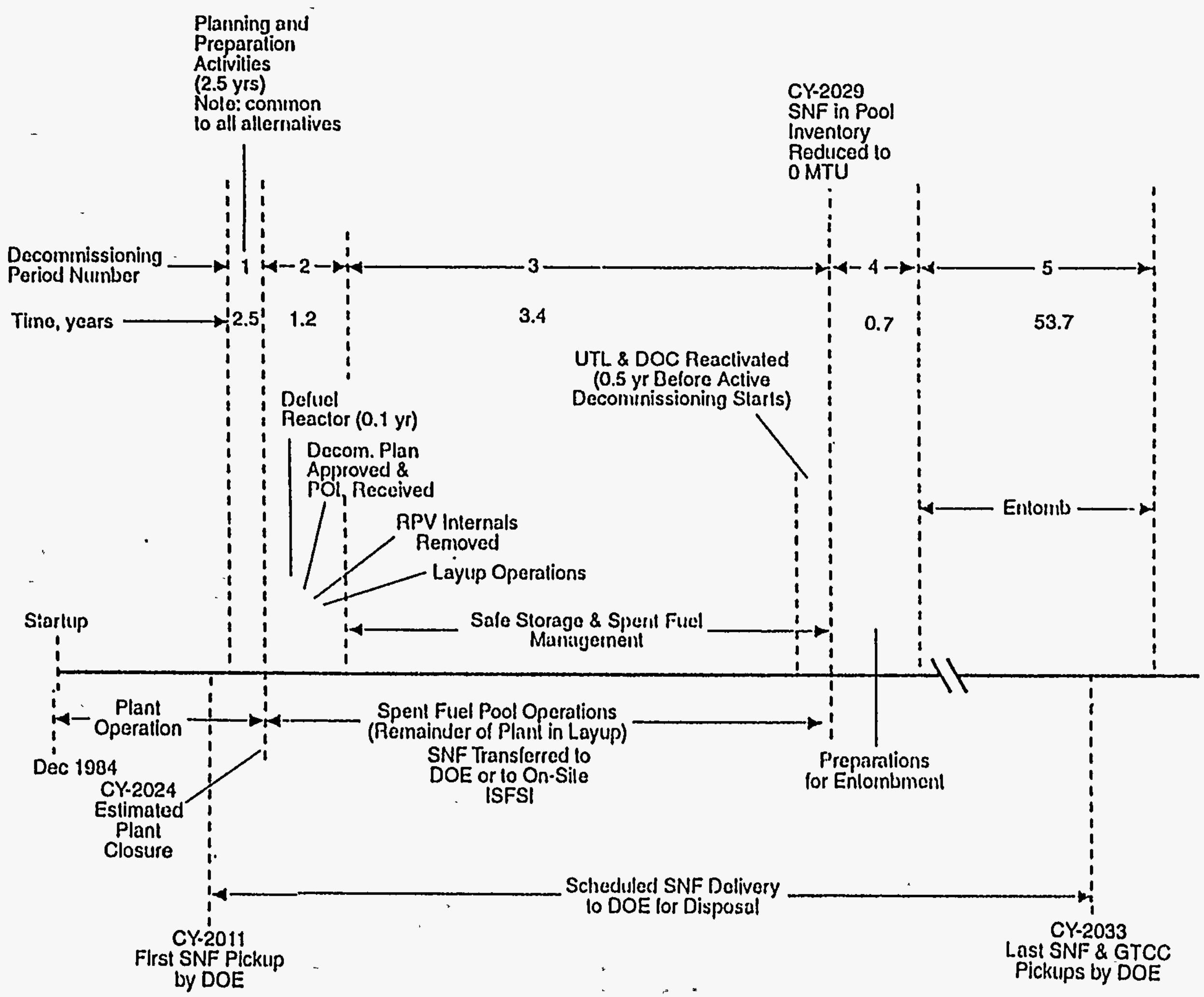

FIGURE 5.1. Schedule of Activities During the Five Decommissioning Periods of ENTOMB1

5.1 BASES FOR ANALYSIS OF ENTOMB

Several assumptions are made in this analysis that are important to the viability of the postulated entombment scenario:

- Offsite LLW disposal capacity is available.
- The RPV internals are removed, packaged, and transported to an appropriate disposal facility for disposal, with most of the material going to an LLW facility and the Greater-Than-Class C [GTCC] material going to a geologic disposal facility or to an interim storage facility pending availability of a geologic repository. The activated RPV, RPV insulation, and sacrificial shield are postulated to remain in place (ENTOMB1 and ENTOMB3) or removed and packaged for disposal as LLW (ENTOMB2).
- The radioactivity on the other contaminated materials is postulated to decay to unrestricted use levels within 60 years following reactor shutdown, for ENTOMB1.

While the cost-effectiveness of a chemical decontamination of the reactor coolant system (RCS) and associated systems may be questionable for this alternative, such a decontamination is postulated to be performed for the purpose of reducing radiation dose rates to the decommissioning workers and reducing the residual inventory of radioactive material within the reactor systems, thereby improving the likelihood that the remaining inventory will decay to unrestricted use levels within the 60-year period.

The Period 4 decommissioning activities discussed for DECON in Chapter 3 are nearly identical for the ENTOMB alternatives, except that the RCS piping and equipment located within the Reactor Building is not disassembled or packaged, but is left intact. The RPV, RPV insulation, and sacrificial shield remain in place in the containment structure for ENTOMB1 and ENTOMB3, but are removed for disposal in ENTOMB2. The HVAC ductwork and equipment in the portion of the Reactor Building below the operating floor (185 ft elevation) remains in place in all three scenarios. Activities within the Radwaste and Control Building and the Turbine Generator Building are essentially identical with those given for DECON in Chapter 3, except that the packaged material is placed within the Reactor Building instead of being shipped to an LLW disposal facility.

The Period 5 decommissioning activities, whose identities and annual costs are listed in Table 5.1, are comprised of controlling access to the entombed structure, annual inspections and surveillance by the various regulatory agencies, and an ongoing environmental monitoring program for the site, which is carried out by a specialty contractor. A final survey of the entombment enclosure and the contained material is assumed to be required in ENTOMB1 and ENTOMB2 for license termination. However, in the 300-year ENTOMB1 scenario, all contained radioactivity is assumed to have decayed to unrestricted release levels, and the detailed radiation survey prior to license termination is assumed to be unnecessary.

TABLE 5.1. Estimated Regulatory and Other Costs During ENTOMB: Period 5

Entity	Cost Element	(1993 $)[a]
Washington State	Compliance Surveillance	244,000/yr[b]
NRC	General inspections (2/yr)	11,652/yr[c]
	Security inspection (1/yr)	3,532/yr[d]
Subtotal, Annual Regulatory Costs		259,184/yr
Other Costs		
Third Party Safety Inspection		4,660/yr
Nuclear Insurance		600,000/yr[e]
Plant Security (8 persons)		426,776/yr[f]
Property Taxes		NA
Environmental Monitoring		48,603/yr
Subtotal, Other Costs		1,080,039/yr
Total Annual Costs		1,339,223/yr

(a) Values do not include contingency. The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Study estimate, see Table B.16 for details.
(c) Two person-weeks per year, including Federal Travel Rates of $91/day.
(d) Three person-days per year, including Federal Travel Rates of $91/day.
(e) Assumed to be the same as for SAFSTOR, same LLW inventory onsite.
(f) Assumed two persons onsite at all times.

Because so many of the decommissioning operations are the same as those discussed in detail for DECON in Chapter 3 and associated appendices, only those activities and waste treatments that are different from those given in Chapter 3 are discussed in any detail in this chapter. The costs and radiation doses for the ENTOMB scenarios are developed using a difference analysis, i.e., costs and doses for activities conducted during DECON but not conducted during ENTOMB are collected and subtracted from the DECON values. Costs and doses for activities conducted only during ENTOMB are developed and added to the DECON values.

5.2 DISCUSSION OF DECOMMISSIONING ACTIVITIES FOR THE ENTOMB SCENARIOS

In ENTOMB, activities in the Radwaste and Control and Turbine Generator Buildings are the same as for DECON, except that instead of placing the containers of packaged material on trucks for shipment to the LLW disposal facility, the containers are placed in the Reactor Building. It is postulated that the effort to accomplish these operations is essentially the same as for placing the containers on trucks for shipment. Thus, no difference in labor cost is postulated for the removal of these materials from those buildings. There are reductions in cost because there will be no offsite transport costs and no disposal costs associated with this material.

Activities within the Reactor Building are limited to the relocation of some equipment items to increase the space available for placement of the packaged LLW from the other buildings, the placement of those packages into the building, the cutting and sealing of penetrations through the Reactor Building walls, and the capping and sealing of the openings in the operating floor and the spent fuel pool, and the dryer/separator pool following placement of the LLW from other buildings. The spent fuel racks remain in place in the spent fuel pool cavity. Care must be taken to ensure that the load limits on the various floors in the Reactor Building are not exceeded when placing the LLW packages.

Because the levels of radioactivity induced in the RPV wall, the RPV insulation, and the surrounding sacrificial shield are not expected to decay to unrestricted use levels within the 60-year time frame, unrestricted release limits are assumed to be met in ENTOMB2 by removing those items, packaging and shipping them to an LLW disposal facility, as was discussed in Chapter 3. The removal of these items will result in some additional space being available for placement of packages of contaminated material. For ENTOMB1 and ENTOMB3, these materials remain in-place within the entombment structure until they have decayed to unrestricted release levels.

Once placement of the waste containers within the Reactor Building has been completed, all openings through the operating floor are sealed by laying a one-foot-thick slab of reinforced concrete over the operating floor, including the spent fuel and dryer/separator pools.

All penetrations through the Reactor Building surfaces are cut and the openings are filled with concrete and capped by welding plates over the openings. The space above the entombment slab on the operating level of the Reactor Building is decontaminated. The Reactor Building bridge crane is disassembled, with the trolley, drum, cables and hooks packaged for disposal, and the bridge beams decontaminated and abandoned in place. The Radwaste and Control and Turbine Generator Buildings are decontaminated to unrestricted release levels, along with the rest of the site, as described in Chapter 3.

That portion of the Reactor Building above the operating floor is decontaminated, but the portion below the operating floor is not decontaminated since it will be within the entombment enclosure. With all of the residual radioactivity remaining in the plant securely sealed within the lower portion of the Reactor Building, only industrial security (two persons onsite around the clock) will be necessary to ensure that no one obtains access to the entombed portion of the building.

The modified Part 50 license will be maintained until the radioactivity on the contained material has decayed to unrestricted release levels. Depending upon the data on levels of radioactivity on the contained materials obtained during the initial characterization effort, the period of required surveillance prior to termination of the license may vary, but for this analysis, ENTOMB1 is assumed releasable 60 years after reactor shutdown. Continuation of ENTOMB1 for up to 300 years after reactor shutdown is assumed for ENTOMB3, to ensure decay of the contained radioactivity to unrestricted release levels. The entombment period is assumed to terminate 60 years after reactor shutdown for ENTOMB2. The license termination survey for ENTOMB1 and ENTOMB2 at 60 years following reactor shutdown is expected to require about twice as much effort as the survey for DECON, because of the need to survey the contaminated materials that were stored within the containment structure.

No in-depth termination survey is assumed to be needed for license termination at 300 years following reactor shutdown.

5.3 RESULTS OF THE ENTOMB ANALYSES

The differences in the decommissioning operations for the entombment alternative that affect cost and radiation dose are discussed in some detail in this section. The effects are shown as additions or reductions to the cost and dose estimates developed for DECON in Chapter 3. The estimated costs and doses associated with activities conducted during DECON but not carried out during ENTOMB, and the estimated costs and doses associated with new activities conducted only during ENTOMB, are summarized in Table 5.2, together with the total estimated costs and doses from DECON. The resulting total estimated costs and cumulative doses for ENTOMB are also presented in Table 5.2. As shown in the table, the cost of ENTOMB is about $180.8 million for ENTOMB1, about $184.1 million for ENTOMB2, and about $505.5 million for ENTOMB3, in constant 1993 dollars without contingency. The cumulative radiation dose to workers is about 603 person-rem for ENTOMB1 and ENTOMB3, and about 667 person-rem for ENTOMB2. Thus, the 60-year ENTOMB scenarios result in a cumulative radiation dose reduction of about 35%, and a cost increase of about 43%.

It has been suggested that a 60-year entombment period is unrealistic, that perhaps the period allowable for entombment should be a total of 300 years following reactor shutdown, comparable with the institutional control period required for closed LLW disposal sites, i.e., an additional 240 years beyond the end of the scenarios analyzed in this study. The extended entombment period would ensure that the radioactive materials contained within the entombment structure will have decayed to unrestricted release levels, and no further action would be required to terminate the nuclear license. However, the costs associated with the entombment period (about $1.3 million 1993 dollars/year) would also continue throughout the extended period. Thus, for the 300-year ENTOMB3 scenario, the total cumulative cost in constant 1993 dollars would be about $506 million, without contingency.

TABLE 5.2. Results of Cost and Dose Analyses for ENTOMB

Cost Element	Estimated Cost (1993 $)		Estimated Dose (person-rem)	
	ENTOMB1	ENTOMB2	ENTOMB1	ENTOMB2
DECON (w/o contingency)	126,583,362	126,583,362	962.48	962.48
Activities NOT conducted during ENTOMB				
RPV removal	1,380,823	0	39.57	0.00
Sacrificial Shield removal	1,936,133	0	24.95	0.00
Recirc. Piping & Components	5,094,615	5,094,615	263.46	263.46
Other System Piping (in. Reactor Bldg.)	1,991,622	1,991,622	11.80	11.80
Containment Structural Beams, etc.	1,461,685	1,461,685	4.42	4.42
SFP Rack and SFP decontamination	1,643,222	1,643,222	1.13	1.13
Other Systems (in Reactor Bldg.)	2,662,456	2,662,456	9.67	9.67
Decontaminate Reactor Bldg.	1,164,656	1,164,656	7.58	7.58
HVAC removal (above Operating Floor)	828,376	828,376	1.42	1.42
Reduced Dry Active Waste	422,867	422,867	0.00	0.00
Reduced Laundry Services	302,476	302,476	0.00	0.00
Reduced Utility Staff	169,846	169,846	0.54	0.54
Reduced Termination Survey (from DECON)	310,300	310,300	0.00	0.00
Total Deductions for ENTOMB	19,369,077	16,052,121	364.54	300.02
New Activities conducted during ENTOMB Preparations				
Reactor Bldg. Penetration sealing		56,800		2.80
Entombment Cap barrier		208,000		0.00
Additions during ENTOMB Prep.		264,800		2.80
Activities during and following ENTOMB prep.	ENTOMB1,2	ENTOMB3		
Storage Period Duration	53.7 yrs	293.7 yrs		
Security	22,917,871	125,344,111		NA
Regulatory Costs	13,918,181	76,122,341		NA
Environ. Monitoring	2,609,981	14,274,701		NA
Nuclear Insurance	32,220,000	176,220,000		NA
Property Taxes	NA	NA		NA
License Termination Survey	310,300	310,300		NA
Third-party Safety Inspect.	250,242	1,368,642		NA
Additions for Storage	72,226,275	393,640,095		NA
Total ENTOMB1 (60 years)	179,705,360	--		600.74
Total ENTOMB2 (60 years)	183,022,316			665.26
Total ENTOMB3 (300 years)	--	504,436,136		600.74
ENTOMB1 (w/25% contingency)	224,631,700	--		600.74
ENTOMB2 (w/25% contingency)	228,777,895	--		665.26
ENTOMB3 (w/25% contingency)	--	630,545,170		600.74

The principal cost drivers for ENTOMB are plant security, compliance surveillance, and nuclear insurance, during the entombment period. The use of electronic security systems tied to a local law enforcement agency or to a private security company could reduce the annual security costs to about $135,000 or perhaps even less. Similarly, the $600,000 per year cost for nuclear insurance seems excessive, considering that all of the radioactive materials on the site are confined within a sealed containment structure, presenting little or no risk to the general public or to workers on the site. Thus, a value in the $20,000 per year range, similar to the premium suggested for the post-license termination period ($17,250), may be more reasonable. Similarly, the costs of the Washington State compliance surveillance programs could probably be reduced to about $22,000 per year, considering the inactive state of the site and the secure containment of the contaminated material. Under these revised continuing expenditure assumptions, the annual cost during entombment is about $245,447 per year, and the constant dollar costs for the 60-year ENTOMB1 and ENTOMB2 scenarios would be about $171 million and $175 million, respectively, including a 25% contingency. Similarly, the 300-year ENTOMB3 scenario cumulative cost would be reduced to about $336 million in constant 1993 dollars, including a 25% contingency.

The viability of the entombment scenario depends strongly upon the premise that the contaminated materials (not activated) will decay to levels of radioactivity that satisfy the criteria for unrestricted use (currently 5μR/hr, from Regulatory Guide 1.86,[2]) by the end of the entombment period. Based on the measurements and calculations presented in Appendix E of NUREG/CR-0672[3] for surface radiation dose rates and inferred contamination levels on the insides of piping, it appears certain that the residual contamination would, in fact, decay to less than the value derived from Regulatory Guide 1.86 by the end of the 60-year period. Supporting evidence is given in NUREG/CR-4289,[4] wherein actual piping samples taken from several operating BWRs yielded contamination levels that were about a factor of 2 less than the levels used in NUREG/CR-0672.[3] In addition, chemical decontamination of the RCS and associated coolant piping and components would provide another factor of 3 to 10 reduction in the residual contamination levels within the systems. Thus, it appears that the residual levels of radioactivity within the plant systems at the end of the entombment period may be as much as a factor of 10 below the limits for unrestricted use, and license termination could be accomplished by completion of the required site termination survey.

If it were determined at 60 years after reactor shutdown that the contained radioactivity had not decayed to levels permitting unrestricted use (ENTOMB1), either the enclosure could be reclosed and entombment continued for as long as necessary (ENTOMB3), or those materials exceeding unrestricted release levels could be removed from the enclosure and disposed of at an LLW disposal facility (ENTOMB2).

5.4 IMPACT OF THE TIME-VALUE OF MONEY ON ENTOMB FUNDING REQUIREMENTS

As discussed in Section 3.5.2, the fact that the expenditures for decommissioning are distributed in time suggests that a present value analysis should be used to estimate the amount of money that needs to be in the plant's decommissioning fund prior to final shutdown. Using the basic formulation presented in Section 3.5.2 and the cost estimates from Table 5.2 with a net discount rate of 3% per year, the present values of the ENTOMB license termination cost at 2.5 years prior to final shutdown are calculated to be $151.9 million for ENTOMB1 and $155.2 million for ENTOMB2, as compared with the constant dollar values of about $225 million and $229 million, respectively, all values including a 25% contingency. Thus, requiring the funding needs to be calculated in constant dollars prior to reactor shutdown results in about a 48% overestimate of the funding needs for ENTOMB, providing a significant safety margin to cover unforeseen events. For the 300-year ENTOMB3 scenario, the present value cost is about $164.5 million, as compared with the constant dollar value of about $631 million, both values including a 25% contingency.

If the reduced security costs and reduced nuclear insurance costs suggested earlier were to be realized, the present values of the 60-year ENTOMB1 and ENTOMB2 license termination costs would be reduced to about $123.5 million and $126.8 million, respectively. For the 300-year ENTOMB3 scenario, the present value cost would be reduced to about $125.1 million. Thus, it is seen that extending the entombment period from 60 years (ENTOMB1) to 300 years (ENTOMB3) adds only about $13 million to the estimated present value costs for the base analysis, and about $1.6 million to the analysis using reduced security and insurance costs).

5.5 REFERENCES

1. U.S. Code of Federal Regulations. Title 10, Part 50. Superintendent of Documents, Government Printing Office, Washington, D.C.

2. Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors," U.S. Nuclear Regulatory Commission, Washington, D.C. June 1974.

3. H. D. Oak, G. M. Holter, W. E. Kennedy, Jr., and G. J. Konzek. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, U.S. Nuclear Regulatory Commission report by Pacific Northwest Laboratory, Richland, Washington. June 1980.

4. K. S. Abel, et al. Residual Radionuclide Contamination Within and Around Commercial Nuclear Power Plants. NUREG/CR-4289, U.S. Nuclear Regulatory Commission report by Pacific Northwest Laboratory, Richland, Washington. February 1986.

6.0 CONCLUSIONS

The changes in the industrial and regulatory situation in the U.S. since the late 1970s have forced revisions to the viable scenarios of the original decommissioning alternatives, DECON, SAFSTOR, and ENTOMB. The principal effect is the delay of major decommissioning actions for at least 5 years following reactor shutdown due to the need for the spent nuclear fuel (SNF) to cool in the reactor pool for that period of time before being transferred to a dry storage facility or to the federal waste management system (FWMS). At a minimum, there will be a short (3-4 years) period of safe storage and an associated increase in decommissioning costs accumulated during that short safe storage period. Alternatively, the SNF could be left in the pool until it has been accepted into the FWMS. This latter choice would delay final decontamination and decommissioning of the reference reactor until such time as the pool had been emptied by delivery to the FWMS. Because of the uncertainties associated with the startup date and acceptance rates for the federal repository, this latter scenario was evaluated only for the purpose of comparing the SNF present value storage costs over time, and was not included in any of the DECON, SAFSTOR, or ENTOMB analyses.

There are two principal cost elements that dominate decommissioning costs. These are: 1) undistributed costs (about 48%), which are dominated by overhead staff labor, and 2) low-level radioactive waste (LLW) disposal costs (about 27%). Decontamination costs and direct labor costs for disassembly and removal of equipment comprise about 20% of the total cost of DECON. The overhead costs are governed by the duration of the decommissioning effort and, on a daily basis, exceed the direct labor costs associated with the decontamination and dismantlement activities. Thus, there is a strong incentive to perform these activities in parallel and on multiple shifts, to the extent possible, to minimize the duration of the active decommissioning efforts and reduce the overhead costs.

The LLW disposal costs are directly proportional to the volume of material requiring regulated disposal and are a very strong function of the disposal rates at the LLW disposal facility. Because it appears that the LLW disposal rates can only increase over time, there is a strong incentive to reduce LLW disposal volumes, by either aggressive chemical and physical decontamination efforts during early dismantlement (DECON), or by allowing the residual contaminants to decay to unrestricted release levels before undertaking dismantlement (SAFSTOR1, ENTOMB1, or ENTOMB3), thereby permitting free release of large volumes of materials that would otherwise require disposal in a regulated LLW burial facility, at considerable expense.

The cumulative costs of maintenance and surveillance during the extended decay period for SAFSTOR and ENTOMB constitute the major fraction of the decommissioning costs for these alternatives. The principal cost elements contributing to these costs are nuclear insurance and security. In this study, some fairly conservative assumptions were made regarding the cost of insurance ($600,000/yr) and security ($750,000/yr for SAFSTOR, $427,000/yr for ENTOMB). It would seem reasonable that the insurance costs could be significantly reduced, considering the greatly reduced risks during the inactive storage periods. The NRC staff is actively working with decommissioning licensees to determine the appropriate levels of insurance at various stages of the decommissioning process. Similarly, it would seem reasonable that the security costs could also be significantly reduced, by eliminating onsite staff and relying on electronic surveillance systems and contracts for emergency response with local security organizations, perhaps more in the range of $100,000/yr or less. Reducing these costs would further enhance the viability of the delayed dismantlement alternatives relative to DECON.

Review of the estimated constant dollar costs and present value costs (using a net discount rate of 3% per year) for the three alternatives shows that in order of increasing constant dollar cost, the alternatives/scenarios rank as follows: 1) DECON, 2) SAFSTOR1, 3) ENTOMB1, 4) ENTOMB2, 5) SAFSTOR2, and 6) ENTOMB3. However, in order of increasing present value cost, the alternatives/scenarios rank differently: 1) SAFSTOR1, 2) DECON, 3) SAFSTOR2, 4) ENTOMB1, 5) ENTOMB2, and 6) ENTOMB3.

The present value costs better represent the amount of funds needed in the decommissioning fund prior to reactor shutdown than do the constant dollar costs, since the present value analysis takes into account the time-distribution of expenditures and the return that can be obtained on invested unexpended funds over time. The range (in 1993 $) from the least expensive scenario (SAFSTOR1, $121.6 million) to the most expensive scenario (ENTOMB3, $164.5 million) is about $43 million. However, for the more likely alternatives (DECON, SAFSTOR1, SAFSTOR2), the spread is only $12 million to $13 million. Thus, the present value costs are not strong discriminators for selecting one alternative/scenario over another. Based on the above, it appears that having about $140 million to $160 million in the decommissioning fund at 2½ years before final shutdown would be sufficient to cover most of the alternatives for the reference boiling water reactor.

Review of the estimated cumulative occupational radiation doses associated with the three alternatives shows that the doses are not large. The doses range from the smallest (about 558 person-rem for SAFSTOR1) to the largest (about 963 person-rem for DECON), a difference of only about 405 person-rem, which is roughly equivalent to a few years of normal reactor operation. Most of the radiation dose for the SAFSTOR and ENTOMB scenarios arises from the initial plant layup activities that are common to all alternatives. The radiation doses from ENTOMB are smaller than from DECON because much of the material removed and packaged during DECON is left in place in the Reactor Building during ENTOMB.

The analyses of demolition and site restoration contained in Appendix H suggest that those activities could add about $48.5 million, including a 25% contingency, to the total decommissioning cost. This estimate is very specific to the circumstances at WNP-2, and can not be applied to any other similar plant without a careful review of those circumstances. The estimate is also specific to the DECON alternative, and could be somewhat reduced for the delayed dismantlement alternatives due to an increase in the volume of materials available for salvage.

7.0 GLOSSARY

Abbreviations, acronyms, symbols, terms, and definitions used in this study and directly related to BWR decommissioning work and associated technology are defined and explained in this chapter. The chapter is divided into two parts. The first contains abbreviations, acronyms, and symbols, and the second contains terms and definitions (including those used in a special sense for this study). Common terms covered adequately in standard dictionaries are not included.

7.1 ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable[a]
ANSI	American National Standards Institute
BOP	Balance of Plant
Bq	Becquerel[a]
BWR	Boiling Water Reactor
CECP	Cost Estimating Computer Program[a]
CFR	Code of Federal Regulations[a]
Ci	Curie[a]
cpm	Counts Per Minute,[a] Count Rate
CS	Carbon Steel
DF	Decontamination Factor[a]
DOE	Department of Energy
DOT	Department of Transportation
dpm	Disintegrations Per Minute,[a] Disintegration Rate
EC	Electron Capture[a]
EFPY	Effective Full Power Year(s)
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FSAR	Final Safety Analysis Report
Ge(Li)	Germanium-Lithium (detectors)
GVW	Gross Vehicle Weight
Gy	Gray[a]
HEPA	High-Efficiency Particulate Air (filters)
HP	Health Physicist[a]
HVAC	Heating, Ventilation and Air Conditioning

(a) See Section 7.2 for additional information or explanation.

ICRP	International Commission on Radiological Protection
LLD	Lower Limit of Detection
LWR	Light Water Reactor
mR	Milliroentgen, see also R (Roentgen)
mrad	Millirad, see also rad
mrem	Millirem, see also rem
mSv	milli-Sievert, see also Sievert
MUF	Material Unaccounted For
MWD/MTU	Megawatt Days per Metric Ton of Uranium
MWe	Megawatts, electric
MWt	Megawatts, thermal
NaI	Sodium Iodide (detectors)
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System[a]
OSF	Overall Scaling Factor
PNL	Pacific Northwest Laboratory
PWR	Pressurized Water Reactor
QA	Quality Assurance
QC	Quality Control
R	Roentgen[a]
rad	Radiation Absorbed Dose
rem	Roentgen Equivalent Man
SF	Scaling Factor
SNM	Special Nuclear Material[a]
SS	Stainless Steel
Sv	Sievert[a]
α	Alpha Radiation[a]
β	Beta Radiation[a]
γ	Gamma Radiation[a]

7.2 GLOSSARY DEFINITIONS

Absorbed Dose: The energy imparted to matter in a volume element by ionizing radiation divided by the mass of irradiated material in that volume element. The SI derived unit of absorbed dose is the gray (Gy); 1 Gy = 100 rad = 1 J/kg (also commonly called "dose").

Acceptable Residual Radioactive Contamination Levels: Those levels of radioactive contamination remaining at a decommissioned facility or on its site that are acceptable to the NRC for termination of the facility operating license and unrestricted release of the site. (See Regulatory Guide 1.86.)

(a) See Section 7.2 for additional information or explanation.

Activity: The number of spontaneous nuclear disintegrations occurring in a given quantity of material during a suitably small interval of time divided by that interval of time. The SI derived unit of activity is the becquerel (Bq) (also called "disintegration rate").

Agreement States: States that have entered into an agreement with the NRC that allows each state to license organizations using radioactive materials for certain purposes.

ALARA: An operating philosophy to maintain worker exposure to ionizing radiation As Low As is Reasonably Achievable.

Alpha Decay: Radioactive decay in which an alpha particle is emitted. This transformation lowers the atomic number of the decaying nucleus by two and its mass number by four.

Anticontamination Clothing: Special clothing worn in a radioactively contaminated area to prevent personal contamination.

Atomic Number (Z): The number of protons in the nucleus of an atom; also the positive charge of the nucleus. Each chemical element has its characteristic atomic number, and the atomic numbers of the known elements (both natural and man-made) form a complete series from 1 (hydrogen) through 105 (hahnium).

Background: Radiation originating from sources other than the source of interest (i.e., the nuclear plant). Background radiation includes natural radiation (e.g., cosmic rays and radiation from naturally radioactive elements) as well as man-made radiation (e.g., fallout from atmospheric weapons testing).

Becquerel (Bq): A unit of activity equal to one nuclear transformation per second (1 Bq = 1 s^{-1}). The former special named unit of activity, the curie, is related to the becquerel according to 1 Ci = 3.7×10^{10} Bq.

Beta Decay: Radioactive decay in which a beta particle is emitted. This transformation changes only the atomic number of the nucleus, raising or lowering Z by one for emission of a negative or positive beta particle, respectively.

Burnup, Specific: The total energy released per unit mass of a nuclear fuel. It is commonly expressed in megawatt-days per metric ton of uranium (MWd/MTU).

Byproduct Material: Any radioactive material (except source material and special nuclear material) obtained incidentally during the production or use of source or special nuclear material.

Capacity Factor: The ratio of the electricity actually produced by a nuclear power plant to the electricity that would be produced if the reactor operated continuously at design capacity.

Cask: A tightly sealing, heavily shielded, reusable shipping container for radioactive materials.

Cask Liner: A tightly sealing, disposable metal container used inside a cask for shipping radioactive materials.

Code of Federal Regulations (CFR): A codification of the general rules by the executive departments and agencies of the Federal government. The Code is divided into 50 Titles that represent broad areas subject to federal regulation. Each Title is divided into Chapters that usually bear the name of the issuing agency. Each Chapter is further subdivided into Parts covering specific regulatory areas.

Constant Dollars: Constant dollar cost is the cost which would be paid for an item or a service in the future if there were no inflation between the time that the cost is estimated and the time the cost is incurred.

Contact Maintenance: "Hands-on" maintenance, or maintenance performed by direct contact of personnel with the equipment. Typically, most nonradioactive maintenance is contact maintenance.

Contamination: Undesired (e.g., radioactive or hazardous) material that is 1) deposited on the surfaces of, or internally ingrained into, structures or equipment, or 2) mixed with another material.

Continuing Care Period: The surveillance and maintenance phase of safe storage or entombment, with the facility secured against intrusion.

Cost Estimating Computer Program: A computer program, designed for an IBM personal computer or equivalent, used for estimating the decommissioning costs of light-water reactor power stations. The program provides estimates for the following phases of decommissioning: component, piping, and equipment removal costs; packaging costs; decontamination costs; transportation costs; burial volumes and costs; labor-hours and occupational exposures; and labor staffing costs.

Count Rate: The measured rate of the detection of ionizing events using a specific radiation detection device.

Crud: Corrosion products and wear particulates which through neutron activation become radioactive.

Curie (Ci): (a) Formerly, a special unit of radioactivity. One Curie equals 3.7×10^{10} disintegrations per second exactly or 1 Ci = 3.7×10^{10} Bq. (b) By popular usage, the quantity of any radioactive material having an activity of one curie. See also becquerel.

Decay, Radioactive: A spontaneous nuclear transformation in which charged particles and/or gamma radiation are emitted.

Decommission: To remove (as a facility) safely from service and reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of license.

Decontamination: Those activities employed to reduce the levels of contamination in or on structures, equipment, and materials.

Decontamination Agents: Chemical or cleansing materials used to effect decontamination.

Decontamination Factor (DF): The ratio of the initial amount (i.e., concentration or quantity) of an undesired material to the final amount resulting from a treatment process.

Deep Geologic Disposal: Placement of radioactive materials in stable geologic formations far beneath the earth's surface, to isolate them from man's environment.

De minimus Level: That level of contamination acceptable for unrestricted public use or access.

Discount Rate: The rate of return on capital that could be realized in alternative investments if the money were not committed to the plan being evaluated (i.e., the opportunity cost of alternative investments), equivalent to the weighted average cost of capital.

Discovery Period: Under certain bonds and policies, provision is made to give the insured a period of time after the cancellation of a contract in which to discover whether he has sustained a loss that would have been recoverable had the contract remained in force. This period varies from six months to three years, and the company can fix the period of time to be allowed. The period may also be determined by statute; in certain bonds, it is of indefinite duration because of such statutory requirement.

Disintegration, Nuclear: The spontaneous (radioactive) transformation of an atom of one element to that of another, characterized by a definite half-life and the emission of particles or radiation from the nucleus of the first element.

Disintegration Rate: The rate at which disintegrations (i.e., nucleartransformations) occur, in events per unit time (e.g., disintegrations per minute [dpm]).

Dismantlement: Those actions required during decommissioning to disassemble and remove sufficient radioactive or contaminated material from a facility to permit release of the property for unrestricted use.

Disposal: The disposition of materials with the intent that they will not enter man's environment in sufficient amounts to cause a significant health hazard.

Distribution Factor (radiation protection): The factor used in computing dose equivalent to allow for the nonuniform distribution of internally deposited radionuclides.

Dose Commitment (D_c) (regulatory): The total dose equivalent to a part of the body that will result from retention in the body of radioactive material. [see 10 CFR 32 § 32.2(a)].

Dose Equivalent (H) (radiation protection): The product of absorbed dose, quality factor, distribution factor, and other modifying factors necessary to obtain at a point of interest in tissue an evaluation of the effects of radiation received by exposed persons, so that the different characteristics of the radiation effects are taken into account. These characteristics may be indicated by modifying adjectives to the term, e.g., dose equivalent, residual.

Dose Equivalent, Maximum Permissible (MPDE) (radiation protection) The largest dose equivalent received within a specified period permitted by a regulatory committee on the assumption that there is no appreciable probability of somatic or genetic injury. Different levels of MPDE may be set for different groups within a population.

Dose Equivalent, Residual: The dose equivalent remaining after correction for such physiological recovery as has occurred at a specific time. It is based on the ability of the body to recover to some degree from radiation injury following exposure. It is used only to predict immediate effects.

Dose Meter: An instrument used for measuring or evaluating the absorbed dose, exposure, or similar radiation quantity (also call "dosimeter").

Dose Rate, Absorbed (D): The increment in absorbed dose during a suitable small interval of time divided by that interval of time.

Dosimeter: See dose meter.

Electron Capture (EC): The capture of an orbital electron by the radioactive nucleus of an atom. This transformation decreases the atomic number of the nucleus by one.

Entombment: The encasement of radioactive materials in concrete or other structural material sufficiently strong and structurally long-lived to ensure retention of the radioactivity until it has decayed to levels that permit unconditional release of the site.

Environmental Surveillance: A program to monitor the discharges of radioactivity or chemicals from industrial operations on the surrounding region. As used in this study, it is the program to monitor the extent and consequences of releases of radioactivity or chemicals from the nuclear power plant.

Excess Insurance: A policy or bond covering the insured against certain hazards, and applying only to loss or damage in excess of a stated amount. The risk of initial loss or damage (excluded from the Excess Policy or bond) may be carried by the insured himself; or may be insured by another policy or bond, providing what is known as "primary insurance."

Exposure: For x or gamma radiation in air, the sum of the electrical charges of all of the ions of one sign produced in air when all electrons liberated by photons in a suitably small element of volume of air are completely stopped in air, divided by the mass of the air in the volume element. It is commonly expressed in roentgens, but the SI unit of exposure is coulombs per kilogram, where $1\ R = 2.58 \times 10^{-4}$ C/kg exactly.

Financial Protection: The ability to respond in damages for public liability and to meet the costs of investigating and defending claims and settling suits for such damages.[a]

Fission: The splitting of a heavy atomic nucleus into two or more nearly equal parts (nuclides of lighter element), accompanied by the release of a relatively large amount of energy and (generally) one or more neutrons. Fission can occur spontaneously, but usually it is caused by nuclear absorption of gamma rays, neutrons, or other particles.

Fission Products: The lighter atomic nuclides (fission fragments) formed by the fission of heavy atoms. It also refers to the nuclides formed by the fission fragments' radioactive decay.

Food Chain: The pathways by which any material (such as radioactive material) passes through the environment through edible plants and/or animals to man.

Fuel Assembly: A bundle of fuel rods (tubes containing nuclear fuel) housed in a fixed geometry in a metal channel.

Gamma Rays: Short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense material such as lead or uranium. The rays are similar to x-rays, but are nuclear in origin, i.e., they originate from within the nucleus of the atom.

Gray (Gy): A unit of absorbed dose; 1 Gy = 1 J/kg = 100 rads.

Green Field: A working environment unencumbered by radiation, congestion, accessibility, etc.

Greenhouse: In nuclear terms, a temporary structure, frequently constructed of wood and plastic, used to provide a confinement barrier between a radioactive work area and a nonradioactive area.

Half-Life, Biological: The time required for the amount of a particular substance in a biological system to be reduced to one-half of its value by biological processes when the rate of removal is approximately exponential.

Half-Life, Effective: The time required for the amount of a particular nuclide in a system to be reduced to half its value as a consequence of both radioactive decay and other processes such as biological elimination and burnup when the rate of removal is approximately exponential.

Half-Life, Radioactive: For a single radioactive decay process, the time required for the activity to decrease to half its value by that process.

Health Physicist: A person trained to perform radiation surveys, oversee radiation monitoring, estimate the degree of radiation hazard, and advise on operating procedures for minimizing radiation exposures.

(a) Definition found in the Atomic Energy Act of 1954, as amended.

High-Level Waste: Radioactive waste from the first-cycle solvent extraction (or equivalent) during spent nuclear fuel reprocessing. Also applied to other concentrated wastes of various origins.

Hot Spot: An area of radioactive contamination of higher than average concentration.

Immobilization: Treatment and/or emplacement of materials (e.g., radioactive contamination) so as to impede their movement.

Indemnified Nuclear Facility: (1) "The Facility" as defined in any Nuclear Energy Liability Policy (Facility Form) issued by the companies or by Mutual Atomic Energy Liability Underwriters, or (2) Any other nuclear facility, if financial protection is required pursuant to the Atomic Energy Act of 1954, or any law amendatory thereof, with respect to any activities or operations conducted thereat.

Independent Spent Storage Installation (ISFSI): A complex designed and constructed for the interim storage of spent nuclear fuel and other radioactive materials associated with spent fuel storages.

Insurance: A contractual relationship which exists when one party (the insurer), for a consideration (the premium), agrees to reimburse another party (the insured) for loss to a specified subject (the risk) caused by designated contingencies (hazards or perils), or to pay on behalf of the insured all reasonable sums for which he may be liable to a third party (the claimant). The term "assurance," commonly used in England, is ordinarily considered identical to, and synonymous, with "insurance."

Intrusion Alarm: A security device that detects intrusion into a protected areas and initiates a visible and/or audible alarm signal.

Ion Exchange: A chemical process involving the selective adsorption (and subsequent desorption) of certain chemical ions in a solution onto a solid material, usually a plastic or resin. The process is used to separate contaminants from process streams, purifying them for reuse or disposal.

Irradiation: Exposure to ionizing radiation.

Liability: Generally, any legally enforceable obligation. The term is most commonly used in a monetary sense.

Liability Insurance: Any form of coverage whereby the insured is protected against claims of other parties. Most liability insurance is written by casualty companies, but some forms (especially those referring to property in the care of the insured) are underwritten in connection with fire or marine business. The insured's liability for damages under such coverage usually results from his negligence.

Licensed Material: Source material, special nuclear material, or byproduct material received, possessed, used or transferred under a license issued by the NRC.

Liquid Radioactive Waste: Solutions, suspensions, and mobile sludges contaminated with radioactive materials.

Long-Lived Nuclides: For this study, radioactive isotopes with long half-lives, typically taken to be greater than about 10 years. Most nuclides of interest to waste management have half-lives on the order of one year to millions of years.

Low-Level Waste: Wastes containing low but not hazardous quantities of radionuclides and requiring little or no biological shielding; low-level wastes generally contain no more than 100 nanocuries of transuranic material per gram of waste. These wastes are presently classified as Classes A, B, and C, and Greater-Than-Class C in 10 CFR 61.

Low-Level Waste Burial Ground: An area specifically designated for shallow subsurface disposal of solid radioactive wastes to temporarily isolate the waste from man's environment.

Mass Number (A): The number of nucleons (protons and neutrons) in the nucleus of a given atom.

Maximum-Exposed Individual: The hypothetical member of the public who receives the maximum radiation dose to an organ of reference.

Megawatt Days Per Metric Ton of Uranium: A unit for expressing the thermal output obtained per unit mass initial uranium in nuclear fuel.

Monitored Retrievable Storage Installation: A complex designed, constructed, and operated by DOE for the receipt, transfer, handling, packaging, possession, safeguarding, and storage of spent nuclear fuel aged for at least one year and solidified high-level radioactive waste resulting from civilian nuclear activities, pending shipment to an HLW repository or other disposal facility.

Monitoring: Making measurements or observations so as to recognize the status or adequacy of, or significant changes in, conditions or performance of a facility or area.

Normal Operating Conditions: Operation (including startup, shutdown, and maintenance) of systems within the normal range of applicable parameters.

Nuclear Reaction: A reaction involving a change in an atomic nucleus, such as fission, fusion, particle capture, or radioactive decay.

Nuclear Steam Supply System (NSSS): A contractual term designating those components of the nuclear power plant furnished by the nuclear steam supply system supplier. Generally includes those systems most closely associated with the reactor vessel, deigned to contain or be in contact with the water coming from or going to the reactor core. The nuclear steam supply system in the reference BWR consists of a reactor, the steam turbine, the turbine condenser, and associated reactor coolant recirculation loops connected to the reactor vessel.

Nuclide: A species of atom characterized by its mass number, atomic number, and nuclear energy state provided the mean life in that state is long enough to be observable.

Occupational Dose, (regulatory): Dose (or dose equivalent) resulting from exposure of an individual to radiation in a restricted area or in the course of employment in which the individual's duties involve exposure to radiation (see 10 CFR 20 § 20.3).

Offsite: Beyond the boundary line marking the limits of plant property.

Onsite: Within the boundary line marking the limits of plant property.

Operable: Capable of performing the required function.

Overpack: Secondary (or additional) external containment or cushioning for packaged nuclear waste that exceeds certain limits imposed by regulation.

Package: The packaging plus the contents of radioactive materials.

Packaging: The assembly of radioactive material in one or more containers and other components as necessary to ensure compliance with applicable regulations.

Peril: The cause of a loss insured against in a policy; e.g., fire, windstorm, explosion, etc.

Person-cSv: In the International System of Units, the sievert (Sv) is the name given to the units for dose equivalent. One centisievert (cSv) equals one rem; therefore, person-rem becomes person-cSv.

Person-rem: Used as a unit measure of population radiation dose, calculated by summing the dose equivalent in rem 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 implied.

Possession-only License: An amended operating license issued by the NRC to a nuclear facility owner entitling the licensee to possess but not operate the facility.

Power Reactor: A nuclear reactor used to provide steam for electrical power generation.

Preliminary Survey: A survey, usually smaller than the main survey, by licensee or inspector, for the purpose of designing a final survey plan to establish whether or not a site is decontaminated sufficiently to warrant unrestricted release according to federal and/or state standards. From the preliminary survey, decisions are then made such as grid size and layout, whether to use a simple random, stratified random or systematic sampling, total sample size, manpower and equipment needed, and probable cost of the final survey. In some cases, where independence of the inspector's final survey is not in danger of compromise, the final survey of the licensee can serve as the preliminary survey of the inspector.

Present Value of Money: The present value of a future stream of cost is the present investment necessary to secure or yield the future stream of payments, with compound interest at a given discount or interest rate. Inflation can be taken into account in this calculation.

Property Damage Liability Insurance: Protection against liability for damage to the property of another not in the care, custody, and control of the insured—as distinguished from liability for bodily injury.

Protective Survey: See Radiation Survey.

Public Liability: Any legal liability arising out of or resulting from a nuclear incident or precautionary evacuation (including all reasonable additional costs incurred by a State, or a political subdivision of a State, in the course of responding to a nuclear incident or a precautionary evacuation), except: 1) Claims under State or Federal workmen's compensation acts of employees of persons indemnified who are employed at the site of and in connection with the activity where the nuclear incident occurs; 2) Claims arising out of an act of war; and 3) Whenever used in subsections a., c., and k. of 10 CFR 50, Section 170, claims for loss of, or damage to, or loss of use of property which is located at the site of and used in connection with the licensed activity where the nuclear incident occurs.[a]

Quality Assurance: The systematic actions necessary to provide adequate confidence that 1) a material, component, system, process, or facility performs satisfactorily or as planned in service, or 2) that work is performed according to plan.

Quality Factor (Q): A modifying factor that weights the absorbed dose for biological effectiveness of the charged particles producing the absorbed dose. It is used for routine radiation protection applications and not for assessing the effects of high-level accidental exposures. Quality factors are the product of the relative biological effectiveness, averaged over several types of tissue, and certain other linear energy transfer factors expressing biological differences resulting from radiation absorption of the radiation type of interest and the reference radiation (200- to 250-keV x-rays); they are assumed to be independent of the type of organ exposed.

Rad (R): A former unit of absorbed dose; 1 rad = 10^{-2} Gy = 10^{-2} J/kg [see gray (Gy)].

(a) Definition found in the Atomic Energy Act of 1954, as amended.

Radiation: 1) The emission and propagation of radiant energy: for instance, the emission and propagation of electromagnetic waves or protons. 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.

Radiation Area: Any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive a dose in excess of 5 millirem in any one hour, or a dose in excess of 100 millirem in any 5 consecutive days. (See 10 CFR 20.202.)

Radiation Leakage (Direct): All radiation coming from a source housing except the useful beam.

Radiation Protection: All measures concerned with reducing deleterious effects of radiation to persons or materials (also called "radiological protection").

Radiation, Scattered: Radiation that has deviated in direction during its passage through a substance. It may also be modified by a decrease in energy.

Radiation, Stray: The sum of leakage and scattered radiation; also called "shine."

Radiation Survey (radiation protection): An evaluation of the radiation hazard potential associated with a specified set of conditions incident to the production, use, release, storage, or presence of radiation.

Radioactive Material: Any material or combination of materials that spontaneously emits ionizing radiation and has a specific activity in excess of 0.002 microcuries per gram of material. [See 49 CFR 173.389(e).]

Radioactive Series: A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nonradioactive nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product."

Radioactivity: The property of certain nuclides of spontaneously emitting particles or gamma radiation or of emitting x radiation following orbital electron capture or of undergoing spontaneous fission.

Radioactivity, Artificial: Man-made radioactivity produced by particle bombardment or electromagnetic irradiation, as opposed to natural radioactivity.

Radioactivity, Induced: The radioactivity in a nuclide that has been produced by man-made nuclear reactions.

Radioactivity, Natural: Radioactivity of naturally occurring nuclides.

Radionuclide: A radioactive nuclide.

Regulatory Guides: Documents that describe and make publicly available 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 may be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the NRC. (Government agencies other than the NRC have regulatory guides pertaining to non-nuclear matters.)

Rem: A former unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors (originally derived from roentgen equivalent man). 1 Rem = 0.01 Sv.

Remote Maintenance:	Maintenance by remote means, i.e., the human is separated by a shielding wall from the item being maintained. Used in the nuclear industry to reduce the occupational radiation doses to maintenance personnel.
Reporting Levels:	Those levels or parameters called out in the environmental technical specifications, the dismantling order, and/or the possession-only license that do not limit decommissioning activities, but that may indicate a measurable impact on the environment.
Repository (Federal):	A site owned and operated by the federal government for long-term storage or disposal of radioactive materials.
Restricted Area:	Any area to which access is controlled for protection of individuals from exposure to ionizing radiation and radioactive materials.
Roentgen (R):	A unit of exposure; $1 R = 2.58 \times 10^{-4}$ C/kg.
Safe Storage:	Those actions required to place and maintain a nuclear facility in such a condition that risk to the public is within acceptable bounds, so the facility can be safely stored for the time desired.
Shield:	A body of material used to reduce the passage of ionizing radiation. A shield may be designated according to what it is intended to absorb (as a gamma-ray shield or neutron shield), or according to the kind of protection it is intended to give (as a background, biological, or thermal shield). A shield may be required to protect personnel or to reduce radiation enough to allow use of counting instruments.
Short-Lived Radionuclides:	For this study, those radioactive isotopes with half-lives less than about 10 years.
Shutdown:	The time during which a facility is not in productive operation.
Sievert:	The special name of the unit of dose equivalent. 1 Sv = 1 J/kg = 100 rem.
Site:	The geographic area upon which the facility is located, subject to controlled public access by the facility licensee (includes the restricted area as designated in the NRC license).
Solid Radioactive Waste:	Radioactive waste material that is essentially solid and dry, but may contain sorbed radioactive fluids in sufficiently small amounts as to be immobile.
Solidification:	Conversion of radioactive wastes (gases or liquids) to dry, stable solids.
Source Material:	Thorium, natural or depleted uranium, or any combination thereof. Source material does not include special nuclear material. [See 10 CFR 40.4(h).]
Special Nuclear Material (SNM):	Plutonium, ^{233}U, uranium containing more than the natural abundance of ^{235}U, or any material artificially enriched with the foregoing substances. SNM does not include source material. [See 10 CFR 40.4(i).]
Surface Contamination:	The deposition and attachment of radioactive materials to a surface. Also, the resulting deposits.
Surveillance:	Those activities necessary to ensure that the site remains in a safe condition (includes periodic inspection and monitoring of the site, maintenance of barriers preventing access to radioactive materials remaining on the site, and prevention of activities that might impair these barriers).
System-Average Dose Rate:	The average dose rate associated with particular system; usually expressed in mSv/hour (mrem/hour).

Technical Specification: Requirements and limits encompassing environment and nuclear safety that are simplified to facilitate use by plant operation and maintenance personnel. They are prepared in accordance with the requirements of 10 CFR 50.36, and are incorporated into the operating and/or possession-only license issued by the NRC.

Termination Survey: Survey by the licensee of the site after it has been decontaminated and believed ready for unrestricted release. This survey will be carried out in accordance with NRC guidelines. The survey will be audited and will serve as a basis for the verification inspection.

Track Drill: A self-propelled, air-operated drill rig with an extendable boom capable of drilling 20-m-deep vertical holes in concrete.

Verification Inspection or Certification: Inspection by an NRC inspector of the site to confirm the licensee's final survey data and conclusions. Spot readings and soil samples to check licensee's instrumental air readings and soil analysis results shall be made. In addition, the inspector has discretionary power to take additional observations, such as sampling in spot areas not specifically sampled by the licensee.

Waste Management: The planning and execution of essential functions relating to radioactive and/or hazardous wastes, including treatment, packaging, interim storage, transportation, and disposal.

Waste Radioactive: Equipment and materials (from nuclear operations) that are radioactive and have no further use. Also called radwaste.

Workmen's Compensation Insurance: Provides protection to workers for injuries or death injuries or death arising by accident out of, and in the course of, employment.

X-Ray: A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (characteristic x-rays) or when a metal target is bombarded with high-speed electrons. X-rays are always nonnuclear in origin (i.e., they originate external to the nucleus of the atoms).

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11. ABSTRACT *(200 words or less)*

With the issuance of the Decommissioning Rule (June 27, 1988), nuclear power plant licensees are required to submit to the U.S. Nuclear Regulatory Commission (NRC) for review, decommissioning plans and cost estimates. This reevaluation study provides some of the needed bases documentation to the NRC staff that will assist them in assessing the adequacy of the licensee submittals. This report presents the results of a review and reevaluation of the PNL 1980 decommissioning study of the WNP-2 nuclear power plant for the DECON, SAFSTOR, and ENTOMB decommissioning alternatives. These alternatives now include an initial 5-7 year period during which the spent fuel is stored in the spent fuel pool, prior to beginning major disassembly or extended safe storage of the plant. This report also includes consideration of the NRC requirement that decommissioning activities leading to termination of the nuclear license be completed within 60 years of final reactor shutdown, consideration of packaging and disposal requirements for Greater-Than-Class C low-level waste, and reflects all costs in 1993 dollars. Sensitivity of the total license termination cost to the disposal costs at different low-level radioactive waste disposal sites, and to different depths of contaminated concrete surface removal with the facilities are also examined.

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16. PRICE

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS										ELAI	
				0	4	8	12	16	20	24	28	32	36
			RADWASTE AND CONTROL BUILDING										
2160	21	6		PROCESS CHEMICAL RADWASTE				[=======	====]				
								1440	720				
3150	10	7		REMOVE CONDENSATE DEMINERALIZER SYS					[=======	=====]			
									1800	1350			
2340	10	5		REMOVE OFFGAS AND STANDBY GAS TREATMENT SYS						[=====	====]		
										1404	936		
3680	10	10		REMOVE MAIN STEAM AND LEAKAGE CONTROL SYSTEMS							[=======	=======	====
											1472	1472	736
31860	10	36		REMOVE OTHER SYSTEM PIPING					[=======	=======	=======	=======	====
									3540	3540	3540	3540	35
1560	10	6										REMOVE CON	
580	10	2										REMOVE, DEC	
320	10	1								DECON IN SITU, TRUCK LOADING			
390	10	1											
1955	10	2									REMOVE CONTAMINATE		
6190	10	8											REM
54185	TOTAL	LABOR	HRS			0	0	1440	6060	6294	5948	5012	
			LICENSING TERMINATION SURVEY										
3270	10	6											
3270	10	6											
6600	10	11											
3100	10	5											
16240	TOTAL	LABOR	HRS										
292030	TOTAL	LABOR	HRS	1280	9120	13520	19300	21500	26480	24934	21088	19012	2

ED TIME - WEEKS													
	40	44	48	52	56	60	64	68	72	76	80	84	88
==	=======	=======	=======	========]									
	3540	3540	3540	3540									
MINATED DRAINS			[=======	====]									
			1040	520									
FILTER/DEMIN CRANE				[===]									
				580									
RADWASTE STORAGE CRANES				[==]									
				320									
				[==]									
				390									
CONCRETE SURFACES				[===]									
				1955									
E HVAC EQUIPMENT, DUCTS					[=======	========]							
					3095	3095							
76	3540	3540	4580	7305	3095	3095							
			OTHER STRUCTURES			[====	========]						
						1090	2180						
				RADWASTE AND CONTROL BLDG				[=======	====]				
								2180	1090				
					TURBINE GENERATOR BLDG				[======	=======	========]		
									1800	2400	2400		
									REACTOR BLDG		[==	========]	
											620	2480	
						1090	2180	2180	2890	2400	3020	2480	
576	15980	11640	17375	20410	10935	10245	6910	6580	4265	5280	3020	2480	

FIGURE 3.9. Schedule of Activities During Dismantlement (Radwaste Building)

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS							ELAP
				0	4	8	12	16	20
			TURBINE GENERATOR BUILDING						
7040	10	8			[=======	========]		REMOVE STEAM	
					3520	3520			
31680	10	36				[=======	=======	=======	=====
						3520	3520	3520	3520
12600	10	12					[=======	=======	======
							4200	4200	4200
3460	10	4							
1920	10	4							
1800	10	4							
400	10	2							
800	10	2							
2940	10	6							
160	10	1							
640	10	2							
3610	10	4							
67050	TOTAL	LABOR	HRS		3520	7040	7720	7720	7720

) TIME - WEEKS									
24	28	32	36	40	44	48	52	56	60
:LINE									
CHEM DECON RCS SYSTEMS									
========]									
1920									
=======	=======	=======	=======	=======	=======	=======	==]		
2880	2880	2880	2880	2880	2880	2880	720		
	DRAIN, DECON DRYER SEPARATOR POOL					[==]			
						2016			
ELEASE RPV, DRYER SEPARATOR POOL WATER							[========]		
							4032		
[=======	=======	=======	=======	=======	=======	=======	=======	========]	
1120	1120	1120	1120	1120	1120	1120	1120	1120	
5920	4000	4000	4000	4000	4000	6016	5872	1120	

FIGURE 3.3 Schedule of Activities During

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS									ELAPSE	
				0	4	8	12	16	20	24	28	3
			DECONTAMINATION/DECOMMISSIONING: PERIOD 4									
1920	10	6		[======	====]	RAD SURVEY ALL FACILITIES						
				1280	640							
			REACTOR BUILDING									
4000	10	5			[======	==]	DECON, REMOVE, PACK FUEL RACKS					
					3200	800						
4320	21	4				[====	====]	DRAIN, PROCESS POOL WATER				
						2160	2160					
1800	10	5					[==	========]		REMOVE SFP COOLING		
							360	1440				
60	10	1						[==]		REMOVE REFUELING CI		
								60				
1860	10	2							[====]		DECON, REM	
									1860			
29920	10	34			[===	=====	=====	=====	=====	=====	=====	
					1760	3520	3520	3520	3520	3520	3520	
12220	10	13					[======	=====	=====	==]	REMOVE CO	
							3760	3760	3760	940		
	10	6								[======	====]	(
										3640	1820	
3600	10	9									[=	
											800	
42720	10	48					[====	=====	=====	=====	=====	
							1780	3560	3560	3560	3560	
12750	10	15										
7700	10	7								REMOVE OTHER SYSTE		
13910	10	13										
1460	10	4										
6600	10	6										
1375	10	4										
2880	10	4										
149095	TOTAL	LABOR	HRS	1280	5600	6480	11580	12340	12700	11660	9700	

'IME - WEEKS												
	36	40	44	48	52	56	60	64	68	72	76	80
'STEM												
E												
'E, PACK POOL LINERS												
===	======]		REMOVE RCS PIPING, PUMPS AND EQUIPMENT									
520	3520											
ROL ROD DRIVE SYSTEM												
AND PACK RPV												
===	====]	REMOVE SACRIFICIAL SHIELD										
600	1200											
===	=====	=====	=====	=====	=====	=====	====]	REMOVE OTHER SYSTEM PIPING				
560	3560	3560	3560	3560	3560	3560	1780					
	[======	=====	=====	=====	REMOVE DRYWELL CONTAMINATED STRUCTURES							
	3400	3400	3400	2550								
IN REACTOR BLDG				[======	======]							
				4400	3300							
	DECON, REMOVE VENTS, DRAINS				[======	=====	=====	==]				
					4280	4280	4280	1070				
				VACUUM, WASH, ALL SURFACES				[========]				
								1460				
				REMOVE CONTAMINATED CONCRETE				[====	======]			
								2200	4400			
					REMOVE, DECON BRIDGE CRANE					[========]		
										1375		
							REMOVE HVAC EQUIPMENT, DUCTS				[========]	
											2880	
680	11680	6960	6960	10510	11140	7840	6060	4730	4400	1375	2880	

FIGURE 3.7. Schedule of Activities During Dismantlement (Reactor Building)

LABOR HOURS MAN-HRS	SHIFTS PER WEEK	ELAPSED TIME WEEKS							ELAPS
				0	4	8	12	16	20
			DEACTIVATION : PERIOD 2						
			DOC ACTIVATED 30 MONTHS PRIOR TO SHUTDOWN						
			DEFUEL REACTOR AND OBTAIN POSSESSION ONLY LICENSE						
1920	10	4		[========]		RAD SURVEY FOR CHEM DECON BA			
				1920					
7920	10	16			[=======	=======	=======	========]	
					1980	1980	1980	1980	
5760	10	12		DEACTIVATE SUPPORT SYSTEMS				[=======	======
								1920	1920
26640	10	37		CUT, REMOVE RPV INTERNALS				[=======	======
								2880	2880
2016	21	2							
4032	21	4							TREAT,
10080	5	36					RAD WASTE PACKAGING		
58368	TOTAL	LABOR	HRS	1920	1980	1980	1980	6780	4800

D TIME - WEEKS									
24	28	32	36	40	44	48	52	56	60
ELINE									
CHEM DECON RCS SYSTEMS									
========]									
1920									
=======	=======	=======	=======	=======	=======	=======	==]		
2880	2880	2880	2880	2880	2880	2880	720		
	DRAIN, DECON DRYER SEPARATOR POOL					[==]			
						2016			
ELEASE RPV, DRYER SEPARATOR POOL WATER							[========]		
							4032		
[=======	=======	=======	=======	=======	=======	=======	=======	========]	
1120	1120	1120	1120	1120	1120	1120	1120	1120	
5920	4000	4000	4000	4000	4000	6016	5872	1120	

FIGURE 3.3. Schedule of Activities During Deactivation (Period 2)