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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

Final Report

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Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

On June 27, 1988, the U.S. Nuclear Regulatory Commission (NRC) published in the Federal Register (53 FR 24018) regulations for the General Requirements for Decommissioning Nuclear Facilities. With the issuance of the rule, owners and operators of licensed nuclear power plants are required to prepare, and submit to the NRC for review, decommissioning cost estimates for shutdown facilities. 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. Included for information (but not part of the license termination cost) is an estimate of the cost to demolish the decontaminated and clean structures on the site and to restore the site to a "green field" condition.

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), and reflects 1993 costs for labor, materials, transport, and disposal activities. Sensitivity 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 is also examined.

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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 National Laboratory 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 information 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 provides additional bases documentation for the NRC staff to perform their reviews of the adequacy and reasonableness of the licensee submittals, and will provide information for the review of the funding certification amounts currently specified in 10 CFR 50.75(c).

It should be remembered that the results presented in this report are specific to the scenarios and assumptions used in the study and may not represent the actual situation at any given BWR power station. However, the cost analyses and the computer program presented herein are developed in sufficient detail that a plant owner can substitute his own site-specific conditions that influence any significant cost element, thereby accounting for site-specific differences.

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 lengthy in-pool cooling time necessary (~5 years) before the projected high burnup (~40,000-50,000 MWD/MTU) spent fuel from the final core loading could be placed into dry storage, based on satisfying the cladding temperature limits for dry storage.

- 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 change 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 need to cool the SNF in the pool for an extended period to satisfy cladding temperature limits for dry storage 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, which is licensed under 10 CFR 72. While continued storage of SNF in the pool is acceptable, the modified Part 50 license could not be terminated until the pool had been emptied and the facility decommissioned.[1] 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 reactor nuclear license terminated. In that event, the storage facility would have to be licensed under 10 CFR 72. However, these latter storage costs are presently considered operations costs under 10 CFR 50.54(bb), 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.

[1]During the preparation of this report, the Commission issued new guidance regarding decommissioning-related activities which could be undertaken by licensees before NRC approval of a decommissioning plan. This report does not evaluate the possible impacts of this new guidance on decommissioning scenarios and cost.

- 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 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 alternatives, 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.

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

Table ES.1 Results of DECON, SAFSTOR, and ENTOMB analyses

Shutdown alternative	Estimated cost (millions 1993 $)[a,b] (Constant $)	(Present value $)[c]	Waste volume disposal (m³)	Radiation dose (person-rem)	Post-shutdown (years)
DECON	164.6	138.6	15,125	836.6	6.3
SAFSTOR1[d]	226.1	122.2	1,094	458.8	60
SAFSTOR2[e]	309.6	135.1	15,115	468.5	60
ENTOMB1[f]	200.1	132.7	445	471.7	60
ENTOMB2[g]	204.6	136.0	1,112	531.7	60
ENTOMB3[h]	601.9	141.9	445	471.7	300

(a) Values are in constant early 1993 dollars, and include a 25% contingency. Costs do not include soil decontamination.
(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 present value discussion on pages xx, xxi.
(d) Assumes only the reactor pressure vessel and concrete bioshield require disposal as LLW.
(e) Assumes all material originally radioactive still exceeds unrestricted release levels. No LLW volume reduction from DECON.
(f) Assumes no removal of the reactor pressure vessel or bioshield. 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 ($1.30 million/yr) would continue until the license is terminated.
(g) Assumes removal of the reactor pressure vessel and concrete bioshield required during preparations for entombment to assure license termination within 60 years following reactor shutdown.
(h) Assumes the reactor pressure vessel and concrete bioshield have decayed to unrestricted release levels, and the detailed termination survey is not required following 300 years of decay.

activities, which could increase the total decommissioning cost as much as $48 million or more (see Appendix H), 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 to the cost of decommissioning. In addition, ISFSI construction and operation costs, used primarily for the DECON option, are not included but might be included by others in decommissioning cost estimates.

The bases used in these analyses have been incorporated into a user-friendly computer program, the Cost Estimating Computer Program (CECP), which was designed for use on an IBM-compatible personal computer for estimating the cost of decommissioning light water reactor power stations to the point of license termination. The CECP will be used 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 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. The transport and disposal costs associated with disposal of LLW from DECON, SAFSTOR1, and SAFSTOR2 in the Chem-Nuclear facility at Barnwell, SC, are compared with the costs for transport and disposal of the LLW in the U.S. Ecology facility at Richland, WA, in Table ES.2. 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.

Because these cost elements are the only ones affected by the choice to dispose of the low-level wastes at different locations, the total license termination cost for Barnwell disposal is about $319 million, or about 94% greater than for Hanford disposal. Assuming a 500-mile transport distance with Hanford disposal increases the total decommissioning cost by about $2.9 million. Similar cost differences may well 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 $\$1000/ft^3$, plus appropriate adders. 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 $174.98 million for the $\$50/ft^3$ rate to $847.40 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.

Table ES.2 Comparison of costs for transport and disposal of LLW resulting from DECON, SAFSTOR1, and SAFSTOR2 for two disposal sites[a]

		Estimated costs in millions of 1993 dollars		
		Richland	Barnwell	Difference (Barnwell - Richland)
DECON:	Transport	1.4	8.5	7.1
	Disposal[b]	45.8	193.4	147.6
	Total	47.2	202.2	155.0
SAFSTOR1	Transport	1.2	3.4	2.2
	Disposal	6.9	19.74	2.2
	Total	8.1	23.1	15.0
SAFSTOR2:	Transport	1.4	8.5	7.1
	Disposal[b]	45.4	193.3	148.1
	Total	46.8	201.8	155.0

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

(b) The rate schedules for the Chem-Nuclear facility and the U.S. Ecology facility include charges for curie content as well as for waste volume. Because the SAFSTOR2 wastes have decayed 51.38 years longer than the DECON wastes, the SAFSTOR2 wastes have a lower curie content than the DECON wastes. This results in lower burial costs for the SAFSTOR2 case, even though the amount of waste is the same in both cases.

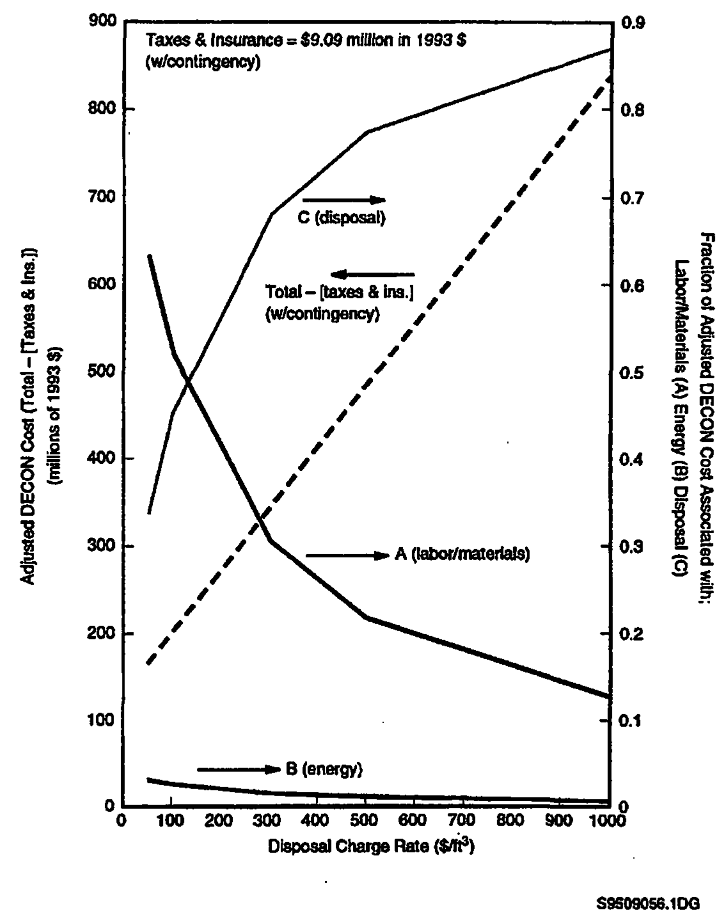

Figure ES.1 Variation of DECON escalation formula terms as functions of low-level waste disposal charge rates (w/contingency)

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 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 $0.7 million.

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 approximately tripled, an increase of 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. 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 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 increased about 70%, from 836 person-rem for the base analysis (15-ft pipe lengths) to 1,435 person-rem for the sensitivity case (5-ft pipe lengths).

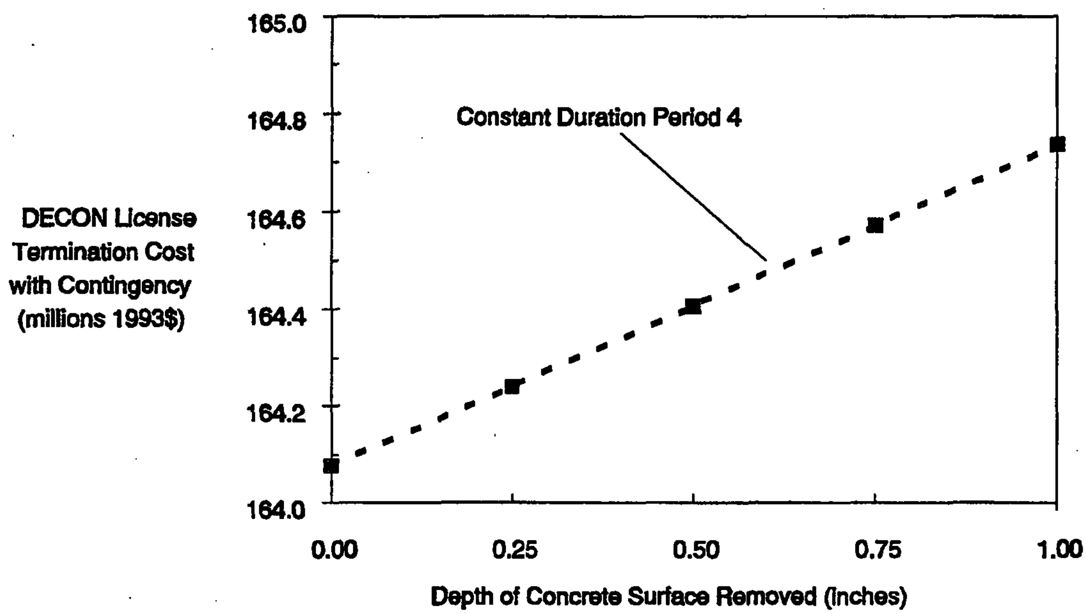

Figure ES.2 Sensitivity of license termination cost to varying depths of contaminated concrete removal during DECON

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: $138.6 million for DECON; $122.2 million for SAFSTOR1 and $135.1 million for SAFSTOR2; and $132.7 million, $136.0 million, and $141.9 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 $122 to $141 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.

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.

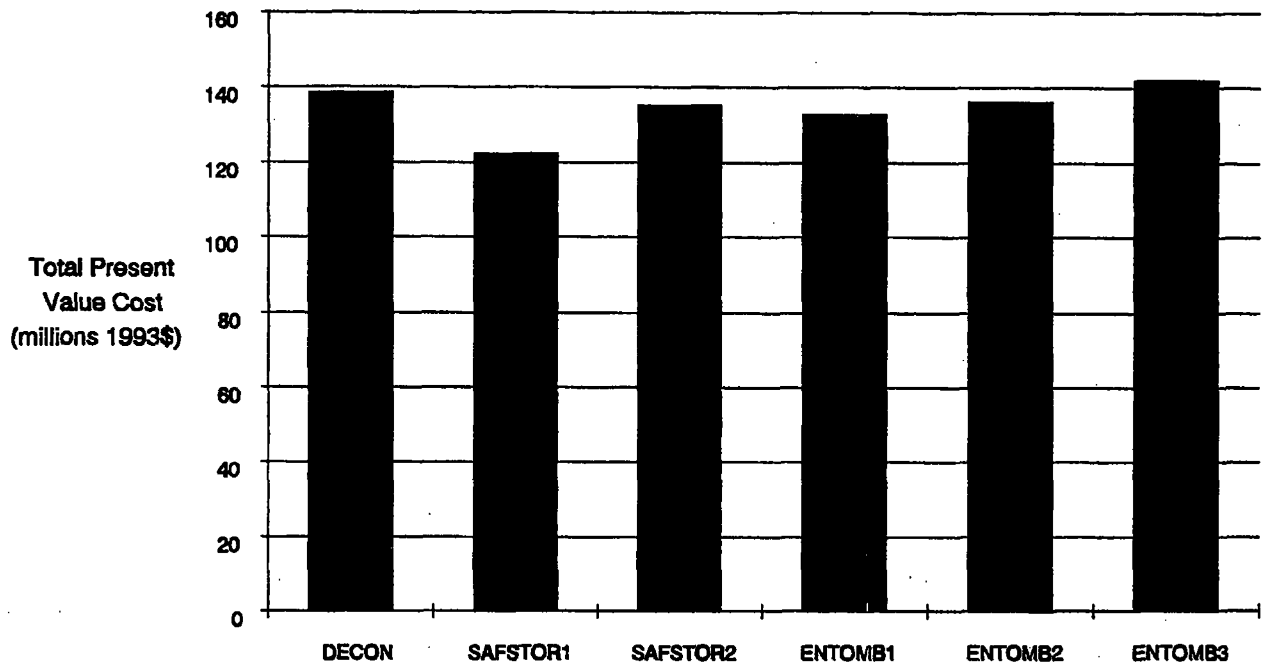

Figure ES.3 Comparison of present values of decommissioning alternatives

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: 514,723 ft^3, 14,575.3 m^3 (96.37%)
Class B/C: 19,152 ft^3, 542.3 m^3 (3.59%)
GTCC: 244 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 (15,124.5 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 SAFSTOR1 LLW volume is reduced from that of DECON to about 1,094 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 (15,115 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 (15,124.5 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 could eliminate future concerns about LLW disposal altogether.

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. Thus, 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 decontaminated 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 report contains information concerning a reevaluation of the reference boiling water reactor (BWR) decommissioning study and its addendums that were 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 document reevaluating the same parameters for the reference pressurized water reactor (PWR) was published in November 1995 as NUREG/CR-5884. Completion of the two reevaluation reports provides the NRC with an information database on the present estimated costs to decommission LWRs. Public comment was solicited on the draft reports and was factored into the final results. The NRC may use this information to determine if amendments to the decommissioning regulations are warranted.

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. Other approaches may be equally acceptable. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

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1 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 National Laboratory[1] 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 information and cost estimates for decommissioning their facilities to the NRC. 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. 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]Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC-06-76RLO 1830.

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 lengthy in-pool cooling time necessary (~5 years) before the projected high burnup (40,000-50,000 MWD/MTU) spent fuel from the final core loading could be placed into dry storage, based on satisfying the cladding temperature constraints for dry storage. 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 change 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 **only** 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 developed in Appendix H, and are presented for information only. The costs of demolition and restoration of the site are **not** presently included when defining the amount of money the NRC requires to be placed in the plant's decommissioning fund. 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. For these reasons, 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 and site restoration (~ $48 million), 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 significantly, depending upon the situation at the plant location.

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 need to cool the high burnup assemblies from the last core discharge in the pool for about 5 years (see Appendix D) 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 within 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[2] 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.

[2]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.

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 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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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 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 was 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. Unless otherwise specified, all tasks are carried out using a 2-shift/day, 5 days/week work schedule.

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. One frequently used 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 until the cladding temperature limits for dry storage can be met (postulated to be 5 years in this analysis) 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 an extended period following reactor shutdown due to the need to store SNF in the reactor pool until the cladding temperature limits can be met, 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 (Section 3.5.1).
- 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 (Table 3.28).
- 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 (Section 3.4.4).
- The effect on total decommissioning costs of removing a range of depths of contaminated concrete surfaces (Figure 3.10).

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)[1] 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 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.

[1]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.

- 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 costs for decontamination of soils beneath and/or around the structures are **not** included in these cost analyses.

- The demolition and site restoration costs given in NUREG/CR-0672 were re-evaluated, with the results presented in Appendix H. However, these actions are **not** required for license termination, and these costs are **not** included in the certification funding amount defined in the Decommissioning Rule.

- The high burnups (40,000-50,000 MWD/MTU) projected for some of the assemblies from the final core discharge at the reference BWR could require cooling in the spent fuel pool for up to 5 years before the cladding temperature limits for dry storage could be met (see Appendix D).

- 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),[2] 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 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

[2]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.)

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.

2. G. M. Holter and E. S. Murphy. 1983. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Effects on Decommissioning of Interim Inability to Dispose of Wastes Offsite*. NUREG/CR-0672, Addendum 1, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

3. E. S. Murphy. 1984. *Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station - Classification of Decommissioning Wastes*. NUREG/CR-0672, Addendum 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

5. 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.

6. N. G. Wittenbrock. 1982. *Technology, Safety and Costs of Decommissioning Nuclear Reactors at Multiple-Reactor Stations*. NUREG/CR-1755, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

7. E. B. Moore, Jr. 1985. *Technology, Safety and Costs of Decommissioning Nuclear Reactors at Multiple-Reactor Stations - Effects on Decommissioning of Interim Inability to Dispose of Wastes Offsite.* NUREG/CR-1755, Addendum 1, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

8. DOE/EIA-0438(90). 1990. *Commercial Nuclear Power 1990 - Prospects for the United States and the World.* U.S. Department of Energy report by Energy Information Administration, Washington, D.C.

3 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 (see Appendix D) 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 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. Special equipment purchased for the project is costed during Period 1, estimated to be about $3.4 million, and the cost of regulatory activities, estimated to be about $0.4 million, are included in the total estimated cost for Period 1 of about $9.5 million, without contingency.

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

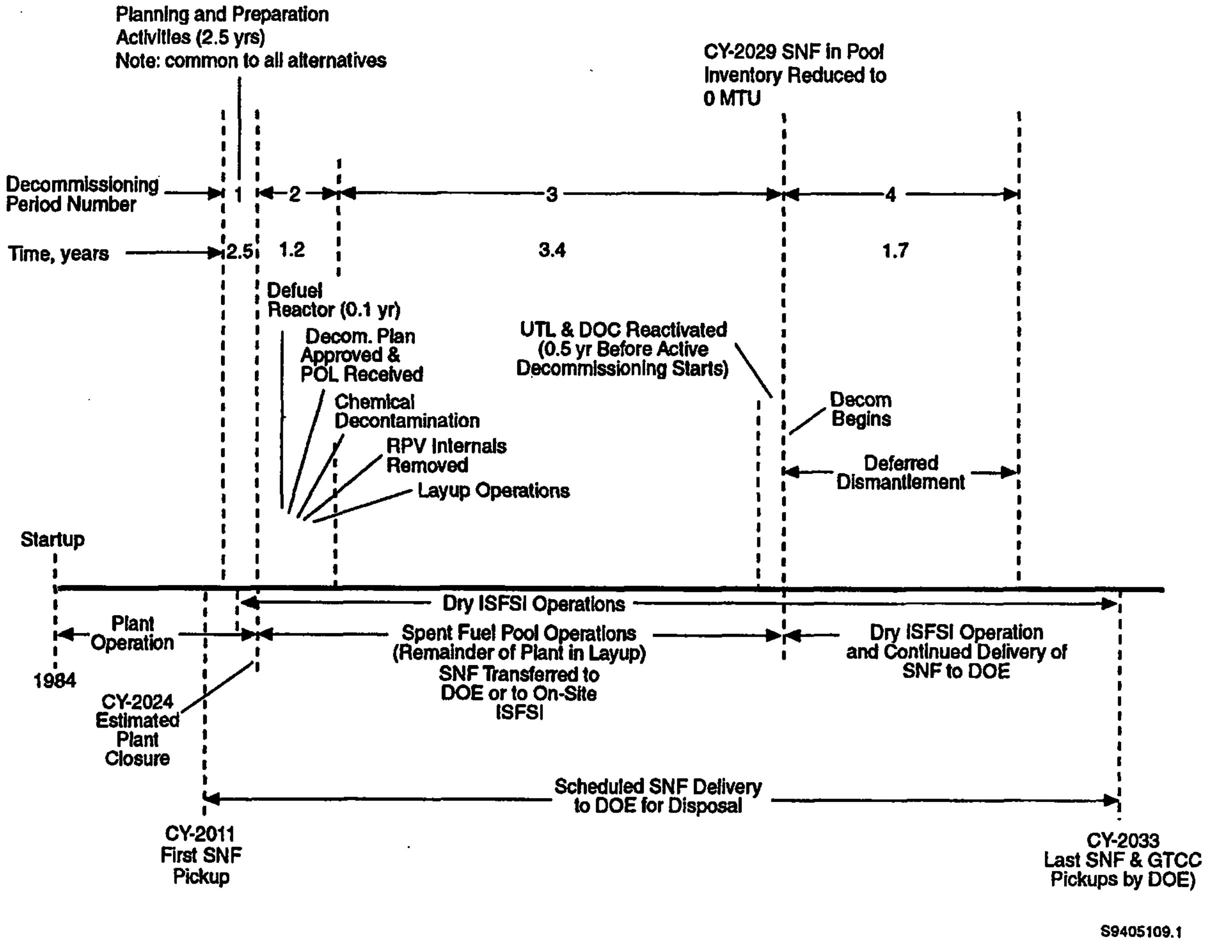

Figure 3.1 Schedule of activities during the four periods of DECON

Table 3.1 Summary of estimated costs and radiation doses during the four periods of DECON

Period number	Duration (years)	Estimated costs (1993 $)							Estimated radiation dose (person-rem)
		DECON[a]	Remove[b]	Package[c]	Transport[d]	Disposal[e]	Undistributed[f]	Total	
1	2.5	--	--	--	--	--	9,459,241	9,459,241	--
2	1.2	13,256,628	781,421	138,020	789,554	3,428,898	22,260,381	40,654,902	323.75
3	3.4	--	--	--	--	--	4,594,011	4,594,011	10.27
4	1.7	782,266	13,496,955	3,507,042	322,172	33,176,085	25,684,770	76,869,290	502.53
Subtotal	8.8	14,038,894	14,278,376	3,645,063	1,111,726	36,604,983	61,998,403	131,677,444	836.55
							25% Contingency	32,919,361	
							Total	164,596,805	

(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 retail 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, and environmental monitoring.

Table 3.2 Estimated Utility staffing and costs for DECON

Positions	Annual salary[a]	Person-years and labor costs per period in 1993 dollars													
		Period 1 (2.5 yr)		Period 2 (0.62 yr)		Period 3[b] (3.4 yr)		Period 4 (1.7 yr)		Pool opn. (P3)[b] (3.9 yr)		ISFSI opn. (P4) (1.7 yr)		ISFSI opn. (P5) (3.3 yr)	
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	3.3	345,919
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	3.3	89,595
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	3.3	241,049
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	3.3	286,503
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	3.3	246,860
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	3.3	70,897
Maintenance Manager	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	6.6	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 Engineer	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	--	--	3.3	521,080
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	3.3	202,716
Custodian	32,248	--	--	1.23	39,665	1.26	40,632	3.4	109,643	11.34	365,692	--	--	3.3	106,418
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]	3.3	286,503
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]	9.9	380,546
Security Patrolman	34,875	--	--	19.69	686,689	5.04	175,770	1.6	55,800[c]	45.36	1,581,930	12.0	41,850[c]	26.4	920,700
Utility Overhead Totals		8.00	600,077	112.7	6,008,571	33.39	1,905,744	55.9	3,390,654	300.51	17,151,693	30.4	1,564,006	76.4	4,318,101

(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							
		Period 1 (2.5 yr)		Period 2 (0.62 yr)		Period 3[b] (6.3 yr)		Period 4 (1.7 yr)	
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
Engineering 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.

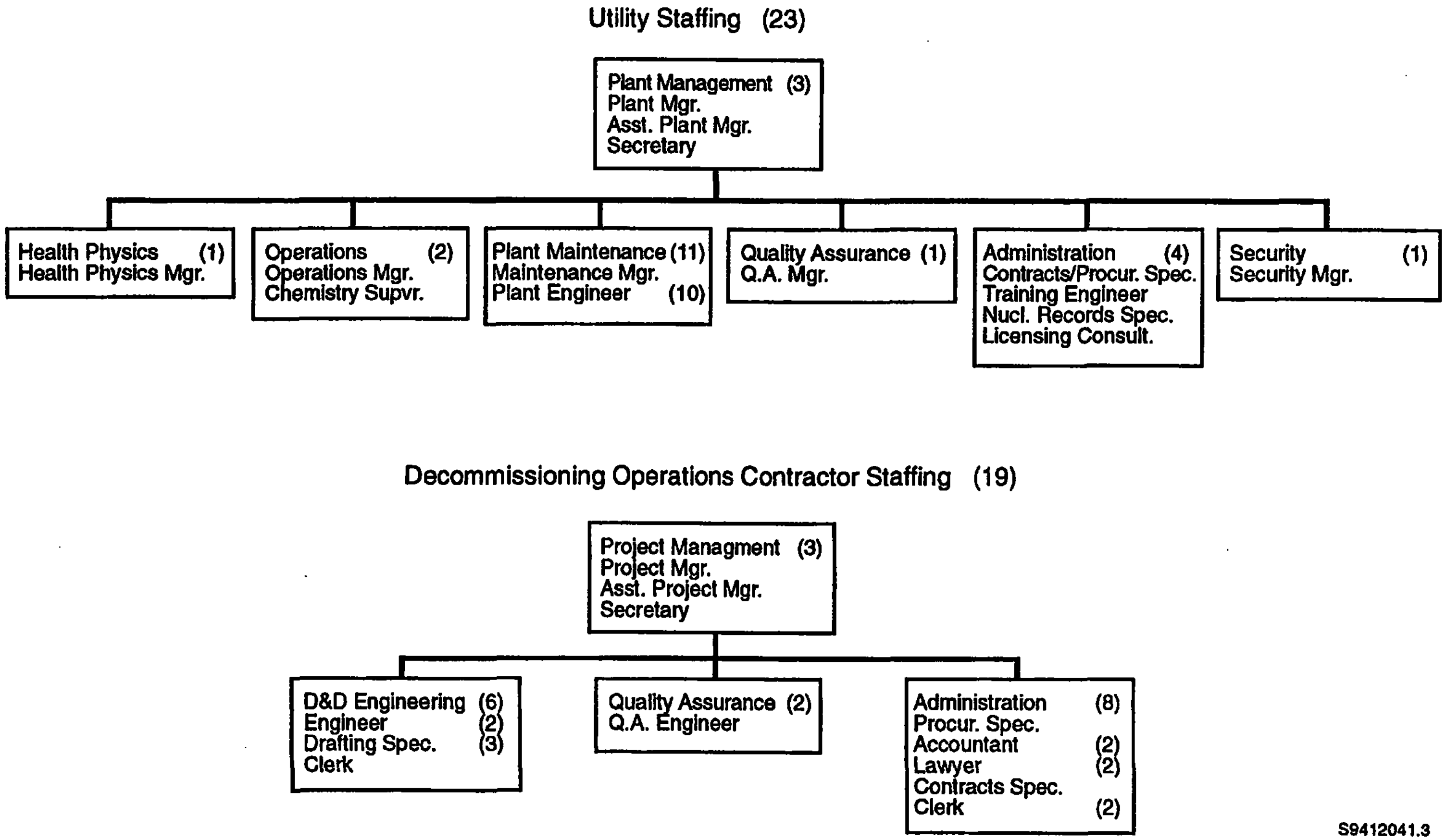

Figure 3.2 Utility and DOC staff structure and level during pre-decommissioning: Period 1

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.

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, the following 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 residual RCS water is cleaned and released.

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 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.

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 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

			Schedule Duration (weeks) DECON, Period 2, Deactivation Activities														
			Reactor defueled by Operations, permission received to proceed with decommissioning														
			Activities include only those which are chargable to decommissioning														
Direct Labor hrs	Duration (weeks)		4	8	12	16	20	24	28	32	36	40	44	48	52	56	60
	4			Conduct radiation survey for baseline for chemical decontamination of systems													
1,920			1,920														
	18								Perform chemical decontamination of systems								
12,960				2,880	2,880	2,880	2,880	1,440									
	12																
5,760							1,920	1,920	1,920	Deactivate support systems							
	37			Cut, remove, package internals													
21,647							2,340	2,340	2,340	2,340	2,340	2,340	2,340	2,340	2,340	587	
	2											Drain, decontaminate dryer separator pool					
2,016																2,016	
	4											Treat, release water from RPV, dryer separator pool					
4,032																	4,032
	36				Packaging of radioactive wastes												
10,080									1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120	1,120
58,415			1,920	2,880	2,880	2,880	7,140	5,700	5,380	3,460	3,460	3,460	3,460	3,460	3,460	3,723	5,152

Figure 3.3 Schedule of activities during Deactivation (Period 2)

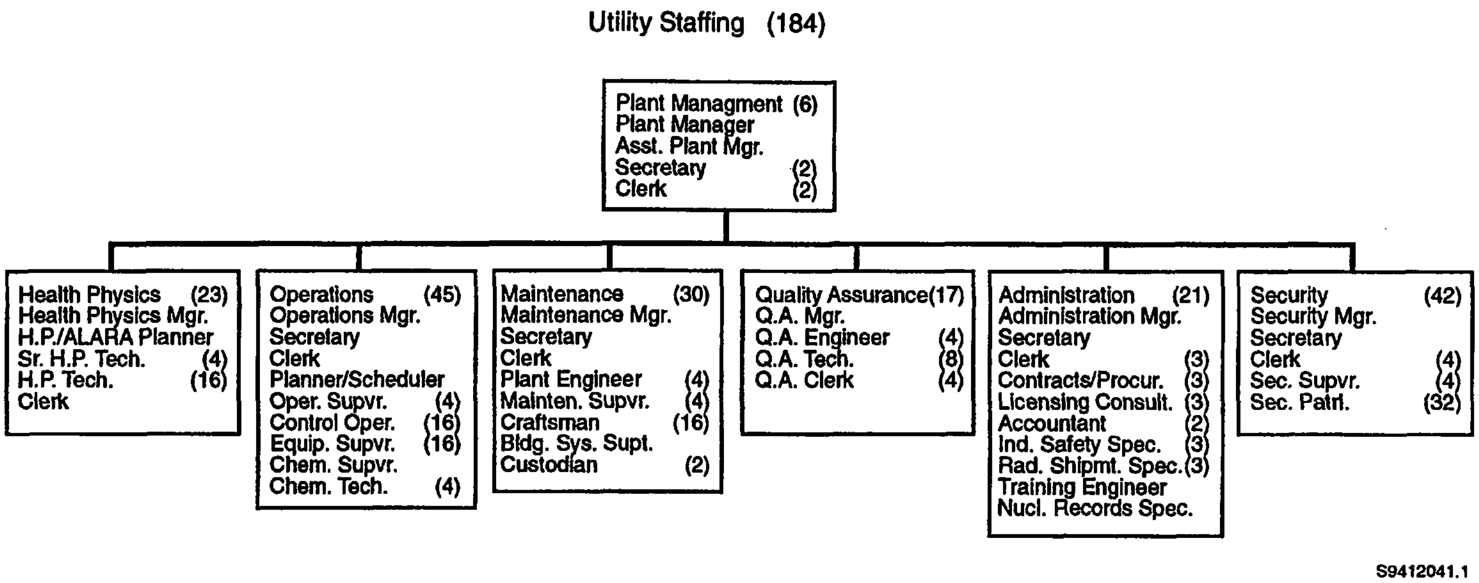

Figure 3.4 Utility staffing structure and levels following receipt of possession-only license: Period 2

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)	4.558[b]	112.22
Subtotals	18.281	160.32
Undistributed Costs		
Utility Support Staff	16.660	165.73
Regulatory Costs	0.431	--
Plant Power	1.135	--
Environmental Monitoring	0.058	--
Dry Active Wastes	0.113	--
Small Tools	0.015	--
Laundry Services	0.526	--
Energy (chem. decon)	0.238	--
Nuclear Insurance (Appendix B)	3.195	--
Subtotals	22.374	165.73
Totals	40.654	323.75

(a) Costs shown do not include contingency.
(b) Does not include RPV ($1.433 million, Table 3.6).

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).

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.

No significant quantities of friable asbestos have been identified within the plant buildings. The principal source of asbestos is the baffles in the cooling towers, which is not friable.

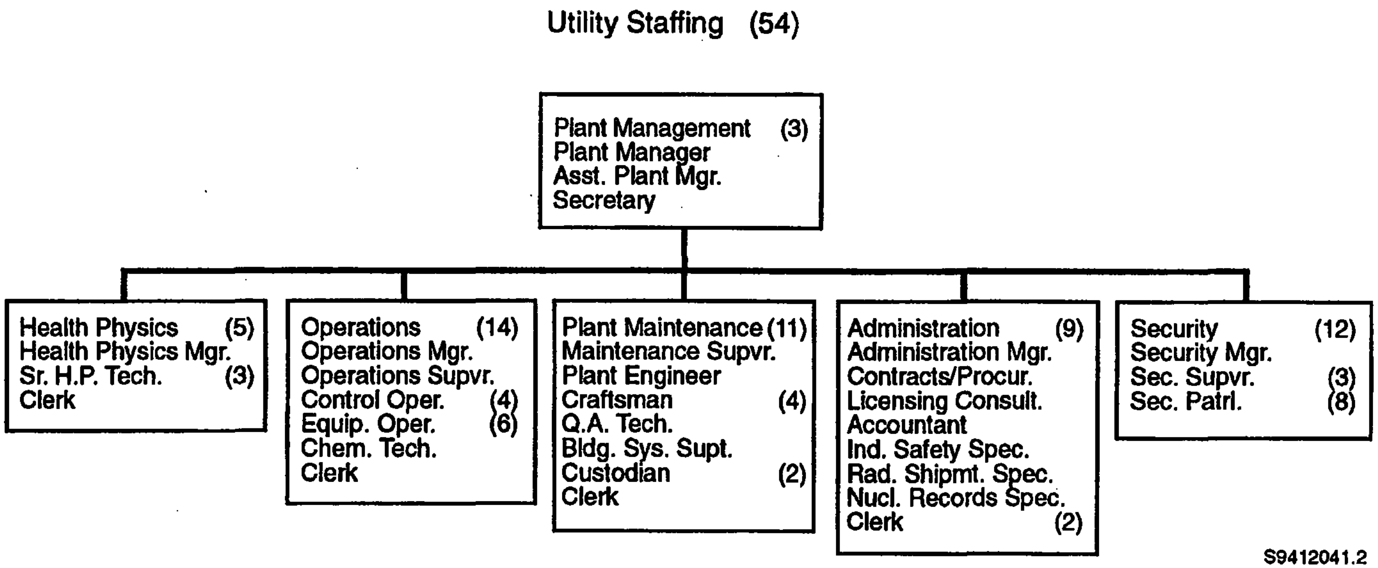

Figure 3.5 Staffing structure and levels during safe storage and SNF pool operations: Period 3

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	1.435[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	4.594	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.

Activities necessary to decontaminate soils around and/or beneath the structures are **not** included in these analyses because the extent of soil contamination is generally small, and varies widely among sites.

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.

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

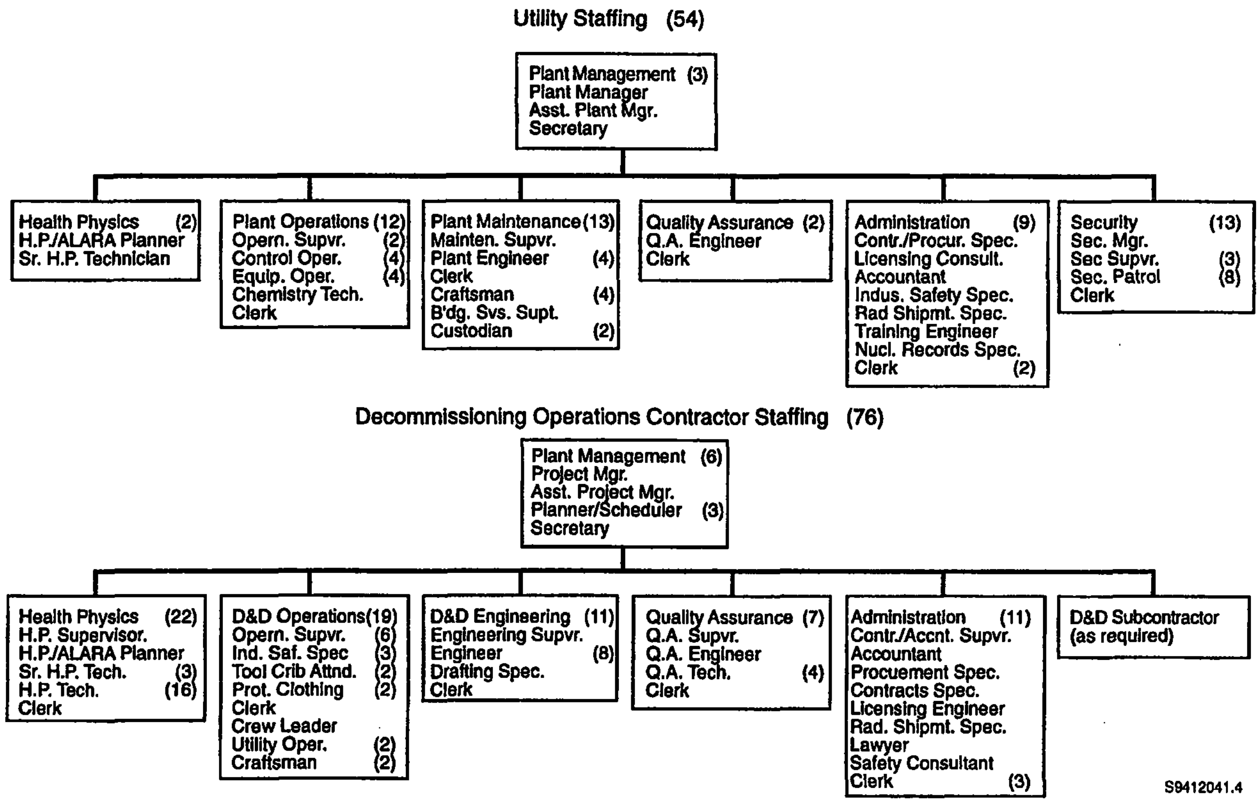

Figure 3.6 Utility and DOC staff structure and levels during deferred dismantlement: Period 4

Direct	Duration			Schedule Duration (weeks) DECON, Period 4, Reactor Building																				
Labor hrs	(weeks)		4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88
	6				Characterization survey																			
1,920			1,280	640																				
	5				Remove, decontaminate, package spent fuel racks																			
4,000			800	3,200																				
	4					Drain, process spent fuel pool water																		
4,032					4,032																			
	5							Remove spent fuel pool cooling system																
1,749						1,589	160																	
	1					Remove refueling bridge crane																		
60					60																			
	6								Decontaminate, remove, package spent fuel pool liner															
1,563							1,120	443																
	34													Remove RCS piping and equipment										
29,863				1,703	3,520	3,520	3,520	3,520	3,520	3,520	3,520	3,520												
	14									Remove control rod drive system														
12,178						3,520	3,520	3,520	1,618															
	9											Segment and package Reactor Pressure Vessel												
5,073									2,250	2,250	573													
	9													Remove sacrificial shield										
3,600											1,200	1,600	800											
	43																	Remove other system piping and hangers						
74,027						3,627	7,040	7,040	7,040	7,040	7,040	7,040	7,040	7,040	7,040	7,040								
	15																Remove contaminated drywell internal structures							
12,738												2,178	3,520	3,520	3,520									
	10									Remove other systems in Reactor Building														
7,767																3,520	3,520	727						
	15										Decontaminate, remove drains, vents													
13,910																	3,520	3,520	3,520	3,350				
	2													Vacuum, wash building surfaces										
1,162																				1,162				
	10															Remove contaminated concrete surfaces								
5,057																					1,920	1,920	1,217	
	5																Remove, decontaminate bridge crane							
1,776																							1,421	355
	4																		Remove HVAC ducts and equipment					
2,902																								2,902
183,377			2,080	5,543	7,612	12,256	15,360	14,523	14,428	12,810	12,333	14,338	11,360	10,560	10,560	10,560	7,040	4,247	3,520	4,512	1,920	1,920	2,638	3,257

Figure 3.7 Schedule and activities during dismantlement (Period 4), Reactor Building

Direct Labor hrs	Duration (weeks)		Schedule Duration (weeks) DECON, Period 4, Turbine Generator Building 4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64
	8						Remove steam turbine/generator											
7,040				3,520	3,520													
	36																	
54,896					6,096	6,100	6,100	6,100	6,100	6,100	6,100	6,100	6,100					
	12									Remove turbine condenser								
12,564						4,164	4,200	4,200										
	4										Remove moisture separator reheaters							
3,456									3,456									
	4											Remove feedwater heaters						
1,920										1,920								
	4												Remove feedwater condensate system					
1,812											1,812							
	2												Remove feedwater pumps/turbine drives					
392												392						
	2												Decontaminate building crane in situ					
800												800						
	6														Decontaminate, remove drains			
2,940													1,960	980				
	<1														Vacuum, wash surfaces			
160														160				
	2										Remove contaminated concrete							
478															478			
	4										Remove HVAC ducts and equipment							
3,049															1,524	1,525		
89,507				3,520	9,616	10,264	10,300	10,300	9,556	8,020	7,912	7,292	8,060	1,140	2,002	1,525		

Figure 3.8 Schedule of activities during dismantlement (Period 4), Turbine Building

Direct	Duration		Schedule Duration (weeks) DECON, Period 4, Radwaste and Control Building																						
Labor hrs	(weeks)		4	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92
	6								Process chemical radwaste																
2,160							1,440	720																	
	7									Remove condensate demineralizer system															
3,126								1,800	1,326																
	5										Remove offgas and standby gas treatment systems														
2,340									1,404	936															
	10												Remove main steam and leakage control systems												
3,680										1,472	1,472	736													
	32															Remove other systems piping and hangers									
55,208								5,928	7,040	7,040	7,040	7,040	7,040	7,040	7,040										
	6																Remove contaminated drains								
1,560															1,040	520									
	5																	Remove, decontaminate filter/demineralizer crane							
1,776																1,421	355								
	2																Decontaminate truck loading and radwaste storage cranes in situ								
710																710									
	2																	Remove contaminated surfaces							
1,504																	1,504								
	8																			Remove HVAC ducts and equipment					
6,182																		3,096	3,087						
78,246	Radwaste and Control Building						1,440	8,448	9,770	9,448	8,512	7,776	7,040	7,040	8,080	2,651	1,859	3,096	3,087						
89,607	Turbine Building			3,520	9,616	10,264	10,300	10,300	9,556	8,020	7,912	7,292	8,060	1,140	2,002	1,525									
183,377	Reactor Build		2080	5,543	7,612	12,256	15,360	14,523	14,428	12,810	12,333	14,338	11,360	10,560	10,560	10,560	7,040	4,247	3,520	4,512	1,920	1,920	2,638	3,257	
351,130	-	#	2,080	9,063	17,228	22,520	27,100	33,271	33,754	30,278	28,757	29,406	26,460	18,740	20,642	14,736	8,899	7,342	6,607	4,512	1,920	1,920	2,638	3,257	
	License Termination Survey																								
	6														Other Structures and Surfaces										
3,270																			2,180	1,090					
	6														Radwaste and Control Building										
3,270																				1,090	2,180				
	11															Turbine Generator Building									
6,600																						2,400	2,400	1,800	
	5																Reactor Building								
3,100																								620	2,480
16,240	22																		2,180	2,180	2,180	2,400	2,400	2,420	2,480

Figure 3.9 Schedule and activities during dismantlement (Period 4), Radwaste & Control Building

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	19.734	112.15
Reactor Pressure Vessel	1.433[a]	35.05
Steam Turbine/ Condenser/ Reheaters, Feed Pumps	12.930	8.74
Recirculation Piping / Components	5.095	263.46
SNF Pool Racks	1.638	1.09
Sacrificial Shield	1.936	24.95
HVAC System	2.366	7.19
Contaminated Surfaces	1.301	8.41
Facility Cranes	0.437	0.16
Containment Structural Steel & Cable Trays	1.462	4.42
Termination Survey	1.058	0.00
Dry Active Waste	1.680	0.00
Floor Drains	0.489	1.66
Waste Water Treatment	0.784	1.52
Undistributed Costs	24.426	33.73
Totals (w/o contingency)	76.969	502.53

(a) Does not include removal/disposal of RPV internals ($4.558 million, Table 3.4).

3.4.1 Removal of Process Systems and Piping

The estimated costs and radiation doses associated with the removal of the contaminated systems, piping and pipe hangers 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.

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.

In addition to the components, piping, and valves, 12,500 potentially contaminated pipe hangers were identified. These hangers range in size from simple U-bolts used for sample piping to massive structures (1,000 pounds or more) designed to support the steam lines. The total to remove the hangers is $4,813,916, without contingency.

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 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): $1,432,553
- Estimated Worker Radiation Dose: 35.05 person-rem

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	148,691	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	257,015	3.10
Reactor Bldg. Closed Cooling Water	159,761	0.31
Reactor Core Isolation Cooling	83,542	0.11
Residual Heat Removal	959,267	0.31
Recirculation Water	98,890	0.20
Reactor Water Cleanup	187,654	39.45
Reactor Bldg. Equipment and Floor Drains	53,928	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
Pipe Hangers	4,813,916	2.70
Other Systems Piping	6,221,156	36.86
Totals (w/o contingency)	19,733,949	112.15

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.

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.

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 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, cost/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.

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

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.

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.

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 $9 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. 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 $12 million, not 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 increased about 70%, from 836 person-rem for the base analysis (15-ft pipe lengths) to 1,435 person-rem for the sensitivity case (5-ft pipe lengths).

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)[(e)]
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.

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.

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 3.12 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 (ft³)	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.

Table 3.13. The total cost for this activity is estimated at about $1.64 million, not including contingency.

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.

Table 3.13 Summary of estimated costs for spent fuel pool racks removal and disposal activities

Cost Element	Estimated Costs (1993 $) 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.

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 sacrificial 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.

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

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.

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, (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.

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.

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

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
Length of Duct (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

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.

Table 3.17 Summary of weights and volumes of contaminated HVAC equipment

Component Group	No. of items	No. of[(a)] containers	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.

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.

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

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

	Estimated costs (1993 $)				
Cost element	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
Totals	358,182	101,560	6,136	1,200,167	2,366,045

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

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. Packed @ 600 lb/55-gal drum.
(c) Average thickness of metal is 1/4 in.
(d) Refueling cavity and dryer/separator pools washed during Period 2.

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 contaminated pool liners in Appendix C. The labor costs for removing the metal liners in all buildings is estimated to be $36,173, and the radiation dose to cutting workers is estimated to be 0.80 person-rem. The total packaged 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 $286,375, and the radiation dose to workers doing the surface removal is estimated to be 6.59 person-rem. The contaminated concrete surface material is postulated to be packaged in 436 55-gallon drums, resulting in a disposal volume of 3,225 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 12,156 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	286,375	6.59
Packaging	11,744	
Transport	1,283	
Disposal	156,383	
Metal Surface		
Wash	24,251	0.29
Segment	36,173	1.09
Package	78,983	
Transport	2,883	
Disposal	663,148	
Totals	1,295,899	8.38
Undistributed		
Wash Water Treat/Dispose[a]	241,141	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.[6] 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 about $0.53 million, without contingency.

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.

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.

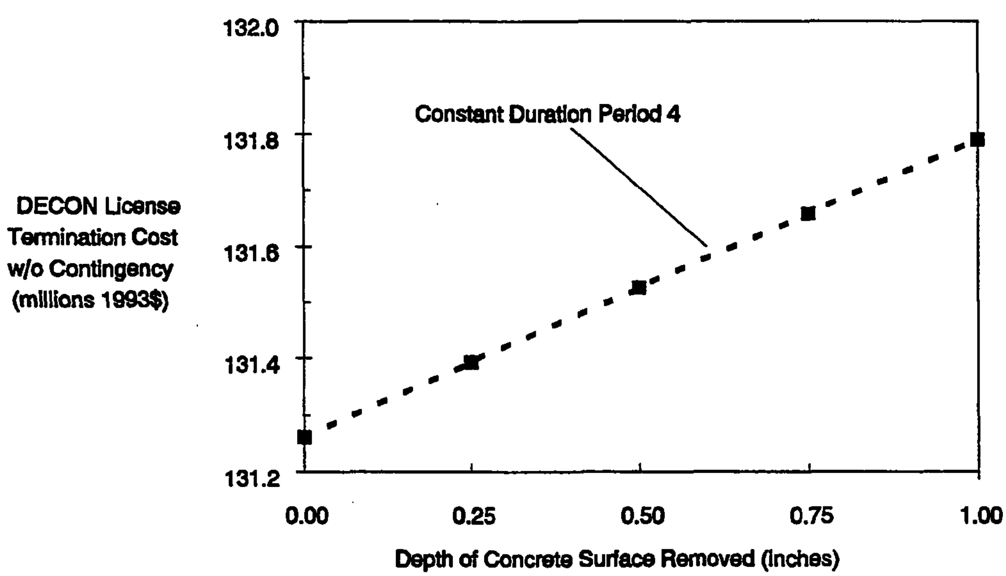

Figure 3.10 Sensitivity of license termination cost to varying depths of contaminated concrete removal during DECON

Table 3.22 Estimated costs and doses for crane removal

Item	No. of containers[a]	Transport wt. (lb)	Estimated cost (1993 $)	Estimated cost (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 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

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 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 8.3 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	17,000	8
Totals		75,680	22

(a) Based on letter, Chris Alexander, Advanced Engineering Services to George J. Konzek, Pacific Northwest National 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.

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.

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.

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 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

Table 3.26 Estimated annual costs for environmental monitoring

Cost element	Activities	Annual cost (1993 \$)
Health Physicist (0.5 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

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.

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 ins 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, 1995, the Barnwell facility will accept waste from generators located inside and outside of the Southeast Compact region (except for the state of North Carolina).

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

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.

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 $255,816,021, 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 $1,111,875 to $6,789,093) and the disposal costs (which increased from $36,627,693 to $154,976,080), 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 $2,320,828, without contingency.

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 $\$1000/ft^3$, plus appropriate adders. 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 $174.70 million for the $\$50/ft^3$ rate to $847.13 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.

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

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 $)		Terms for LLW Disposal Cost Escalation Formula[c]			
	Burial	Total DECON	Labor/mats. (A)	Energy (B)	Disposal (C)	Total - [taxes & ins.][d] (millions of 1993 $)
50	55.75	174.70	0.63	0.031	0.336	165.61
100	91.14	210.09	0.51	0.026	0.453	201.00
300	232.70	351.66	0.306	0.015	0.679	342.57
500	374.27	492.20	0.217	0.011	0.773	484.13
1000	728.17	847.13	0.125	0.006	0.869	838.03

(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.

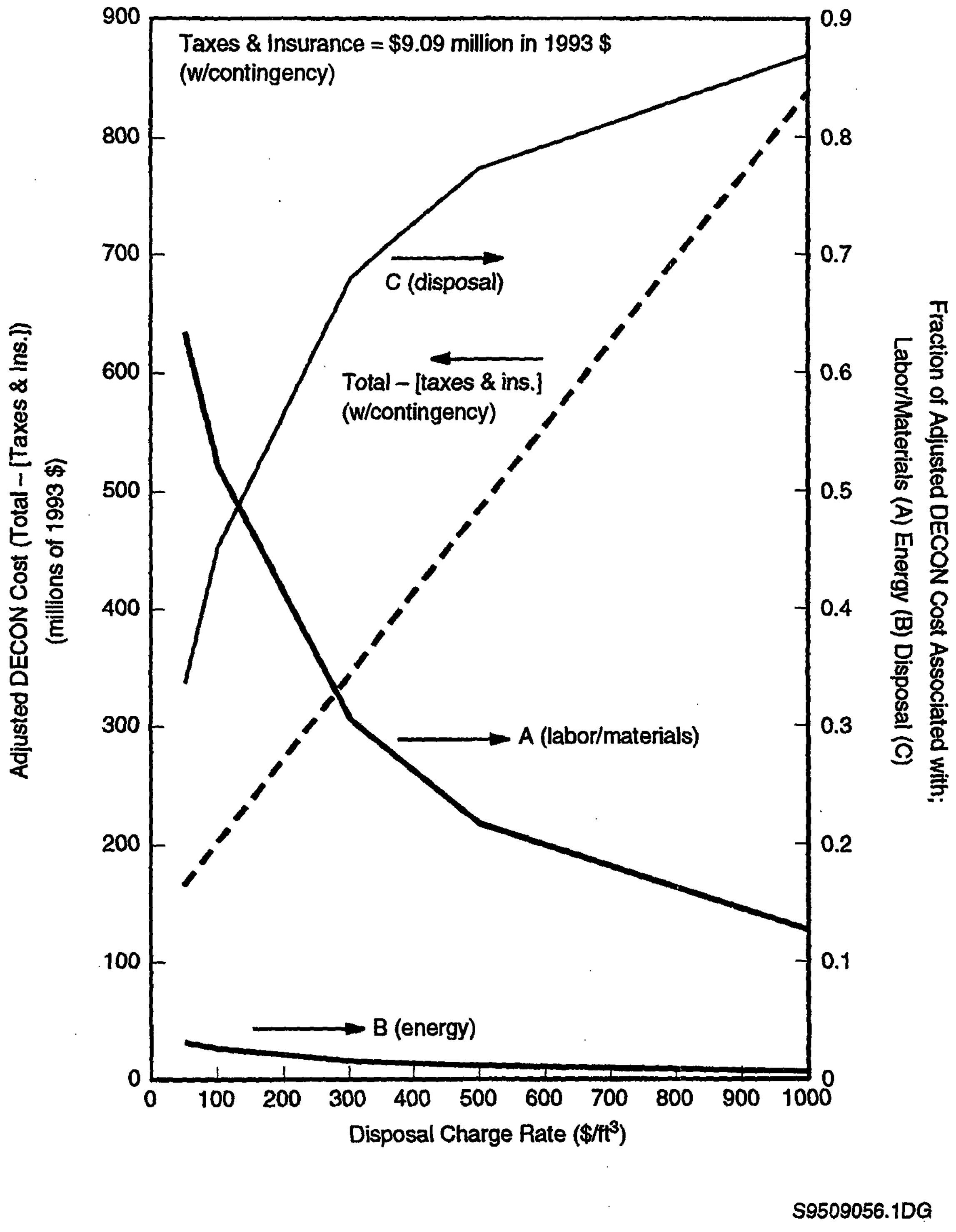

Figure 3.11 Variation of DECON escalation formula terms as functions of low-level waste disposal charge rates

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:

$$\begin{aligned} PV(DECON) = & \sum_{i=1}^{k} \frac{(\text{Pre-Engineering})_i}{(1+x)^i} \\ & + \sum_{i=k}^{m} \frac{(\text{Deactivation})_i}{(1+x)^i} \\ & + \sum_{i=m}^{n} \frac{(\text{Safe Storage})_i}{(1+x)^i} \\ & + \sum_{i=n}^{n} \frac{(\text{DOC Ramp-up})_i}{(1+x)^i} \\ & + \sum_{i=n}^{p} \frac{(\text{Decon/Dismantle})_i}{(1+x)^i} \end{aligned}$$

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 $110.9 million, as compared with the constant dollar value of $131.7 million, neither values including a 25% contingency. Thus, requiring the funding needs to be calculated in constant dollars prior to reactor shutdown results in a nearly 19% 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: 515,191 ft^3 [14,588.6 m^3] (96.37%); 2) Class B/C: 19,152 ft^3 [542.3 m^3] (3.58%); and 3) GTCC 244 ft^3 [6.90 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:

$[\text{Total Cost} - (\text{T \& I Cost})]_{(1993\ \$)}$ = \$156 million

A (labor/materials) = 0.673
B (energy) = 0.033
C (disposal) = 0.294
[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*.[7]

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 7 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 4.23, based on the estimated total burial costs at Hanford (\$45.8 M) and at Barnwell (\$193.4 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 PowerStation.* 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 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[1] 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

[1]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

		Estimated costs (1993 $)[a]							
Period number	Duration[b] (years)	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	781,421	136,754	789,442	3,411,803	22,248,537	40,624,585	323.75
3	3.4	--	--	--	--	--	3,628,466	3,628,466	10.27
4 (SAFSTOR1)	53.7	455,539	--	24,270	19,059	51,288	116,284,561	116,834,717	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	--	933,115	243,470	129,870	2,054,654	6,976,552	10,337,666	0.06
5 (SAFSTOR2)	1.7	326,727	13,496,955	3,482,772	303,113	32,794,102	26,719,883	77,123,551	9.77
Total SAFSTOR1	58.61	13,712,167	1,714,536	404,494	938,371	5,517,746	158,597,357	180,884,670	458.75
Total SAFSTOR2	60.00	14,038,894	14,278,376	3,643,796	1,111,614	36,257,193	178,340,688	247,670,560	468.45
							Total Cost for SAFSTOR1 with 25% contingency	226,105,838	
							Total Cost for SAFSTOR2 with 25% contingency	309,588,200	

(a) Costs shown do not include contingency except where explicitly labeled.
(b) Pre-shutdown period not included in SAFSTOR time duration total.
(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.

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 and DOC staffs occurs 1 year prior to the end of Period 4 for SAFSTOR1 and SAFSTOR2. The costs and occupational radiation doses associated with these two alternatives 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 1-year period for SAFSTOR1 AND SAFSTOR2. 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.

Because 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.

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 $2,106,002 given in the table, the total basic costs during the 53.7-year safe storage period are $116,834,717 for SAFSTOR1 and SAFSTOR2. These costs include the ramp-up of the utility and DOC staffs during the final year of safe storage, which are presented in Table 4.4. The

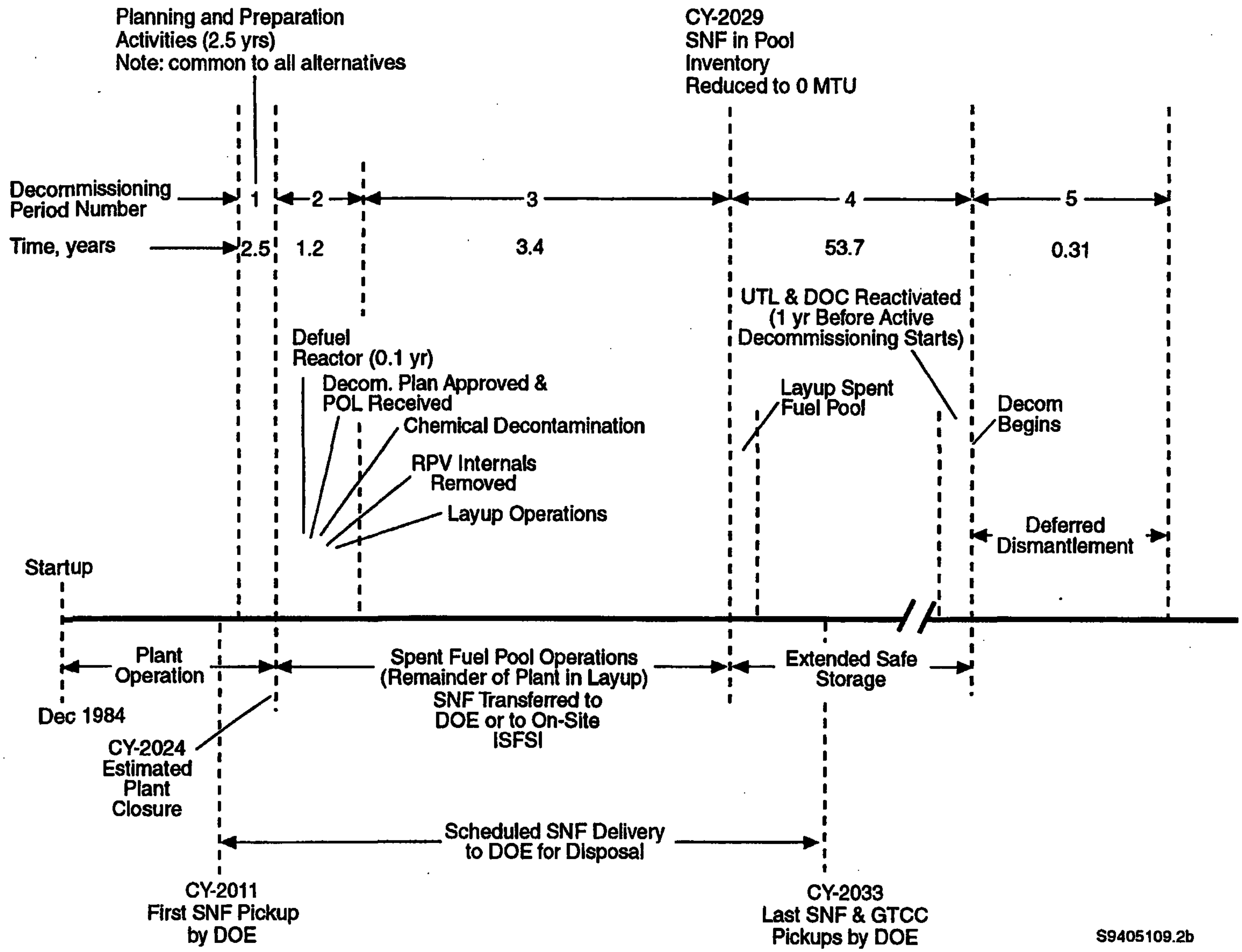

Figure 4.1 Schedule of activities during the five decommissioning periods of SAFSTOR1

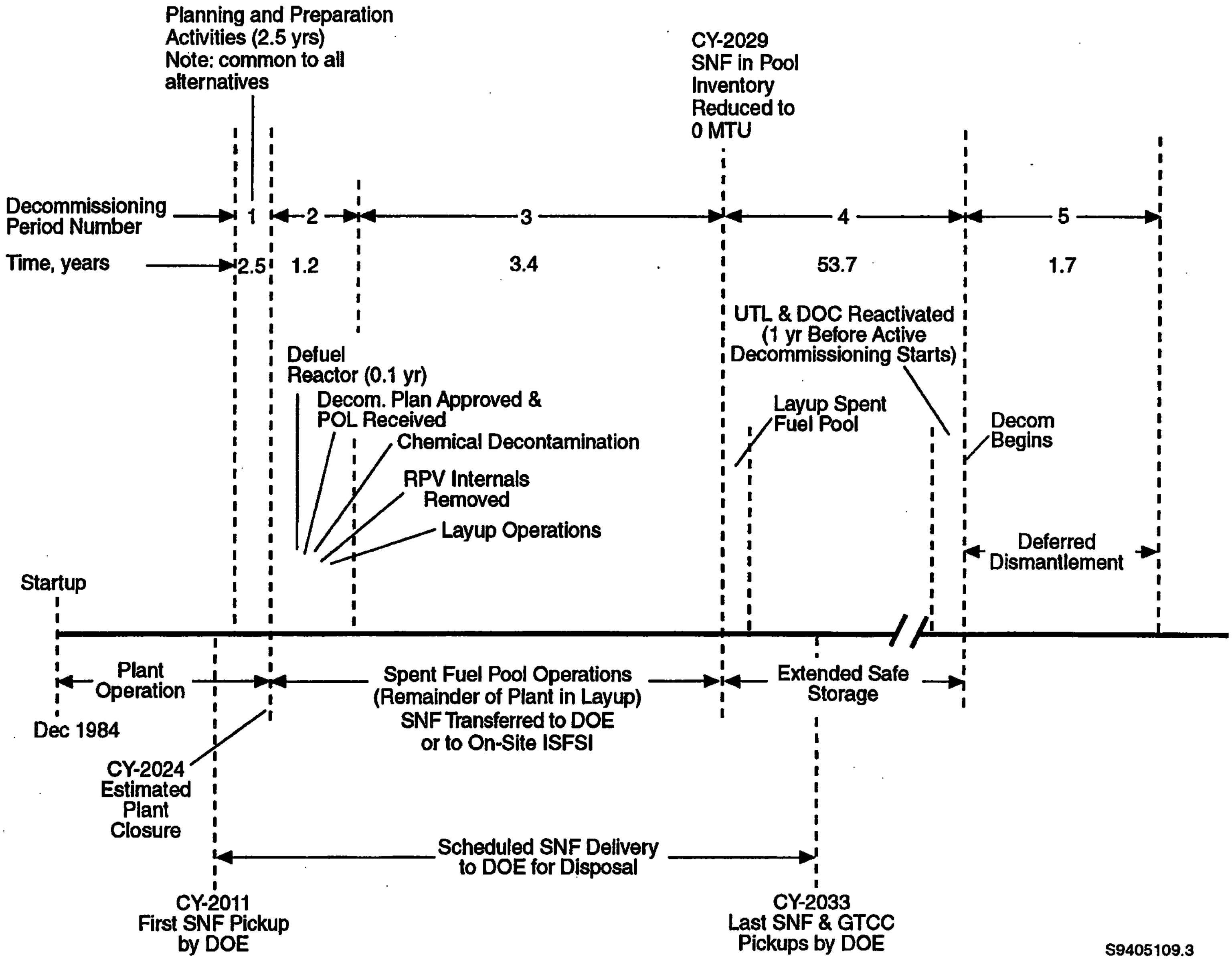

Figure 4.2 Schedule of activities during the five decommissioning periods of SAFSTOR2

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.2.
(f) Based on Table B.3.
(g) Included in $750,000 Fixed-Cost Contract.
(h) Derived from information provided by Pacific Nuclear Services.
(i) Included in Period undistributed costs.

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.

4.3 Deferred Dismantlement--SAFSTOR Period 5

It is postulated that 58.3 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 4.3 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 @ $0.034/kWh)	8,910
Environmental Monitoring	48,603[d]
Oregon State DOE (On-site Inspection Program)	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 42% overhead on utility salaries.
(d) See Table 3.26, Chapter 3.
(e) Study estimate (see Appendix B, Section B.13 for details). This program would continue during periods of active decommissioning, but is anticipated to cost about $10,000/yr during the safe storage period.
(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.

Table 4.4 Estimated pre-decommissioning/planning costs: Period 4

Staff positions	Annual salary (1993 $)[a]	Person-yrs per period (SAFSTOR)	Period cost (1993 $) (SAFSTOR)
Utility Overhead Staff			
Plant Manager	180,592	1.00	180,592
Secretary	50,407	1.00	50,407
Contracts/Procurement Spec.	92,382	1.00	92,382
Quality Assurance Manager	136,368	1.00	136,368
Health Physics Manager	99,357	1.00	99,357
Nuclear Records Spec.	89,758	1.00	89,758
Plant Operations Manager	138,699	1.00	138,969
Training Manager	153,382	1.00	153,382
Plant Engineers[b]	98,115	2.00	196,230
Maintenance Manager	123,739	1.00	123,739
Utility Overhead Totals		11.00	1,261,184
DOC Overhead Staff			
Project Manager	220,272	1.00	220,272
Assistant Project Manager	178,275	1.00	178,275
Secretary/Clerk	47,829	5.00	239,145
Accountant	117,369	2.00	234,738
Engineers	122,899	2.00	245,798
Drafting Specialist	67,813	3.00	203,439
Contracts Specialist	117,369	1.00	117,369
Procurement Specialist	106,743	1.00	106,743
Lawyer	150,744	2.00	301,488
QA Engineer	83,825	1.00	83,825
DOC Overhead Total		19.00	1,931,092
Total Ramp-up Overhead Staff Costs (w/o contingency)			3,192,276

(a) Salary rates include the appropriate overhead 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 $180.9 million, and the total decommissioning cost for SAFSTOR2 is estimated to be $247.7 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 for SAFSTOR1 would be the same as SAFSTOR2, about $248 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 $122.2 million for SAFSTOR1 and $135.1 million for SAFSTOR2, including a 25% contingency.

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 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.

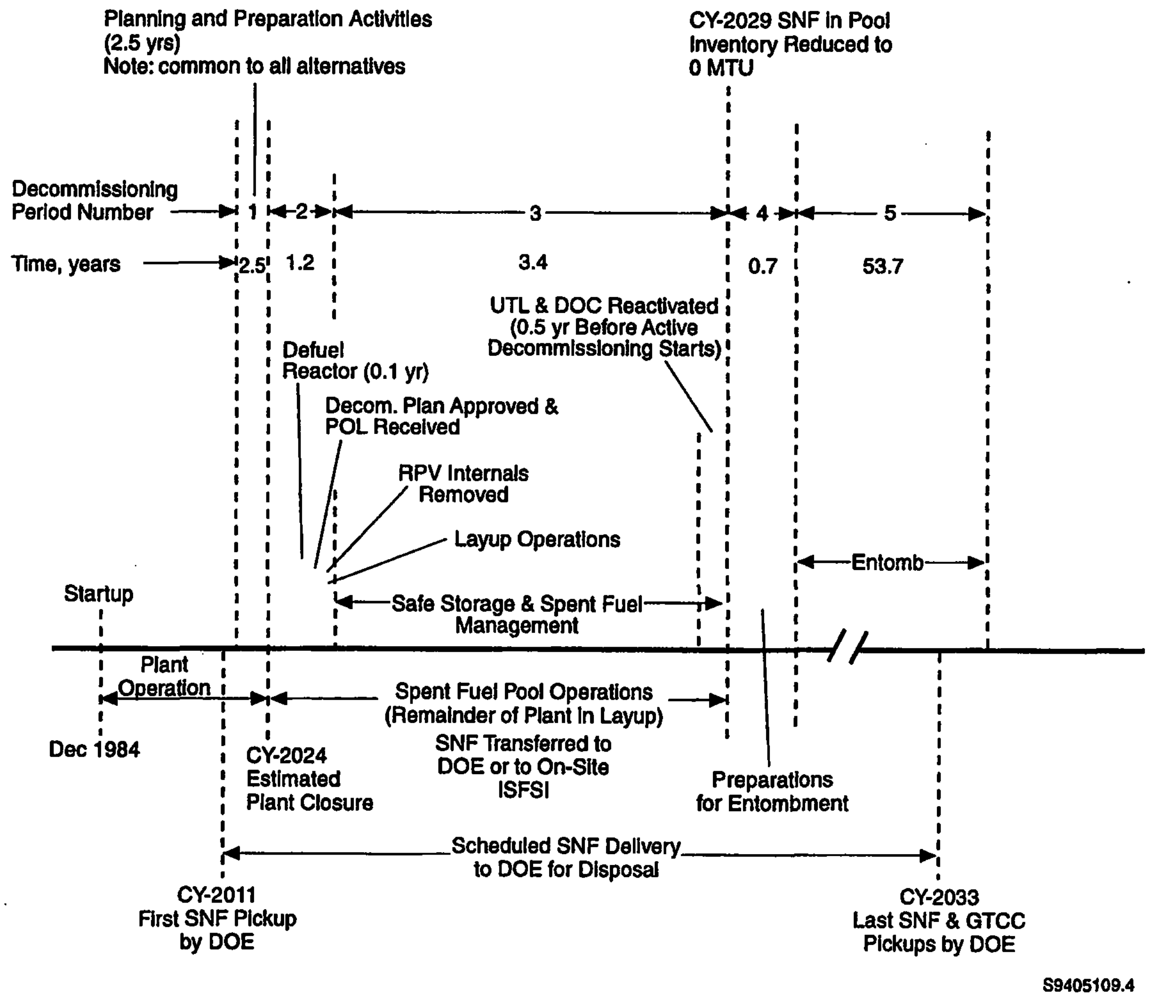

Figure 5.1 Schedule of activities during the five decommissioning periods of ENTOMB1

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 ENTOMB3 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.

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.

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.

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 access ports into the Reactor Building are sealed by welding doors shut or installing permanent sealed barricades. Openings in the operating floor are sealed by welding steel plates in place.

All piping 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 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 $160.3 million for ENTOMB1, about $163.7 million for ENTOMB2, and about $481.8 million for ENTOMB3, in constant 1993 dollars without contingency. The cumulative radiation dose to workers is about 472 person-rem for ENTOMB1 and ENTOMB3, and about 532 person-rem for ENTOMB2. Thus, the 60-year ENTOMB scenarios result in a cumulative radiation dose reduction of about 37% to 44%, and a cost increase of about 24%.

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 $481.5 million, without contingency.

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

Table 5.2 Results of cost and dose analyses for ENTOMB

	Estimated cost (1993 $)		Estimated dose (person-rem)	
Cost element	ENTOMB1	ENTOMB2	ENTOMB1	ENTOMB2
DECON (w/o contingency)	131,677,444	131,677,444	838.85	838.85
Activities NOT conducted during ENTOMB				
RPV removal	1,432,553	0	35.05	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
Pipe Hangers (removal & packaging)	1,225,788	1,225,788	1.08	1.08
Other System Piping (removal & packaging)	1,581,491	1,581,491	14.74	14.74
Reactor Bldg. Systems (removal & packaging)	834,203	834,203	9.66	9.66
All Systems (shipping & burial costs)	10,255,537	10,255,537	0	0
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
Turbine Bldg. Equipment (shipping & burial)	11,159,049	11,159,049	0	0
Decontaminate Reactor Bldg.	1,102,935	1,102,935	6.16	6.16
Other Site Bldgs. (shipping & burial)	2,308,017	2,308,017	0.00	0.00
HVAC removal (above Operating Floor)	134,502	134,502	2.32	2.32
Reduced Dry Active Waste	732,788	732,788	0.00	0.00
Reduced Laundry Services	472,457	472,457	0.00	0.00
Reduced Utility Staff	2,136,406	2,136,406	6.98	6.98
Reduced Termination Survey (from DECON)	138,644	138,644	0.00	0.00
Total Deductions for ENTOMB	43,650,025	40,281,339	369.95	309.95
New Activities conducted during ENTOMB Preparations				
Reactor Bldg. Penetration sealing		56,800		2.80
Operating Floor barrier installation		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	138,644	138,644		NA
Third-party Safety Inspect.	250,242	1,368,642		NA
Additions for Storage	72,054,919	393,468,439		NA
Total ENTOMB1 (60 years)	160,347,138	--		471.70
Total ENTOMB2 (60 years)	163,715,824			531.70
Total ENTOMB3 (300 years)	--	481,760,658		471.70
ENTOMB1 (w/25% contingency)	200,102,922	--		471.70
ENTOMB2 (w/25% contingency)	204,644,780	--		531.70
ENTOMB3 (w/25% contingency)	--	601,869,822		471.70

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 $126 million and $131 million, respectively, including a 25% contingency. Similarly, the 300-year ENTOMB3 scenario cumulative cost would be reduced to about $200 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 $132.6 million for ENTOMB1 and $136.0 million for ENTOMB2, as compared with the constant dollar values of about $200 million and $204 million, respectively, all values including a 25% contingency. Thus, calculating the funding needs in constant dollars prior to reactor shutdown can overestimate the actual funding needs for ENTOMB by up to 50%, depending upon the actual net discount rate and can provide a significant safety margin to cover unforeseen events. For the 300-year ENTOMB3 scenario, the present value cost is about $142 million, as compared with the constant dollar value of about $602 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 $102.9 million and $106.3 million, respectively. For the 300-year ENTOMB3 scenario, the present value cost would be reduced to about $104.6 million. Thus, it is seen that extending the entombment period from 60 years (ENTOMB1) to 300 years (ENTOMB3) adds only about $9 million to the estimated present value costs for the base analysis, and about $1.7 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 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 a period of several years following reactor shutdown to allow the spent nuclear fuel (SNF) to cool sufficiently to permit dry storage without damaging the cladding. 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 all of the remaining SNF has been accepted into the federal waste management system (FWMS). However, 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 groups of costs that dominate decommissioning costs. These are: 1) undistributed costs (about 47%), which are dominated by overhead staff labor, and 2) low-level radioactive waste (LLW) disposal costs (about 28% for Hanford disposal). Decontamination costs and direct labor costs for disassembly and removal of equipment comprise about 22% 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, historically, LLW disposal rates have only increased 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) ENTOMB1, 3) ENTOMB2, 4) SAFSTOR1, 5) SAFSTOR2, and 6) ENTOMB3. However, in order of increasing present value cost, the alternatives/scenarios rank differently: 1) SAFSTOR1, 2) ENTOMB1, 3) SAFSTOR2, 4) ENTOMB2, 5) DECON, and 6) ENTOMB3. Smaller values of the net discount rate would tend to favor the DECON alternative.

The present value costs may 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. However, the present value results are sensitive to the available net discount rate and to the inflation of decommissioning costs at rates different from the general rate of inflation. Thus, the uncertainty of the present value results, when calculated over an extended time period, can be rather large.

The range (in 1993 $) from the least expensive scenario (SAFSTOR1, $122.2 million) to the most expensive scenario (ENTOMB3, $141.9 million) is about $20 million. For the more likely alternatives (DECON, SAFSTOR1, SAFSTOR2), the spread is about $13 million to $16 million. Thus, the present value costs are not strong discriminators for selecting one alternative/scenario over another.

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 459 person-rem for SAFSTOR1) to the largest (about 837 person-rem for DECON), a difference of only about 378 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 cannot 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 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
ANSI	American National Standards Institute
BOP	Balance of Plant
Bq	Becquerel[1]
BWR	Boiling Water Reactor
CECP	Cost Estimating Computer Program[1]
CFR	Code of Federal Regulations[1]
Ci	Curie[1]
cpm	Counts Per Minute,[1] Count Rate
CS	Carbon Steel
DF	Decontamination Factor[1]
DOE	Department of Energy
DOT	Department of Transportation
dpm	Disintegrations Per Minute,[1] Disintegration Rate
EC	Electron Capture[1]
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[1]
HEPA	High-Efficiency Particulate Air (filters)
HP	Health Physicist[1]
HVAC	Heating, Ventilation and Air Conditioning
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
OSF	Overall Scaling Factor
PNL	Pacific Northwest Laboratory
PWR	Pressurized Water Reactor
QA	Quality Assurance
QC	Quality Control
R	Roentgen[1]
rad	Radiation Absorbed Dose
rem	Roentgen Equivalent Man
SF	Scaling Factor
SNM	Special Nuclear Material[1]
SS	Stainless Steel
Sv	Sievert[1]
α	Alpha Radiation[1]
β	Beta Radiation[1]
γ	Gamma Radiation[1]

[1] See Section 7.2 for additional information or explanation.

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.)

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 x 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., nuclear transformations) 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 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 x 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.

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.

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 Fuel 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.

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)].

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).

7.3 General References

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With the issuance of the Decommissioning Rule in 1988, nuclear power plant licensees are required to submit to the U.S. Nuclear Regulatory Commission (NRC) decommissioning cost estimates for review. 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 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 NRC consideration 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 at different low-level radioactive waste disposal sites, and to different depths of contaminated concrete surface removed, is also examined.

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Final Report

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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 Decommissioning Rule (July, 1988), 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 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) 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. Included for information (but not presently part of the license termination cost) is an estimate of the cost to demolish the decontaminated and clear structures on the site and to restore the site to a "green field" condition.

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), and reflects 1993 costs for labor, materials, transport, and disposal activities. Sensitivity 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 is also examined.

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Appendix A

Study Contacts

Appendix A

Study Contacts

Those many individuals who contributed information that subsequently led to the completeness of this study are greatly appreciated and specially acknowledged in this appendix.

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Appendix B

Cost Estimating Bases

Appendix B

Cost Estimating Bases

The cost information developed in this reevaluation study is based on unit cost data presented in this appendix. Categories for which basic unit cost data are given include: salaries, waste packaging, cask rental, transport, waste disposal, special equipment, and services and supplies. Reactor-specific cost data also are provided concerning taxes, insurance, and license termination survey costs. In addition, the impact on decommissioning costs resulting from cascading costs and contingency allowance is discussed. The bases for the estimated decommissioning costs for specialized decommissioning tasks such as removal of the reactor pressure vessel, the turbine and condenser, and systems chemical decontamination are contained in Appendices E, F, and G, respectively, and are not repeated here. The cost data presented in this appendix are all early-1993 costs.

A decommissioning cost estimating computer program (CECP) developed at Pacific Northwest National Laboratory (PNNL) for the U.S. Nuclear Regulatory Commission (NRC) is utilized in this boiling water reactor (BWR) reevaluation study. The CECP, 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, inventory data, and labor rates supplied by the user, the CECP 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 CECP also calculates person-hours, crew-hours, radiation exposure person-hours, and cumulative radiation dose associated with decommissioning. Inventories of process system components, piping, and valves for the WNP-2 plant (the reference BWR plant) were used to develop and test the CECP. The CECP, the inventories, and the base unit cost factors developed for use in this study are described in greater detail in Appendix C.

The cost data presented in this appendix, together with the CECP, can be used to develop cost estimates for other decommissioning projects, based upon appropriate consideration of the key assumptions given in Section B.1. These data should be carefully examined to ascertain their applicability to the facility under consideration, and may require significant adjustments for a specific situation.

B.1 Bases and Assumptions

The following major bases and assumptions apply to this reevaluation of the decommissioning cost estimates for the reference BWR:

- The cost estimates in this reevaluation study, just as in NUREG/ CR-0672,[1] take into consideration only those costs for decommissioning that affect the public health and safety - i.e., costs to reduce the residual radioactivity in a facility to a level that permits the facility to be released for unrestricted use and the NRC license to be terminated. Hence, the cost estimates in this study do *not* include such items as the cost to remove clean materials and equipment nor to restore the land to a "green field," which would require additional demolition and site restoration activities. Although these additional costs for site restoration may be needed from the viewpoint of public relations or site resale value, they are not related to health and safety and therefore were considered to be outside of NRC's area of responsibility.

- The cost estimate is site-specific for the reference BWR (WNP-2) analyzed in this reevaluation study to account for the unique features of the nuclear steam supply system, electric power generation systems, site location, and site buildings and structures.

- Labor rates for each craft and salaried worker representative of the WNP-2 location are used in this development of a site-specific decommissioning cost estimate. Washington Public Power Supply System (WPPSS), the operator of the WNP-2 plant, provided typical craft labor rates and salary data for utility personnel from utility records.

- Pre-decommissioning engineering services for such items as writing decommissioning activity specifications and procedures, detailed activation analyses, structural modifications, etc. are assumed to be provided by a Decommissioning Operations Contractor (DOC). It is further assumed that the licensee contracts with the DOC for subsequent management of the decommissioning program(s).[1]

- Material and equipment costs for conventional demolition and/or construction activities were taken from R. S. Means Construction Cost Data[(2)] and Means Estimating Handbook.[(3)]

- The waste disposal costs presented in this study were specifically developed for the reference BWR, which is located within the Northwest Compact, assuming disposal at the U.S. Ecology site in Richland, Washington. To provide additional information, the costs also were estimated for shipping and disposal of the reference BWR wastes at the Barnwell site in Barnwell, South Carolina.

- At the direction of the NRC, consideration of the use of a radwaste broker's services *were excluded* from this reevaluation study.

- Heavy-lift rigging and overland transport costs for selected large components are based on information provided by a qualified vendor of these services, who has handled the overland transport and installation of NSSS components for several plants.

- This study does not address the removal or disposal of spent fuel from the site. The costs for such activities are assumed to be covered by U.S. Department of Energy's 1 mill/kWh surcharge. However, the study does include consideration of the constraints that the presence of spent fuel onsite may impose on other decommissioning activities and on schedules.

- This study does not address the removal or disposal of mixed waste from the site. The costs for such activities are assumed to be operational costs covered by an active (and continued in force) Resource Conservation and Recovery Act (RCRA) permit for the facility. However, the study does include consideration of the constraints that the presence of mixed waste onsite may impose on decommissioning alternatives and on schedules.

- The study presumes the installation of spent fuel dry storage modules such that decommissioning operations can proceed with minimum impact (i.e., all fuel is transferred to the dry storage compound within 5 years following shutdown). Separate, distinct funding for post-shutdown activities associated with the spent nuclear fuel (SNF) are delineated in 10 CFR Part 50.54(bb), "Conditions of Licenses." All such costs associated with the SNF are considered to be operational costs in this re-evaluation study, *not* decommissioning costs. Therefore, neither the disposition of the SNF nor the cost of the dry storage modules has been included within this decommissioning cost estimate. (See Appendix D for additional details.)

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[1]Although a potential cost savings exists in keeping the decommissioning work in-house, many utilities do not have the workforce available and in some instances, the expertise to manage this type of activity. Consequently, the potential savings from using the in-house workforce, with the attendant lower overhead costs, could easily be negated if the licensee had to temporarily augment its permanent staff to manage the decommissioning program.

- The utility's staffing requirements during decommissioning vary with the level of effort associated with the various phases of on-site storage of SNF. Consequently, the staff size required to support and maintain wet storage (i.e., the spent fuel pool) following final shutdown is substantially greater than that required to monitor the independent spent fuel storage installation (ISFSI).

B.2 Manpower Costs

Salary data for the decommissioning staff positions used in this study are given in Table B.1. The labor costs shown in Table B.1 are representative of labor costs for this particular decommissioning project at the reference BWR, which is the WNP-2 plant, located at Richland, Washington. The utility overhead positions and overhead rates data[2] shown in the table were supplied by the Washington Public Power Supply System, the operator of the WNP-2 plant.

It is acknowledged in this study that overhead rates applied to direct staff labor are expected to be significantly higher for subcontracting organizations (e.g., the DOC) than for operating utilities, because of the larger ratio of supervisory and support personnel to direct labor that usually exists in subcontracting organizations. Having personnel in the field rather than in the home office also increases the overhead costs, because of travel and living expenses for many of the personnel. In view of these factors, an overhead rate on direct staff labor of 110%, plus 15% DOC profit on labor, is assumed to be applicable to all DOC personnel in this study.

Because regional labor costs can deviate significantly from those used in this study, care should be used in the application of these data to other decommissioning projects.

B.3 Mobilization and Demobilization Costs

There are significant costs associated with a contractor establishing its presence at the work site. These costs, called mobilization and demobilization costs, will vary with the size and complexity of the job. These costs include temporary office facilities, obtaining the required special equipment, and assembling the work force. Similarly, there are costs associated with closing down a work site. For the dismantlement of a large nuclear power plant, these costs were previously estimated by an engineer experienced in estimating costs for utility construction projects to be about $1.25 million (without contingency) in 1978 dollars.[5,6] Applying an escalation factor of 2.11, based on the Implicit Price Deflator,[7] brings the mobilization and demobilization costs to $2.64 million, without contingency, in 1993 dollars.

B.4 Cask Charges

Some of the waste material shipped to a burial site is sufficiently radioactive to require transport in reusable shielded casks. In general, it is most economical to rent such casks. The casks assumed to be used in this study for shipping highly radioactive materials are listed in Table B.2, together with their application and their estimated rental charges.

[2]Since overhead rates may vary for similar job codes, selected averages were used for some job positions shown in Table B.1.

Table B.1 Labor costs for decommissioning[a]

Utility overhead position	Base pay ($/yr)	Assumed overhead rate (%)	Cost ($/yr)
Plant Manager	113,580	59	180,592
Assistant Plant Manager	96,497	58	152,465
Secretary	25,103	100.8	50,407
Clerk Typist	21,653	85	40,058
Accountant	45,738	107	94,678
Contracts/Procurement Specialist	46,307	99.5	92,382
Industrial Safety Specialist	52,494	109	109,712
Planning/Scheduling Engineer	55,046	71	94,129
Radioactive Ship. Specialist	68,019	60	108,830
Chemistry Supervisor	62,098	53	95,010
Chemistry Technician	43,950	58	69,441
Quality Assurance Manager	74,518	83	136,368
Quality Assurance Engineer	60,085	89.3	113,741
Quality Assurance Technician	41,992	88.3	79,071
Health Physics Supervisor	62,098	60	99,357
Sr. Health Physics Technician	56,899	63	92,745
Health Physics/ALARA Planner	56,899	63	92,745
Health Physics Technician	43,950	61	70,760
Nuclear Records Specialist	52,490	71	89,758
Building Services Supervisor	62,098	53	95,010
Training Manager	62,098	147	153,382
Operations Manager	87,955	58	138,969
Administration Manager	74,518	71	127,426
Operations Supervisor	65,286	60.5	104,784
Control Operator	48,318	58	76,342
Plant Equipment Operator	43,950	58	69,441
Plant Engineer	62,098	58	98,115
Maintenance Manager	80,875	53	123,739
Maintenance Supervisor	74,518	53	114,013
Licensing Specialist (Lawyer)	61,224	227	200,202
Craftsman	43,950	53	67,244
Custodian	30,742	53	47,035
Security Manager	74,518	60	119,229
Security Shift Supervisor	41,992	60	67,187
Security Patrolman	33,342	60	53,347

Table B.1 (contd)

DOC overhead position[b,c]	Base pay ($/yr)	Assumed overhead rate (%)	Cost ($/yr)
Project Manager	91,210	141.5	220,272
Assistant Project Manager	73,820	141.5	178,275
Secretary/Clerk	19,805	141.5	47,829
Industrial Safety Specialist	47,600	141.5	114,954
Planning/Scheduling Engineer	52,630	141.5	127,101
Radioactive Shipment Specialist	55,950	141.5	135,119
Lawyer/Financial Administrator[d]	62,420	141.5	150,744
Contracts/Accounting Supervisor	62,420	141.5	150,744
Contracts Specialist/Buyer[d]	48,600	141.5	117,369
Procurement Specialists	44,200	141.5	106,743
Accountant	48,600	141.5	117,369
Operations Supervisor	61,140	141.5	147,653
Health Physics Supervisor	61,550	141.5	148,643
Health Physics/ALARA Planner[d]	51,440	141.5	124,228
Engineering Supervisor	61,140	141.5	147,653
D&D Operations Supervisor	61,140	141.5	147,653
Engineers	50,890	141.5	122,899
Drafting Specialist[d]	28,080	141.5	67,813
Quality Assurance Supervisor	61,140	141.5	147,653
Quality Assurance Engineer	34,710	141.5	83,825
Quality Assurance Technician	31,710	141.5	76,580
Sr. Health Physics Technician	51,440	141.5	124,228
Health Physics Technician	31,710	141.5	76,580
Protective Equipment Technician	31,770	141.5	76,725
Tool Crib Attendant	31,770	141.5	76,725
Protective Clothing Attendant	31,770	141.5	76,725
Licensing Engineer	50,890	141.5	122,899
Safety Consultant[d]	242,200	---	242,200
Dedicated Decontamination Workers			
Crew Leader	47,230	141.5	114,060
Craftsman	42,810	141.5	103,386
Laborer	22,710	141.5	54,845
Utility Operator	36,470	141.5	88,075

(a) Salary rates are in 1993 dollars, assuming 2080 hours per person-year.
(b) Salary rates include 110% overhead, plus 15% Decommissioning Operations Contractor (DOC) profit on labor.
(c) The DOC staff costs are maintained consistent with those used in the PWR reevaluation study.[4]
(d) Study estimate.

Table B.2 Shielded casks for shipment of radioactive materials

Cask description[a]	Application	Daily rental ($)
NAC-LWT; 51,200 lb empty COC No. 9225/B(U)F[b]	Transport of greater-than-class-C (GTCC) LLW waste	3,130[c]
TN-8 OWT; 79,200 lb empty COC No. 9015B	Transport of greater-than-class-C LLW waste	3,340[c]
NuPac No. 10-142; 68,000 lb empty COC No. 9208	Transport of high-integrity container or 55-gal drums	1,250
NuPac No. 14/210H; 58,400 lb COC No. 9176	Transport of high-integrity container or 55-gal drums	1,250
CNS No. 8-120B; 59,320 lb COC No. 9168	Transport of radioactive material in the form of activated reactor components	1,250

(a) NAC-LWT = Nuclear Assurance Corporation-Legal Weight Truck Cask; TN-8 OWT = Transnuclear, Inc. Over Weight Truck Cask; CNS = Chem-Nuclear Systems, Inc.; NuPac = Pacific Nuclear.
(b) COC No. means Certificate of Compliance Number as listed in Reference 8.
(c) The daily rental rate is predicated on a sliding scale, according to risk, with spent nuclear fuel being the highest risk cargo and the GTCC material assumed at the same rate in this study.

B.5 Radioactive Waste Packaging Costs

The shipping containers assumed to be used for packaging radioactive waste materials for disposal are listed in Table B.3, together with brief descriptions, burial volumes, probable applications, and unit costs, for each type of container.

Table B.3 Packaging for radioactive materials

Description	Burial volume (ft^3), [m^3]	Application	Estimated unit cost ($)
Steel cask liner for 8-120B cask; 62 in. OD x 72 in. high; 2,000 lb empty	126 [3.57]	Shallow-land burial of activated RPV internals	4,695
Steel cask liner for 8-120B cask; 62 in. OD x 32 in. high; 1,500 lb empty	56 [1.59]	Shallow-land burial of activated RPV	3,200
Steel cask liner for NAC-LWT cask; 13 in. OD x 178 in. long; 700 lb empty	13.7 [0.39]	Jet pump components	1,000
Canister; 9-in. square x 178-in. high; 300 lb empty	8.4 [0.24]	Deep geologic disposal of GTCC LLW core components	520
Special Steel Boxes:			
4 ft x 4 ft x 3 ft, 400 lb empty	48 [1.36]	RPV head segments	430
4 ft x 4 ft x 2.5 ft, 350 lb empty	40 [1.13]	RPV head flange segments	400
4 ft x 4 ft x 1.5 ft, 250 lb empty	24 [0.68]	RPV lower flange segments	365
4 ft x 8 ft x 1.5 ft, 400 lb	48 [1.34]	Shroud supports, studs, nuts	730
6.7 x 8.9 x 14 ft, 2,800 lb empty	835 [23.64]	Spent fuel racks (10)	4,510
6.1 x 8.9 x 14 ft, 2,642 lb empty	760 [21.52]	Spent fuel racks (2)	4,106
6.7 x 7.3 x 14 ft, 2,438 lb empty	685 [19.40]	Spent fuel rack (1)	3,700
4 x 10 x 14 ft, 2,114 lb empty	560 [15.86]	Spent fuel rack (1)	3,025
4.5 x 7.3 x 14 ft, 1,860 lb empty	460 [13.03]	Spent fuel rack (1)	2,485
5 x 5 x 38 ft, 4,300 lb empty	950 [26.90]	Reheater tube bundles	4,500
10 x 10 x 25 ft, 6,500 lb empty	2,500 [70.79]	Moist. Sep. tube bundles	6,000
94 x 115 x 26 in., 1,000 lb empty	162.7 [4.61]	Sacrificial shield segments	1,050
High-Integrity Container (HIC); 75.5 in. dia. x 78 in high; 900 lb empty	200 [5.66]	Dewatered, solids, or solidified water meeting LSA requirements	5,750 - 9,900[a]
Maritime container (Sea-Van) 8 x 8.5 x 20 ft; 4,180 lb empty	1360 [38.51]	Shallow-land burial of LLW	3,650
Modified Maritime containers 8 x 4 x 20 ft; 3,000 lb empty	640 [18.12]	Shallow-land burial of LLW	4,965
8 x 2 x 20 ft; 2,500 lb empty	320 [9.06]	Shallow-land burial of LLW	4,600
8 x 1 x 20 ft; 2,000 lb empty	160 [4.53]	Shallow-land burial of LLW	4,000
DOT 17-H steel drum; 55-gal; 51 lb empty	7.4 [0.21]	Shallow-land burial of LLW	26.95

(a) Depending upon the inserts used, the estimated cost of HICs is believed to fall within the range shown. For the purpose of this study, a mid-range value of $7,825/unit is used.

B.6 Transportation Costs

The radioactive materials resulting from decommissioning are assumed to be shipped in exclusive-use[3] trucks to a low-level waste disposal site (at Richland, WA, or Barnwell, SC), or, in the case of highly activated reactor components, to the federal geologic repository or other such disposal facility as the NRC may approve.

Rates for shipping radioactive wastes were provided by Tri-State Motor Transit Co. and from its published tariffs for this type of cargo.[10]

Costs of transporting low-level waste to the disposal site are calculated using the CECP. The algorithms contained in the CECP utilize the TROJAN reactor as the reference reactor site and the U.S. Ecology site in Richland, WA, as the reference disposal site, use ratios of study distance/reference distance to adjust the reference costs to the study conditions. The CECP data base (see Appendix C) contains great-circle distances from all commercial reactor sites to the postulated geologic repository at Yucca Mountain and to the low-level disposal sites at Barnwell, SC (Chem-Nuclear) and Richland, WA (U.S. Ecology). For convenience, the location of the supplier of transport casks is defined as Barnwell, SC. While not strictly true, the possible error is only about 200 miles out of about 2700 miles for those casks not based at Barnwell.

To calculate transportation costs, the CECP employs a different cost formula for each cask (CNS 8-120B, NuPac 14/210H, NAC-LWT, and TN-8) that is postulated to be used in decommissioning. These formulas, based on data supplied in Reference 10, are given below.

Round-Trip Cost for Using the CNS 8-120B Cask, U.S. Ecology Richland, WA, Site

$$\text{Cost} = R1 \times d1/d10 + R2 \times d2/d20 + n \times (R3 \times w/w0 \times d/d0 + OW1 + P) + (n - 1) \times (R4 \times d/d0 + OW2),$$

where

R1	=	cost of transporting empty cask from cask supplier (Barnwell, SC) to reference reactor site (TROJAN), \$11,855.99,
d1	=	distance between study reactor site (WNP-2) and the cask supplier, 2,659 miles,
d10	=	distance between reference reactor site (TROJAN) and the cask supplier, 2,799 miles,
R2	=	cost of transporting empty cask from the reference burial site (U.S. Ecology, WA) to supplier (Barnwell, SC) = \$10,122.75,
d2	=	distance between study burial site (U.S. Ecology, WA) and cask supplier, 2,674 miles,
d20	=	distance between reference burial site (U.S. Ecology, WA) and cask supplier, 2,674 miles,
n	=	number of casks to be shipped to the burial site,
R3	=	cost of transporting fully loaded cask from reference reactor site (TROJAN) to reference burial site (U.S. Ecology, WA), \$2,456.80,
w	=	weight of study loaded cask, in pounds,
w0	=	weight of fully loaded cask, 74,000 pounds,
d	=	distance between study reactor site (WNP-2) and study burial site (U.S. Ecology, WA), 15 miles,
d0	=	distance between reference reactor site (TROJAN) and reference burial site (U.S. Ecology, WA), 297 miles,
R4	=	cost of transporting empty cask from reference burial site (U.S. Ecology, WA) to reference reactor site (TROJAN) = \$1,216.06,

[3]Exclusive use, as defined in 49 CFR 173.401(i),[9] is also referred to as "sole use" or "full load." In any case, it means the sole use of a conveyance by a single consignor and for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee. Specific instructions for the maintenance of exclusive-use shipment controls must be issued in writing and included with the shipping paper information provided to the carrier by the consignor.

OW1 = overweight charges, \$219.05,
OW2 = overweight charges, \$69.37, and
P = permit cost, \$120.00.

Round-Trip Cost for Using the CNS 8-120B Cask, Chem-Nuclear Barnwell, SC, Site

Cost = n x (R1 x d/d0) + n x (R2 x d/d0 x w/w0 + OW + P),

where
R1 = cost of transporting empty cask from Barnwell, SC, to reference reactor site (TROJAN), \$11,855.99,
d = distance between Barnwell, SC, and study reactor site (WNP-2), 2,659 miles,
d0 = distance between Barnwell, SC, and reference reactor site (TROJAN), 2,799 miles,
R2 = cost of transporting fully loaded cask from reference reactor site (TROJAN) to Barnwell, SC, \$14,185.80,
n = number of casks to be shipped to the burial site,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask, 74,000 pounds,
OW = overweight and other charges, \$1,531.67 and
P = permit cost, \$125.00.

Round-Trip Cost for Using the 14/-210H Cask, U.S. Ecology Richland, WA, Site

Cost = R1 x d1/d10 + R2 x d2/d20 + n x (R3 x d/d0 + OW + P) + (n - 1) x (R4 x d/d0) + n x R5 x d1/d10,

where
R1 = cost of transporting empty cask from cask supplier (Barnwell, SC) to reference reactor site (TROJAN), \$5,150.16,
d1 = distance between study reactor site (WNP-2) and the cask supplier, 2,659 miles,
d10 = distance between reference reactor site (TROJAN) and the cask supplier, 2,799 miles,
R2 = cost of transporting empty cask from the reference burial site (U.S. Ecology, WA) to supplier, \$4,412.10,
d2 = distance between study burial site (U.S. Ecology, WA) and cask supplier (Barnwell, SC), 2,674 miles,
d20 = distance between reference burial site (U.S. Ecology, WA) and cask supplier (Barnwell, SC), 2,674 miles,
n = number of casks to be shipped to the burial site,
R3 = cost of transporting fully loaded cask from reference reactor site (TROJAN) to reference burial site (U.S. Ecology, WA), \$964.65,
d = distance between study reactor site (WNP-2) and study burial site (U.S. Ecology, WA), 15 miles,
d0 = distance between reference reactor site (TROJAN) and reference burial site (U.S. Ecology, WA), 297 miles,
R4 = cost of transporting empty cask from reference burial site (U.S. Ecology, WA) to reference reactor site (TROJAN), \$914.76,
OW = overweight charges, \$242.70,
P = permit cost, \$120.00, and
R5 = cost of transporting HIC from supplier to reference reactor site (TROJAN), \$4,210.50.

Round-Trip Cost for Using the 14/-210H Cask, Chem-Nuclear Barnwell, SC, Site

Cost = n x (R1 x d/d0) + n x (R2 x d/d0 + OW + P) + n x (R3 x d/d0)

where
R1 = cost of transporting empty cask from Barnwell, SC, to reference reactor site (TROJAN), \$5,150.16,
d = distance between Barnwell, SC, and study reactor site (WNP-2), 2,674 miles,

d0	=	distance between Barnwell, SC and reference reactor site (TROJAN), 2,799 miles,
R2	=	cost of transporting fully loaded cask from reference reactor site (TROJAN) to Barnwell, SC, $5,235.45,
n	=	number of casks to be shipped to the burial site,
OW	=	overweight and other charges, $1849.91,
P	=	permit cost, $125.00, and
R3	=	cost of transporting HIC from supplier to the reference reactor site (TROJAN), $4,210.50.

Round-Trip Cost for Using the NAC-LWT to the Geologic Repository

$$\text{Cost} = R1 \times d1/d10 + R2 \times d2/d20 + n \times (R3 \times w/w0 \times d/d0 + OW + P) + (n - 1) \times (R4 \times d/d0 + OW)$$

where

R1	=	cost of transporting empty cask from cask supplier to reference reactor site (TROJAN), $9,264.56,
d1	=	distance between study reactor site (WNP-2) and the cask supplier, 2,659 miles,
d10	=	distance between reference reactor site (TROJAN) and the cask supplier = 2,799 miles,
R2	=	cost of transporting empty cask from the repository to cask supplier, $6,279.36,
d2	=	distance between study repository and cask supplier, 2,070 miles,
d20	=	distance between reference repository and cask supplier, 2,070 miles,
n	=	number of casks to be shipped to the repository,
R3	=	cost of transporting fully loaded cask from reference reactor site (TROJAN) to reference repository, $3,102.24,
w	=	weight of study loaded cask, in pounds,
w0	=	weight of fully loaded cask, 55,200 pounds,
d	=	distance between study reactor site (WNP-2) and repository, 793 miles,
d0	=	distance between reference reactor site (TROJAN) and reference repository, 907 miles,
R4	=	cost of transporting empty cask from reference repository to reference reactor site (TROJAN), $2,406.40,
OW	=	overweight charges, $268.00, and
P	=	permit cost, $120.00.

Round-Trip Cost for Using the TN-8 Cask to the Geologic Repository

$$\text{Cost} = R1 \times d1/d10 + R2 \times d2/d20 + n \times (R3 \times w/w0 \times d/d0 + OW + P) + (n - 1) \times (R4 \times d/d0 + OW + P),$$

where

R1	=	cost of transporting empty cask from cask supplier to reference reactor site (TROJAN), $18,790.61,
d1	=	distance between study reactor site and cask supplier, 2,659 miles,
d10	=	distance between reference reactor site (TROJAN) and the cask supplier, 2,799 miles,
R2	=	cost of transporting empty cask from the reference repository to cask supplier, $13,551.44,
d2	=	distance between study repository and cask supplier, 2,070 miles,
d20	=	distance between reference repository and cask supplier, 2,070 miles,
n	=	number of casks to be shipped to the repository,
R3	=	cost of transporting fully loaded cask from reference reactor site (TROJAN) to reference repository, $5,286.12,
w	=	weight of loaded cask, in pounds,
w0	=	weight of fully loaded cask, 84,040 pounds,
d	=	distance between study reactor site (WNP-2) and study repository, 793 miles,
d0	=	distance between reference reactor site (TROJAN) and reference repository, 907 miles,
R4	=	cost of transporting empty cask from reference repository to reference reactor site (TROJAN), $4,165.95,
OW	=	overweight charges, $365.00, and
P	=	permit cost, $120.00.

For non-cask truck shipments, the calculations are much simpler. For cargo consisting of 55-gallon drums, assorted metal boxes, or maritime containers, the round-trip truck transportation charges are:

Round-Trip Legal-Weight Truck Shipment Cost for Low Level Waste, U.S. Ecology Richland, WA, Burial Site

$$\text{Cost} = R \times D/D0 + PC$$

where
- R = the round-trip cost between reference reactor site (TROJAN) and reference disposal site (U.S. Ecology, WA), $1,211.82,
- D = distance between study reactor site (WNP-2) and U.S. Ecology, WA, 15 miles,
- D0 = distance between the reference reactor site (TROJAN) and U.S. Ecology, WA, 297 miles,
- PC = permit cost, $120, for cargoes not exceeding 40,000 pounds.

Round-Trip Legal-Weight Truck Shipment Cost for Low Level Waste, Chem-Nuclear Barnwell, SC, Burial Site

$$\text{Cost} = R \times D/D0 + PC$$

where
- R = the round-trip cost between reference reactor site (TROJAN) and reference disposal site (Barnwell, SC), $4,226.49,
- D = distance between study reactor site (WNP-2) and Barnwell, SC, 2,659 miles
- D0 = distance between reference reactor site (TROJAN) and Barnwell, SC, 2,799 miles,
- PC = permit cost, $95, for cargoes not exceeding 40,000 pounds.

For the same type of cargo as above, but exceeding 40,000 pounds, the truck transportation charges are calculated as follows:

Round-Trip Over-Weight Truck Shipment Cost for Low Level Waste, U.S. Ecology Richland, WA, Burial Site

$$\text{Cost} = R \times D/D0 \times W/W0 + PC + OWP$$

where
- R = the round-trip cost between reference reactor site (TROJAN) and reference disposal site (U.S. Ecology, WA), $1,211.82,
- D = distance between study reactor site (WNP-2) and U.S. Ecology, WA, 15 miles,
- D0 = distance between reference reactor site (TROJAN) and U.S. Ecology, WA, 297 miles,
- W = cargo weight, assumed to be greater than 40,000 pounds,
- W0 = reference weight, 40,000 pounds,
- PC = permit cost, $120,
- OWP = overweight permit cost, $95.

Round-Trip Over-Weight Truck Shipment for Low Level Waste, Chem-Nuclear Barnwell, SC, Burial Site

$$\text{Cost} = R \times D/D0 \times W/W0 + 0.4 \times D + PC + OWP$$

where
- R = the round-trip cost between reference reactor site (TROJAN) and reference disposal site (Barnwell, SC), $4,226.49,
- D = distance between study reactor site (WNP-2) and Barnwell,SC, 2,659 miles,

D0 = distance between reference reactor site (TROJAN) and Barnwell, SC, 2,799 miles,
W = cargo weight, assumed to be greater than 40,000 pounds,
W0 = reference weight, 40,000 pounds,
PC = permit cost, $95,
OWP = overweight permit cost, $543.

For the specific case of the reference BWR, trucks are used to transport equipment and material to the disposal sites. No rail transportation is used.

B.7 Waste Disposal Costs

As previously mentioned, most radioactive materials resulting from decommissioning are assumed to be shipped for disposal to a burial site (U.S. Ecology, Inc., at Richland, WA), or, in the case of highly activated reactor components, to a geologic repository or other such disposal facility as the NRC may approve. In addition, there is a third type of waste that a licensee may have to consider during decommissioning - mixed waste. The unit costs for all three cases of waste disposal are discussed in the following subsections.

B.7.1 Costs for Shallow-Land Burial

The primary shallow-land burial costs used in this study are presented in Table B.4. They are the February 9, 1993, schedule of charges from U.S. Ecology, Inc., which operates the burial site at Richland, Washington. However, because sensitivity of the total license termination cost to the disposal costs at different low-level radioactive waste disposal sites is also examined in this report, the January 1, 1993, schedule of charges from Chem-Nuclear Systems, Inc., which operates the burial site at Barnwell, South Carolina, is presented in Table B.5.

B.7.2 Costs for Geologic Disposal

Based upon discussions with an industry expert, a nominal unit cost value of approximately $6,500 per cubic foot ($229,540 per cubic meter) is estimated for use in this study for geologic repository disposal costs. Thus, for the canisters presently considered for geologic disposal (0.24-m^3 burial volume) in this study, the disposal charge is $55,090/canister. It should be recognized that the cost presented here is quite speculative, since a geologic repository or other such disposal facility as the NRC may approve does not presently exist.

B.7.3 Costs for Mixed Waste Disposal

Firm cost estimates for offsite services concerning disposal of solid mixed LLW were not obtained, since such services are not currently available in the U.S. No offsite disposal or treatment facility for mixed waste has been available since 1985. However, joint regulation by both the NRC and the EPA is expected to make the unit cost of disposing of mixed waste much higher than the cost of disposing of other low-level wastes. Utilities are finding ways to treat some of their mixed waste so that it is no longer a chemical hazard, thus making it possible to dispose of the radioactive component along with other LLW. The remainder of mixed waste, however, is currently stored onsite.[11,12]

An August 1991 Nuclear Waste News article reported: "Complications attending mixed waste disposal are expected to yield massive disposal costs, which are likely to rise still further as generators, seeking to avoid costs as high as $20,000 per cubic foot, cut their mixed waste output drastically, thereby pushing up costs for the remaining waste."[13]

Table B.4 U.S. Ecology shallow-land burial costs at Richland, WA

US ECOLOGY
WASHINGTON NUCLEAR CENTER
DISPOSAL CHARGES
SCHEDULE A
EFFECTIVE FEBRUARY 9, 1993

A. DISPOSAL CHARGES

1. Packages (except as noted in Section 2)

R/HR AT CONTAINER SURFACE	PRICE PER CU. FT.
0.00 - 0.20	$35.92
0.201 - 1.00	37.70
1.01 - 2.00	39.10
2.01 - 5.00	40.60
5.01 - 10.00	44.50
10.01 - 20.00	53.20
20.01 - 40.00	61.40
Greater than 40.00	$66.90 + ($0.541 x R/HR in excess of 40)

2. Disposal Liners Removed From Shield (Greater Than 12.0 Cu.Ft. Each)

R/HR AT CONTAINER SURFACE	SURCHARGE PER LINER	PRICE PER CU. FT.
0.00 - 0.20	No Charge	$35.92
0.21 - 1.00	263.50	35.92
1.01 - 2.00	592.90	35.92
2.01 - 5.00	999.20	35.92
5.01 - 10.00	1,592.00	35.92
10.01 - 20.00	2,086.00	35.92
20.01 - 40.00	2,393.40	35.92
Greater than 40.00	2,619.40 + ($22.96 x R/HR in excess of 40)	35.92

B. Surcharge for Curies (per load)

Less than 50 curies	No Charge
50 - 100 curies	$1,097.90
101 - 300 curies	2,195.80
301 - 500 curies	2,744.90
501 - 1,000 curies	3,293.90
1,001 - 5,000 curies	3,842.80
5,001 - 10,000 curies	5,599.50
10,001 - 15,000 curies	7,905.20
Greater than 15,000 curies	8,959.20 + ($0.426 x curies in excess of 15,000)

C. Minimum Charge Per Shipments

All shipments will be subject to a minimum charge of $1,000 per generator per shipment.

Table B.4 (Continued)

US ECOLOGY
WASHINGTON NUCLEAR CENTER
SURCHARGES AND OTHER SPECIAL CHARGES
SCHEDULE B
EFFECTIVE FEBRUARY 9, 1993

SURCHARGES AND OTHER SPECIAL CHARGES

A. CASK HANDLING FEES

1. Truck Casks

a. Remains on Vehicle During Unloading	$1,000 each
b. Removed from Vehicle During Unloading	$25,000 each

2. Rail Cask

$50,000 each plus outside riggers' charges

B. POLY HICS IN ENGINEERED CONCRETE BARRIERS

1. Large Barrier - $9,520 plus other applicable costs herein

2. Small Barrier - $8,325 plus other applicable costs herein

C. SURCHARGE FOR HEAVY OBJECTS (NON-CASK SHIPMENTS)

Less than 5,000 pounds	No Charge
5,001 -10,000	$ 500.00
10,001 -15,000	1,000.00
15,001 -20,000	2,500.00
20,001 -25,000	5,000.00
Over -25,000	10,000.00

D. SURCHARGE FOR SPECIAL NUCLEAR MATERIAL

Greater than 5 grams per shipment	$10.00 per gram

E. DECONTAMINATION SERVICES (IF REQUIRED)

Per Hour	$150.00
Supplies	Cost Plus 25%

F. OTHER SERVICES (IF REQUIRED)

Rates shown on Schedule A, Items A and B and Schedule B, items C and E are based on utilization of on-site personnel and equipment. If additional personnel or equipment are required for handling or disposal of waste, additional charges may be assessed.

Table B.4 (Continued)

US ECOLOGY
WASHINGTON NUCLEAR CENTER
TAX AND FEE RIDER
SCHEDULE C
EFFECTIVE FEBRUARY 9, 1993

The rates and charges set forth in Schedule A & B shall be increased by the amount of any fee, surcharge or tax assessed on a volume or gross revenue basis against or collected by US Ecology, as listed below:

Perpetual Care and Maintenance Fee	$1.75 per cubic foot
Business & Occupation Tax	5.5% of rates and charges
Site Surveillance Fee	$1.99 per cubic foot
Surcharge (RCW 43.200.233)	$6.50 per cubic foot
Commission Regulatory Fee	1.0% of rates and charges

1560R

Table B.5 Chem-Nuclear shallow-land burial costs at Barnwell

CHEM-NUCLEAR SYSTEMS, INC.
140 Stoneridge Drive • Columbia, South Carolina 29210

BARNWELL LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT FACILITY RATE SCHEDULE

All radwaste material shall be packaged in accordance with Department of Transportation and Nuclear Regulatory Commission Regulations in Title 49 and Title 10 of the Code of Federal Regulations, Chem-Nuclear's Nuclear Regulatory Commission and South Carolina Radioactive Material Licenses, Chem-Nuclear's Barnwell Site Disposal Criteria, and amendments thereto.

1. BASE DISPOSAL CHARGES: (Not including Surcharges, Barnwell County Business License Tax, and Cask Handling Fee)

A.	Standard Waste	$59.00/ft^3
B.	Biological Waste	$61.00/ft^3
C.	Special Nuclear Material (SNM)	$59.00/ft^3

Note 1: Minimum charge per shipment, excluding Surcharges and specific other charges is $1,000.

Note 2: Base Disposal Charge includes:

Extended Care Fund	$ 2.80/ft^3
South Carolina Low-Level Radioactive Waste Disposal Tax	$ 6.00/ft^3
Southeast Regional Compact Fee	$ .89/ft^3

2. SURCHARGES:

A. Weight Surcharges (Crane Loads Only)

Weight of Container	Surcharge Per Container
0 - 1,000 lbs.	No Surcharge
1,001 - 5,000 lbs.	$ 675.00
5,001 - 10,000 lbs.	$1,200.00
10,001 - 20,000 lbs.	$1,685.00
20,001 - 30,000 lbs.	$2,170.00
30,001 - 40,000 lbs.	$3,185.00
40,001 - 50,000 lbs.	$4,185.00
greater than 50,000 lbs.	By Special Request

Effective January 1, 1993

Table B.5 (Continued)

Barnwell Rate Schedule **Effective January 1, 1993**
Page Two

B. **Curie Surcharges For Shielded Shipment:**

Curie Content Per Shipment	Surcharge Per Shipment
0 - 5	$ 4,150.00
> 5 - 15	$ 4,710.00
> 15 - 25	$ 6,235.00
> 25 - 50	$ 9,405.00
> 50 - 75	$11,460.00
> 75 - 100	$15,525.00
> 100 - 150	$18,630.00
> 150 - 250	$24,955.00
> 250 - 500	$31,280.00
> 500 - 1,000	$37,375.00
> 1,000	By Special Request

C. **Curie Surcharges for Non-Shielded Shipments Containing Tritium and Carbon 14:**

Curie Content Per Shipment	Surcharge Per Shipment
0 - 100	No Surcharge
greater than 100	By Special Request

D. **Class B/C Waste Polyethylene High Integrity Container Surcharge**

Curie Content Per Shipment	Large Liners with Maximum Dimension of 82" Diameter and 79" Height	Overpacks with Maximum Dimension of 33" Diameter and 79" Height	55-Gallon Drum size with Max. Dimension of 25.5" Diameter and 36" Height
0 - 25	$29,325	These containers will be assessed charges the same as other containers in accordance with this rate schedule plus $2,900 per overpack and $750 per drum	
> 25 - 50	$30,760		
> 50 - 75	$32,775		
> 75 - 100	$35,300		
>100 - 150	$38,525		
>150 - 250	$44,965		
>250 - 500	$52,210		
>500	Upon Request		

NOTES: 1. Class B/C poly HICs which do not conform to the above require prior approval and pricing will be provided upon request.

2. The above Large Liner charges are inclusive of the base disposal charge (1.A.), weight surcharge, curie surcharge, cask handling surcharge, disposal overpack charge, and the Barnwell surcharge.

Table B.5 (Continued)

Barnwell Rate Schedule **Effective January 1, 1993**
Page Three

E.	Cask Handling Fee	$1,795.00 per cask, minimum
F.	Special Nuclear Material Surcharge	$8.15 per gram
G.	Barnwell Surcharge	2.4%

3. MISCELLANEOUS:

A. Transport vehicles with additional shielding features may be subject to an additional handling fee which will be provided upon request.

B. Decontamination services (if required): $150.00 per man-hour plus supplies at current Chem-Nuclear rate.

C. Customers may be charged for all special services as described in the Barnwell Site Disposal Criteria.

D. Terms of payment are NET 30 DAYS upon presentation of invoices. A service charge per month of 1-1/2% shall be levied on accounts not paid within thirty (30) days.

E. Company purchase orders or a written letter of authorization in form and substance acceptable to CNSI shall be received before receipt of radioactive waste material at the Barnwell Disposal Site and shall refer to CNSI's Radioactive Material Licenses, the Barnwell Site Disposal Criteria, and subsequent changes thereto.

F. All shipments shall receive a CNSI allocation number and conform to the Prior Notification Plan. Additional information may be obtained at (803) 259-3577 or (803) 259-3578.

G. This Rate Schedule is subject to change and does not constitute an offer of contract which is capable of being accepted by any party.

H. A charge of $12,650.00 is applicable to all shipments which require special site set-up for waste disposal.

I. Class B/C waste received with chelating agents, which requires separation in the trench, may be subject to a surcharge if Stable Class A waste is not available for use in achieving the required separation from other wastes.

Table B.5 (Continued)

Chem-Nuclear Systems, Inc.

Attachment 1

Barnwell Low-Level Radioactive Waste Management Facility
1993 Disposal Pricing

1. Base Disposal Charges — Refer to Rate Schedule effective January 1, 1993

2. Surcharges

   A. Weight Surcharges — Refer to Rate Schedule effective January 1, 1993 for weights under 50,000 lbs

Weight Surcharges for Shielded Shipments >50,000 lbs	Weight Surcharge Per Shipment
> 50,000 - 60,000	$ 7,350.00
> 60,000 - 70,000	$ 8,950.00
> 70,000 - 80,000	$ 10,500.00
> 80,000 - 90,000	$ 12,100.00
>90,000 - 100,000	$ 13,700.00

   B. Curie Surcharges for Shielded Shipment

   (up to 1,000 curies) — Refer to Rate Schedule effective January 1, 1993

Curie Content per Shielded Shipment	Curie Surcharge Per Shipment
> 1,000 - 5,000	$57,500.00
> 5,000 - 10,000	$71,900.00
> 10,000 - 20,000	$97,800.00
> 20,000 - 30,000	$120,800.00
> 30,000 - 40,000	$149,500.00
> 40,000 - 50,000	$172,500.00

3. Class B/C Waste Polyethylene High Integrity Container Surcharge — Refer to Rate Schedule effective January 1, 1993

Table B.5 (Continued)

Chem-Nuclear Systems, Inc.

4. Cask Handling Fee

Cask Type	Price
NFS-4, NAC-1	$ 11,800.00
NL 1/2 (when approved for horizontal offload)	$ 11,800.00
AP101	$ 11,800.00
FSV-1	$ 14,900.00
CNS 3-5	$ 12,600.00
TN8L	$ 23,700.00
TN RAM	$ 14,900.00

Cask handling fees shown above are applicable only for these casks listed. Special pricing for non-routine handling or for casks not listed is available by special request.

5. Special Nuclear Material Surcharge — Refer to Rate Schedule effective January 1, 1993

6. Barnwell Surcharge — Refer to Rate Schedule effective January 1, 1993

Additionally, Section 3 from our published rate schedule, entitled "Miscellaneous," Item H may also apply (due to the high radiation levels of the liner) if special disposal site set-up provisions must be made prior to cask off-loading and waste disposal. Disposal of low-level radioactive waste will be charged in accordance with the current Barnwell Low-Level Radioactive Waste Management Facility Rate Schedule in effect at the time of disposal.

NOTE 1: The above pricing schedule does not include the Southeast Compact Commission Access Fee of $220.00/ft^3. Battelle will be responsible for prepayment of this access fee on a quarterly basis.

NOTE 2: This pricing is effective January 1, 1993, and is subject to change upon notification to Battelle by Chem-Nuclear.

For purposes of this study, the ultimate cost of disposal of mixed wastes (either liquid or solid) expected to be present on the reference BWR site at final shutdown is considered to be an operational cost, since the majority of such wastes are postulated to be generated during operation of the plant. It should be recognized, however, that regardless of when solid mixed LLW is generated, commercial treatment, storage, and disposal services for the waste are currently quite limited. Based upon the aforementioned projected disposal costs and upon the uncertainties surrounding the ultimate disposition of solid mixed wastes, it is assumed further that implementation of waste minimization techniques used during the operating years of the plant will also be used during decommissioning. Therefore, only a relatively small amount, if any, of additional solid mixed LLW is assumed to be generated during decommissioning of the reference BWR. Additional information concerning mixed wastes can be found in Appendix H.

B.8 Costs of Services, Supplies, and Special Equipment

Various types of services and supplies are required for decommissioning the reference BWR. The estimated unit costs of the major items are discussed here. The estimated unit costs for special equipment items anticipated for use during decommissioning are summarized in Table B.6.

Energy Costs

Electricity - A principal services cost item is electric power. Based upon discussions with WPPSS personnel, it is estimated that electrical replacement power costs would probably be provided to WNP-2 by the Bonneville Power Administration at the preferred customer rate of $0.027/kWh, or $27/MWh.

During an 11-month outage that ended in February 1992, with about 1,000 people onsite, a Northwest PWR (Trojan) was reported to have an average site electricity consumption of about 5 MW. A significant portion of the electricity was used for heating, air conditioning, lights, etc. A similar inquiry to Trojan on October 7, 1993, 11 months after permanent shutdown of the plant, concerning their average site consumption for their current possession-only status (i.e., with less than 300 people onsite and all fuel stored in their fuel pool) revealed an average site consumption of about 4 MW.

For this study, the estimated electrical usage at the reference BWR, during periods of active decommissioning, is based upon a reevaluation of the rigorous analyses concerning energy requirements conducted previously in NUREG/CR-0672.[1] The results of that reevaluation are given in Table B.7.

It is interesting to note that reevaluation results indicate a peak base load at the reference BWR of approximately 4 MW, revealing a good correlation to the aforementioned similar-size plant currently in a permanent shutdown condition.

By using the electricity consumption values presented in Table B.7 for periods of active decommissioning, and by following the appropriate schedule for a specific decommissioning alternative, the power usage by month after shutdown is estimated. In addition, the costs for energy used during system decontamination and draining and radioactive liquid handling are given separately in Appendix G.

Oil - At the reference BWR, fuel oil is burned in an auxiliary boiler to provide heating steam to the power block buildings. The unit cost of #2 diesel fuel for the boiler is $1.27/gal, in 1993 dollars, based upon information provided by the supplier of the fuel to the reference plant. Based upon a review of plant records, fuel oil for heating (as a supplement to

Table B.6 Special tools and equipment costs

Item	Estimated number required	Estimated unit cost ($000)
Remote manipulator for underwater, in-vessel cutting	1	1,102.5
Underwater plasma-arc cutting system	2	77.2
Cutting table, plus jigs	1	33.0
Oxyacetylene cutting system	1	3.3
Plasma-arc equipment	2	33.0
Track-mounted drive unit	4	4.4
Drum compactor	2	47.4
Closed circuit, high-resolution television	(plant equip.)	55.1[a]
High-pressure water jet	1	176.4[b]
Kelly Decontamination System™	3	186.0[c]
Underwater lights, viewing windows/periscope	As required	11.0
Submersible pumps with disposable filter	3	6.6
Power-operated, mobile, scissors-type manlift (Sky Climber™, Series 47)	4	38.6
Genie Zoom-Boom™ manlift, 45-ft	1	52.9
Bobcat™ front-end loader (highly maneuverable, light-duty	2	19.8
6818-kg forklift	3	99.2[d]
9100-kg mobile hydraulic crane	2	40.8
Safety nets	As required	50.7
Polyurethane foam generator	2	9.9
Wall-saw (35 h.p.) w/power unit	2	22.1
Slab-saw (35 h.p.)	2	4.4
Concrete drill with HEPA-filtered dust collection system	4	4.4
Concrete surface spaller	4	9.9
Portable ventilation enclosure	10	3.3
Vacuum cleaner (HEPA-filtered)	3	9.9
Filtered-exhaust fan unit	4	7.7
Water vacuum	4	~1.0
Core drill stand	4	16.8
Water hose (300 feet)	4	~1.0
Hydraulic hose (200 feet)	4	6.3
Total		~$2.135 million

(a) Estimated for modifications of existing systems.
(b) System includes floor surface wand, tank interior wand, and compressor unit.
(c) Manufactured by Container Products Corporation. The unit cost shown includes 1 week of training in the use of the equipment.
(d) Assumes the availability of two forklifts from plant operations.

Table B.7 Estimated electricity usage during decommissioning[a]

System(s) or equipment	Estimated energy usage (MWh/month)
HVAC	
Main Buildings:	
Reactor/Primary Containment	366
Reactor	512
Turbine Generator	578
Radwaste & Control[b]	315
Control Tower	27
Other Buildings[c]	169
Lighting	
Reactor Bldg.	84
Turbine Generator Bldg.	84
Radwaste & Control Bldg.	84
Auxiliary Bldgs.[d]	28
Communications	9
Security	59
Fire Protection	3
Compressed Air	55
Cranes & Hoists:	
Reactor/Primary Containment	34
Turbine Generator Bldg.	6
Radwaste Area	2
Domestic Water	379
Decommissioning Equipment	140
Total	2,934 (~4.1 MW load)

(a) The energy values shown in the table are based upon a reevaluation of the rigorous analyses concerning electrical requirements for DECON as delineated in NUREG/CR-0672.[1]

(b) Radwaste area only.

(c) Includes Standby Service Water Pumphouse, Make-up Water Pumphouse, Diesel Generator Building, Service Building, Machine Shop, and Water Treatment Areas.

(d) Includes Office Building, Warehouse, Guardhouse, and Gas Bottle Storage Building.

reactor-generated energy used for heating) was consumed at an average rate of about 115,170 gallons/year for the period 1990 through 1992.[4] However, during periods of active decommissioning evaluated in this study, it is postulated that the auxiliary boiler will be required for a total of 131 days per year to meet the heating requirements at the reference plant. An estimated consumption rate of about 90 gallons per hour results in an annual consumption rate of 282,960 gallons (131 days x 24 hrs/day x 90 gal/hr). At $1.27/gal, this results in an estimated annual cost of $359,360 for fuel oil.

Protective Clothing and Equipment Services

Protective clothing and equipment services are anticipated to be provided by an offsite subcontractor, as required, at an estimated cost of $21 per day per person, based upon discussions with industry personnel.

Hanford Site Support Services

On the Hanford site, which is controlled by the U.S. Department of Energy, contractors and subcontractors obtain services from the Operations and Maintenance contractors for the movement of large objects, such as the turbine rotors, to the low-level waste burial ground. Included in the cost of these services are road preparation and maintenance, utilities, fire protection, security, patrol, transportation, medical aid, etc. Based upon discussions with industry contacts, these services, including labor, equipment, and materials, are estimated to cost about $132,300 per trip.

Material Costs

Material costs are a function of the size of the piping/tank/equipment being dismantled. Principal components are absorbent materials, plastic sheeting and bags, and gases for torches. The quantities and unit costs used in these analyses are listed below.

		Piping						Tanks
Material		**0-2 in. dia**		**2-14 in. dia.**		**32-47 in. dia.**		**1/2 in. tank wall**
Abs. Matl.	@$0.32/ft^2	10 ft^2	$3.20	15 ft^2	$4.80	20 ft^2	$6.40	length x dia. x $0.32
Plastic	@$0.04/ft^2	25 ft^2	$1.00	37.5 ft^2	$1.50	50 ft^2	$2.00	length x dia. x $0.04
Gases	@$6.75/hr	0.017 hr	$0.11	0.033 hr	$0.22	0.33 hr	$2.23	Hours of cut x $6.75
		$4.32/cut		$6.52/cut		$10.63/cut		As calculated per tank
Including 15% DOC profit:		$4.97/cut		$7.50/cut		$12.22/cut		1.15 x As calculated per tank

Small Tools and Minor Equipment

In decommissioning, the cost for small tools and minor equipment is often difficult to estimate. Many of these tools will become contaminated and ultimately will be disposed of by burial. The 1993 edition of R. S. Means[(2)] recommends a maximum allowance of 2% of the contractor's direct labor cost. For, say, $10 million of direct labor costs, 2% would be

[4]Letter, Neil D. Zimmerman, Washington Public Power Supply System, to George J. Konzek, Battelle Northwest, transmitting reference plant diesel fuel consumption at WNP-2, dated October 11, 1993.

roughly $200,000. Further assuming an average small tool were to cost $1,100 (e.g., small chain hoists, saws, drills, oxyacetylene torches, sets of hand tools, etc.), the decommissioning operations contractor (DOC) would purchase approximately 180 tools for the crews.[14] This appears to be in the appropriate range for decommissioning work. Therefore, a 2% allowance for these items is incorporated into the cost calculations for the small tools and minor equipment.

Blades Used for Cutting Concrete

The unit cost for blade material is estimated at $0.44/in.-ft of cut.

Scaffolding

Based upon discussions with WNP-2 plant personnel, sufficient scaffolding and associated equipment is kept in several staging areas onsite, to meet their needs during reactor outages. In addition, the supply of scaffolding is replenished as required. Therefore, the reference plant's inventory of scaffolding is deemed sufficient to meet anticipated decommissioning requirements.

B.9 Property Taxation[5]

The Washington Public Power Supply System was organized in 1957 by Washington public utility districts under state legislation as a municipal corporation and joint operating agency to enable public utilities to finance, construct, and operate major electric generating facilities, including WNP-2. WPPSS has no taxing authority and is exempt from property taxes for WNP-2 under Washington state law. WPPSS does pay a WNP-2 generating tax in lieu of property taxes; however, these taxes will cease upon final shutdown of the plant.

It should be recognized that the property tax situation described in this appendix is predicated on site-specific information. Therefore, the conclusions reached herein concerning impacts on decommissioning costs for the reference BWR may not be the same for other BWR power stations.

B.10 Nuclear Insurance Costs

The 1978 nuclear insurance costs given in NUREG/CR-0672[1] were originally developed in 1975 based upon information provided by American Nuclear Insurers (ANI).[6] Cost projections for this commitment have increased significantly since then. In addition, cost estimates in the 1978 time frame typically only included insurance premiums associated with nuclear liability policies. More recent information, obtained from industry personnel and their brokers, suggests that additional insurance coverage will be needed to limit owner liability immediately after final shutdown, during subsequent decommissioning and dismantling operations, and for a prudent period of time following termination of the possession-only license.

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[5]Property taxes are commonly referred to as collateral or undistributed costs. Such costs can extend over one or more decommissioning periods. Thus, these expenses can be expected to continue following final shutdown and during the dormancy periods of safe storage or entombment, until the possession-only license is terminated. While the property taxes will continue to be assessed after the license is terminated, these costs will no longer be considered decommissioning costs.

[6]ANI is a voluntary unincorporated association of stock insurance companies which provides property and liability insurance protection to the nuclear energy industry. ANI is one of three pools - a pool is a group of insurance companies that together provide resources to insure risks which are beyond the financial capability of a single company.

The estimated nuclear insurance costs used in this study are based on information provided by Johnson & Higgins of Arizona, Inc. Johnson & Higgins has indicated that "the task of estimating post-shutdown insurance costs for the reference facility is made easier by the fact that they have had several years of experience placing insurances for a commercial facility which has been shut down for decommissioning. Once actual plant dismantlement begins, however, we can only look to information which the insurers have provided for guidance. No commercial reactor of this size and type has yet undergone the complete decommissioning process."[7]

A summary of the estimated total post-shutdown insurance costs, by stage, is presented in Table B.8. The bases for the values shown in the table are developed in subsequent sections.

Table B.8 Summary of estimated post-shutdown insurance costs in 1993 dollars

	Cost category	
Stage	Decommissioning cost, $[a]	SNF management cost, $[a]
Transition (first 1.2 years following shutdown, until receipt of Property Rule waiver)	3,195,120[c]	
Following general plant layup preps and receipt of Property Rule waiver	0	1,107,600/year
Extended Safe Storage with the fuel pool empty	600,000/year	0
During periods of active decommissioning	1,198,600/year	0
After termination of the possession-only license	17,250/year	0

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Shown for completeness; these costs are not decommissioning costs.
(c) Following shutdown, about 1.2 years of decommissioning activities are postulated (e.g., chemical decontamination of the selected reactor piping systems, cutting and packaging of the reactor pressure vessel internals, etc.); therefore 1.2 x $2,662,600/year premium, or about $3,195,120 is attributable to decommissioning operations. Following cessation of the initial decommissioning operations, all of the insurance costs are postulated to be attributable to SNF management operations until: 1) active decommissioning operations begin again in about 3.4 years or 2) extended safe storage commences.

B.10.1 Assumptions

The estimated property damage insurance and nuclear liability insurance costs presented in this study are based upon the following assumptions provided by Johnson & Higgins:

1. The reference plant is insured by ANI for primary property insurance, and carries full limits of property, liability, and business interruption coverage. This is a significant assumption, in that the reactor plant selected as the reference facility does not purchase several coverages which would typically be carried by a single unit site of reference capacity. As a quasi-governmental entity, the reference facility owner enjoys greater flexibility in risk retention than a public utility. To allow these premium projections to have broader applicability to the "typical" single unit site, the following coverage amounts and premium levels are assumed:

[7] Letter, Daniel S. McGarvey, Johnson & Higgins of Arizona, Inc., to George J. Konzek, Battelle Northwest, transmitting reference plant decommissioning cost projections, dated March 16, 1993.

Coverage	Limit	Annual premium
ANI Excess Property	$800,000	$1,450,000
NEIL I Business Interruption	$3,500,000/week	$1,000,000
ANI Suppliers & Transportation	$200,000,000	$27,000

2. For consistency of applicability, it is further assumed that the reference plant has an engineering rating factor (ERF)[8] of 1.00, and enjoys no credit advantage through ANI's individual experience modifier.

3. The shutdown reactor is defueled completely to the spent fuel pool and is granted a waiver of Property Rule insurance limit requirements as have other decommissioning facilities to date. This waiver can be expected to require from one year to eighteen months to obtain.

   Note: For this study, it is conservatively estimated to take 1.2 years, after shutdown, to receive the waiver.

4. With the waiver granted, a $200 million limit of Property Damage insurance is determined to be sufficient to protect essential cooling, monitoring, and defueling systems. This is a conservatively high figure when viewed against those in place at current decommissioning facilities, and assumes that plant conversion or other use of site assets are not anticipated.

5. A $300 million limit in Excess Decontamination insurance is determined to be the appropriate amount required to respond to the worst postulated post-shutdown accident. Again, this amount is conservatively selected.

6. Credits of forty percent (40%) and fifty percent (50%) are applied to ANI primary Property and Liability premiums, respectively, to recognize the permanently shutdown nature of the plant. These credits are extended fifty percent up front, and fifty percent at policy year end subject to safe plant operation and acceptable loss prevention efforts.

7. Nuclear Electric Insurance Limited, NEIL I coverage (business interruption)[9] is immediately suspended following plant permanent shutdown. A loss recovery under NEIL I is not technically feasible for a plant which has permanently ceased power generation.

8. Immediately following plant shutdown, property insurance levels are reduced to the minimum ($1.06 billion) required by the Property Rule (10 CFR 50.54(w)). The $560 million first excess layer is met through NEIL II coverage versus ANI excess because it is less costly and offers dividend potential.

9. NEIL II Excess property coverage is provided at fifty percent of pre-shutdown cost following plant defueling. This is consistent with traditional NEIL shutdown credits.

10. The price per million of Excess Decontamination coverage is approximately forty percent (40%) of full Property Damage coverage, as has been recently observed.

[8]The rating factor is a premium multiplier, based upon the insurance company's evaluation for rating the perceived safety and risk.
[9]Nuclear Electric Insurance Limited is an industry self-insurance corporation organized in 1980 for the purpose of providing protection for power replacement costs when a reactor has suffered an outage caused by an accident. Since then, NEIL has initiated a second type of insurance coverage (NEIL II) that provides property damage excess coverage. The NEIL II coverage provides a second layer of insurance up to a specified maximum that tracks the primary coverage that a utility has with another insurer.

11. A $1 million deductible level is selected. This is consistent with current ANI minimum decommissioning deductible requirements. The reference plant has traditionally selected a higher deductible level. All premium assumptions contained herein are based upon the $1,000,000 deductible. A $200 million level of Suppliers' and Transporters' (S&T)[10] coverage is maintained in anticipation of a large number of radiological shipments during preliminary decommissioning process.

12. Insurance pricing during the first few months after shutdown is not substantially reduced, save for the extension of traditional shutdown credits.

13. A full $200 million level of Facility Form[11] (nuclear liability) coverage, as well as participation in the Secondary Financial Protection and Worker Form programs, is required throughout the decommissioning process.

14. Scheduled reductions for Property and Liability coverages proceed according to these rough guidelines, which have been obtained over time from ANI:

Property

Stage	Percent reduction
Shutdown for Decommissioning	20-40
Plant defueled offsite	50-67
Plant defueled onsite	40-50

Liability

Stage	Percent reduction
Shutdown for Decommissioning	40-60
Fuel Offsite (if option available)	50-70
Decommissioning and Decontamination Operations	20-40
Decontamination Complete	70-80

15. Finally, total pre-shutdown nuclear insurance expenses are approximately $7 million per year.

B.10.2 Predictions for the Annual Costs of the Insurance Program for the Reference BWR Following Final Shutdown

On the basis of the aforementioned assumptions, the following predictions are made for the annual cost of the insurance program from final shutdown to Property Rule Waiver receipt:

[10]S&T is Nuclear Liability Suppliers and Transporters Form that provides third party liability protection in amounts up to $200 million for bodily injury or property damage resulting from specific nuclear perils; S&T is generally utilized by companies who supply parts, equipment, materials, services, and transportation to owners and operators of nuclear facilities.
[11]An insurance company evaluation for rating the perceived safety and risk.

Property		Liability	
Primary Property	$1,700,000	Facility Form	$395,000
($500 million ANI)		S&T Policy	$27,000
Excess Property	$ 510,000	Worker Form	$23,100
($560 million NEIL)		SFP	$7,500
Program Total:			$2,662,600/yr

Following defueling to the spent fuel pool, completion of general plant layup preparations, and receipt of the Property Rule waiver, the annual premium is projected to be:

Property		Liability	
Primary Property	$490,000	Facility Form	$290,000
($200 million ANI)		S&T Policy	$27,000
Excess Property	$270,000	Worker Form	$23,100
($300 million ANI)		SFP	$7,500
Program Total:			$1,107,600/yr

From this point forward, premiums will likely fluctuate according to the level of activity on site. During periods of active decommissioning and dismantlement, for instance, the annual insurance costs could be adjusted to:

Property		Liability	
Primary Property[(a)]	$ 350,000	Facility Form	$431,000
		S&T Policy[(b)]	$27,000
Excess Decontamination	$ 360,000	Worker Form	$23,100
		SFP	$7,500
Program Total:			$1,198,600/yr

(a) Limit would likely be lowered to account for reduction in property value and required core defueling/monitoring equipment. This example assumes coverage is lowered from $200 to $100 million.
(b) Assumes limit is maintained at $200 million in anticipation of continued shipping exposure.

As selected pieces of equipment are removed, the spent fuel pool defueled, the workforce reduced, and low-level waste shipments slow, a site figure of $600,000 annually is believed to represent a good approximation of a reasonable safe storage premium level.

These figures assume a relatively conservative risk management philosophy. A utility seeking to aggressively lower plant operating expenses may opt to lower premiums more sharply by reducing the amount of coverage purchased. As can be seen from these projections, the reduction in insurance expenses for a single-unit site following planned permanent cessation of operations can be significant.

In addition, the reference BWR's premium projections are now being tempered by a number of the following stipulations and/or caveats that could further modify, or at worst, preclude premium credit consideration for any or all stages of the decommissioning and decontamination of the reactor:

- Nuclear insurance premium projections are based upon the assumption that the reference BWR's "retirement" is due to the expiration of the usual 40-year operating license and **not** due to an "incident" of any kind.

- Any premium credit would be contingent upon the evaluation and approval of both the NRC and nuclear liability engineering representing the insurer(s) relative to each stage of decommissioning and decontamination.

- The specific Facility Form Engineering Rating Factor of the reference BWR's retirement may differ substantially from that of a similar reactor due to the procedures involved, the number of contractor personnel onsite, whether or not spent nuclear fuel is stored onsite, etc.

It should be recognized that final ratings, with respect to a specific reactor's retirement, would be promulgated by the respective Insurance Services Office. For example, ANI has established and applied a risk assessment program to decommissioning activities at a variety of insured nuclear facilities. This risk assessment begins at the planning stages and continues throughout the decommissioning effort. This program is primarily based upon an engineering evaluation of the adequacy of performance in the major areas of nuclear safety, quality assurance, and documentation. Thus, the results of the engineering assessment can affect the level of premium assessed and the rate of change of premium during decommissioning.

B.10.3 Summary of the Estimated Costs of Insurance Following Permanent Cessation of Operations

The total insurance costs for the first 1.2 years following shutdown of the reference BWR (i.e., the "transition period" pending receipt of a waiver of Property Rule limit requirements) are estimated to be about \$3.2 million. Following defueling to the spent fuel pool, completion of general plant layup preparations, and receipt of the Property Rule waiver, the annual premium is projected to be \$1.1 million. Subsequent premiums will likely fluctuate according to the level of activity onsite. It is postulated that the nuclear liability insurance costs covering the 3.4-year period of safe storage with concurrent SNF storage in the reactor spent fuel pool are allocated 10% to decommissioning and 90% to SNF management operations during that period. Upon reduction of the SNF inventory to zero and commencement of active decommissioning, subsequent insurance costs for the reactor facility are attributable to decommissioning operations, with a separate cost for the onsite independent spent fuel storage installation (ISFSI).

During periods of active decommissioning and dismantlement, the annual insurance costs could rise again to about \$1.2 million per year. The reduction in estimated insurance expenses for the reference BWR following a planned permanent cessation of operations is significant compared with the operating level premiums.

B.10.4 Estimated Costs of Insurance Following Termination of the Possession-Only License

For this study, \$5 million in nuclear liability insurance is postulated to be carried for 30 years following termination of the possession-only license, at an estimated annual cost of \$17,250. This lower insurance coverage for this relatively small annual premium is deemed prudent, since it provides "discovery term"[12] protection for the insured covering the entire life of the policy, plus 10 years after cancellation of the policy. It should be recognized, however, that liability is limited to whatever amount of insurance was in effect during the period for which a claim might be made - i.e., the period covering the operating years, the period following permanent cessation of operation, the decommissioning period, and the 30 years (in this case) following termination of the possession-only license. In summary, what this means is that upon cancellation of the policy, the clock starts ticking on the 10-year discovery term for any claims that might be made covering the lifetime of the policy (as defined above), but after the 10 years have elapsed, no claims against the policy can be made. Again, it should be recognized that any change in credit of the normal operating premium would need approval by the NRC and the nuclear liability pools.

B.11 License Termination Survey Costs

In order to terminate the reference BWR's license, the NRC must determine that release of the facility and site for unrestricted use (i.e., without the need for future radiological controls) will not constitute an unreasonable risk to the health and safety of the public. To make such a determination, there must be evidence to show that radiation levels of the facility, site, and adjacent environs permit release for unrestricted use.

The release criteria that the NRC has been using for license termination include those found in the following:

- Regulatory Guide 1.86, *Termination of Operating Licenses for Nuclear Reactors* (NRC 1974),

- *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Materials* (NRC 1987), Office of Nuclear Material Safety and Safeguards (NMSS), and

- *Branch Technical Position for Disposal or Onsite Storage of Thorium or Uranium Water from Past Operations* (46 FR 52061, October 23, 1981).

In addition, the decommissioning rule[(15)] requires submittal of a final radiation survey plan as part of the decommissioning plan. Plans for a termination survey[13] should be designed to provide evidence, with a high degree of assurance, that residual radioactive contamination levels will meet criteria for release for unrestricted use. A termination survey plan should also be designed so that procedures, results, and interpretations can be verified by the NRC staff.

Currently, the NRC has a draft guidance manual, NUREG/CR-5849,[(16)] for conducting radiological surveys in support of license termination. This manual updates information contained in NUREG/CR-2082,[(17)] and provides guidance for licensees on conducting radiological surveys of their facilities and sites to demonstrate that residual radioactive contamination levels,

[12]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 a loss has been sustained that would have been recoverable had the contract remained in force. This period varies, and the company can fix the period of time to be allowed. This period may also be determined by statute; in certain bonds, it is of indefinite duration because of such statutory requirement.
[13]This survey is known by several titles, including **termination survey, post remedial-action survey, final status survey** and **final survey**. The term termination survey is used in this study.

as derived from NUREG/CR-5512,(18) meet NRC criteria for unrestricted use.[14] The guidance emphasis in NUREG/CR-5849 is on the termination survey, which should demonstrate that the facility and site meet the criteria for unrestricted use.

The NRC requires that the termination survey be performed in a manner that assures the results are complete and accurate. Surveys are to be performed by trained individuals who follow standard, written procedures. Properly calibrated survey instruments, sensitive to the identified contaminants at levels specified in the NRC decommissioning criteria, should be used. The custody of samples must be tracked from collection to analysis. Data must be recorded in an orderly and verifiable way and must be reviewed for accuracy and consistency. Every step, from training of personnel to the calculation and interpretation of the results, must be documented in an auditable manner. These requirements are achieved through a formal program of quality assurance and quality control (QA/QC). The draft manual, NUREG/CR-5849, provides acceptable approaches for: 1) survey planning and design, 2) radiological instrumentation, 3) survey techniques, 4) laboratory procedures, 5) interpretation of survey results, and 6) survey documentation and reports.(19)

The needs of both licensee and inspector for design of their respective final surveys, having somewhat divergent objectives, should be kept in mind. One is an integral part of the other insofar as the licensee's final information is input to the inspector's final survey design for verification of the licensee's compliance. Therefore, the survey plan prepared by the licensee (or his survey contractor, as assumed in this study)[15] should be reviewed by the certification inspector prior to initiation of the licensee's final survey. It should be anticipated that the certification inspector will emphasize review of the analytical techniques, quality assurance measures, and statistical bases for sampling. In turn, the licensee's survey contractor should carefully consider the incorporation of comments offered by the certification inspector. This early agreement should minimize the need for a completely independent survey by the certification inspector.(17)

The estimated cost of the termination survey for the reference BWR is based upon 1) the reference BWR plant facilities shown in Figures B.1 through B.4, and 2) the information in draft NUREG/CR-5849 and NUREG/CR-2082.

Although the latter document used a reference PWR (Trojan) as the model for development of the methodology presented therein, it proved useful in developing the cost estimate for the reference BWR's termination survey. The total estimated cost of the final termination survey for the reference BWR is about $1.06 million, including about $0.175 million in NRC-related costs for the confirmation survey. The elemental costs of the survey are presented in Table B.9. Brief discussions/derivations of the survey-related costs shown in the table are presented following the table.

The following preparatory work is necessary to complete the termination survey(s):

- Reference grid systems (i.e., grid drawings to scale)[16] are developed for subsequent use by the licensee and by the radiological contractor who will ultimately conduct the termination survey. It is estimated that this task will require two draftsmen for 13 weeks at a cost of $33,904:

$$(13 \text{ wks} \times 40 \text{ hrs/wk} \times \$32.60/\text{hr})\ 2 = \$33{,}904$$

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[14]NUREG/CR-5512 provides a technical basis for translating contamination levels in buildings and land/soil to annual dose. It presents scenarios for individual exposure to residual contamination, pathway of exposure, modeling and dose calculations.

[15]To the extent that monitoring requires hardware (analysis equipment, calibration standards, supplies, etc.) as contrasted with services (computer programming, data storage and analysis routines, interpretation, etc.), selected elements of a quality assurance program on monitoring for compliance with decommissioning criteria--e.g., control of measuring and test equipment, control of special processes such as sampling procedures and statistical models, corrective action, etc.--may not apply to the extent that physical aspects of the monitoring program are contracted out to a specialized company with the hardware. Quality assurance of these categories then becomes the primary responsibility of the contractor or subcontractor. However, the site owner is jointly responsible for QA on the final results, namely compliance with the decommissioning criteria.(17)

[16]System of coordinates established on a site for purposes of referencing survey locations.

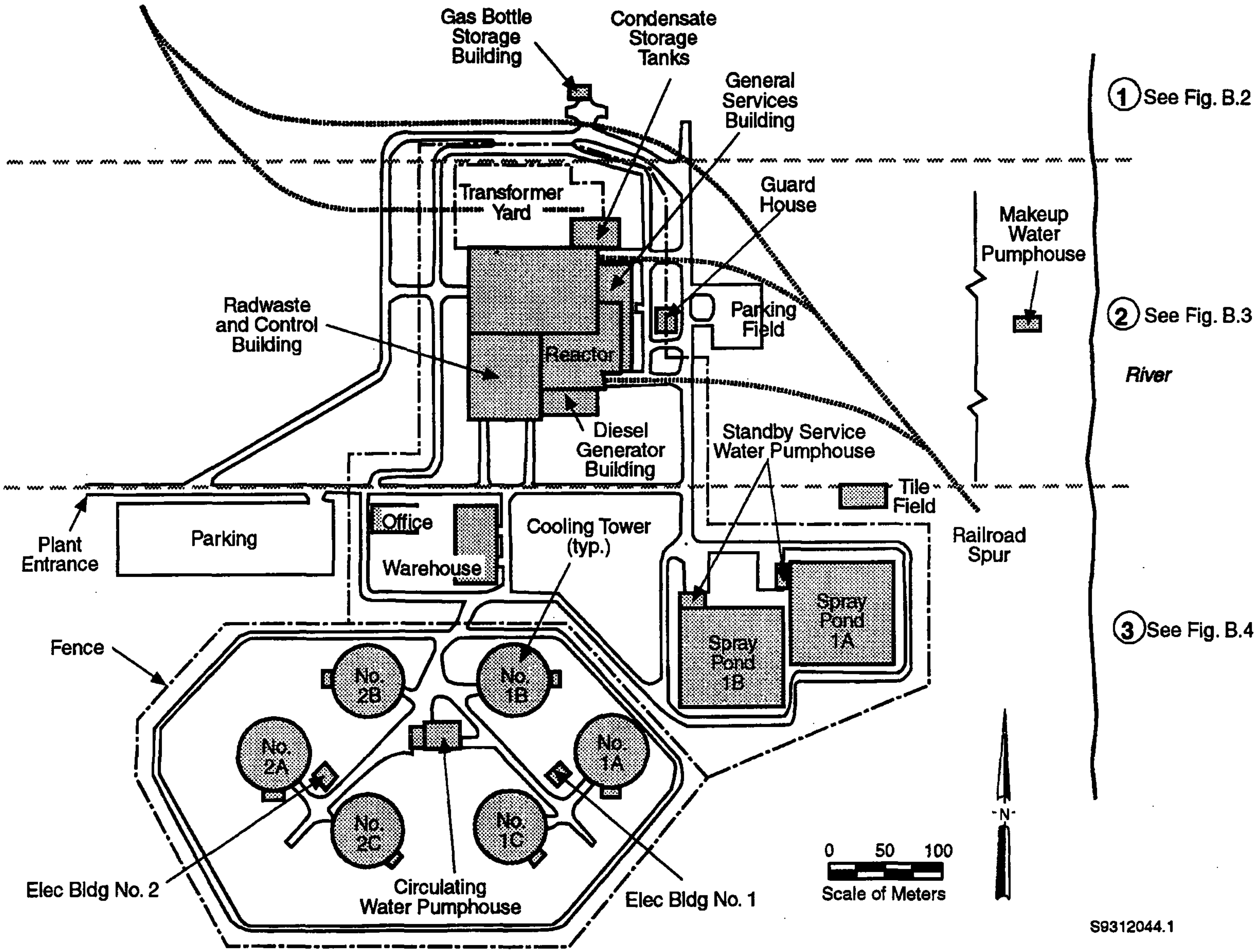
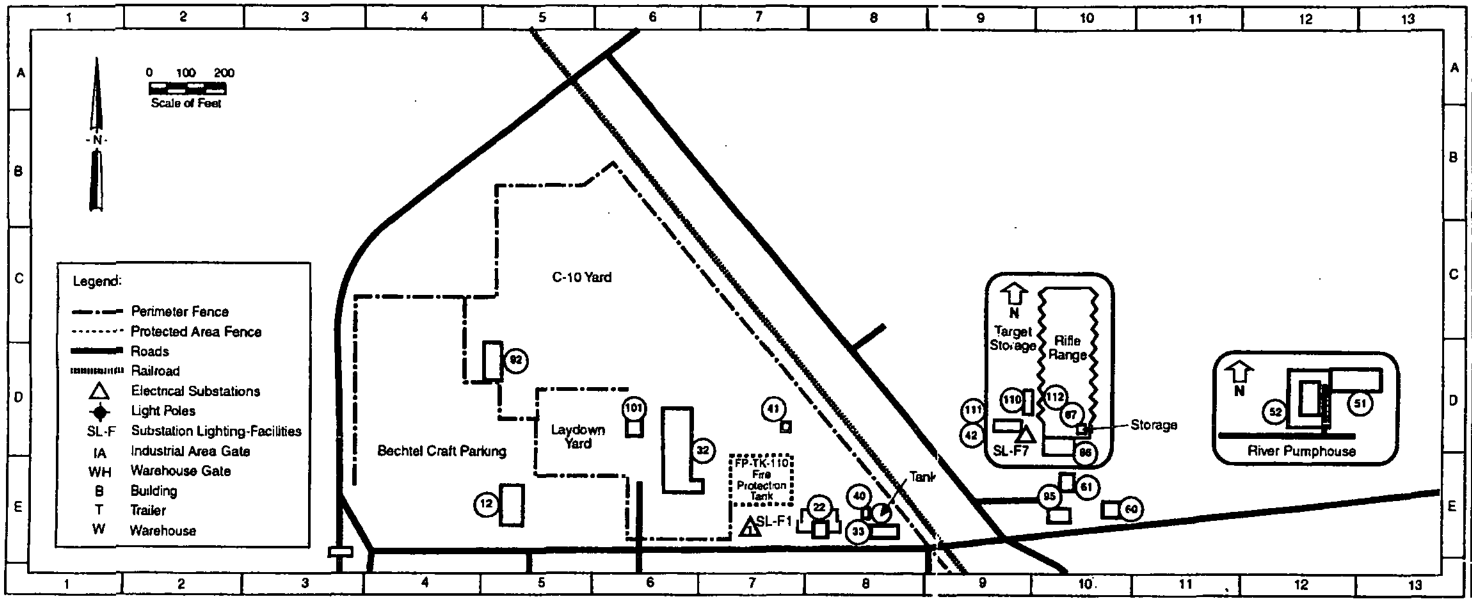


Figure B.1 Site layout of the reference BWR plant facilities - Sheet 1



Number	Loc.	Description
T 12	E-4	Diesel Maintenance
B 22	E-8	Gas Bottle Storage (Hydrogen)
B 32	E-7	Outage Contract Shop/Sheetmetal/ Pipefitters/Electricians/Ironworkers
B 33	E-8	Pumphouse #2
B 40	D-7	Pumphouse #1
B 41	E-9	Storage Facility/Rifle Range
B 42	F-14	River Pumphouse
B 51	E-10	Bioassay Trailer
T 52	E-10	Fire Brigade/Equipment Storage
B 60	E-10	Fire Training Building
B 61	D-10	Firing Range/Security Training Facility
T 86	D-5	Control Booth/Security
T 87	D-6	Testing Laboratory
T 92	D-10	Fire Training Building
B 95	D-10	Latrine
T 101	D-10	Storage Trailer - Security
T 110	D-10	Storage Trailer - Security
T 111		Storage Trailer - Security
T 112		

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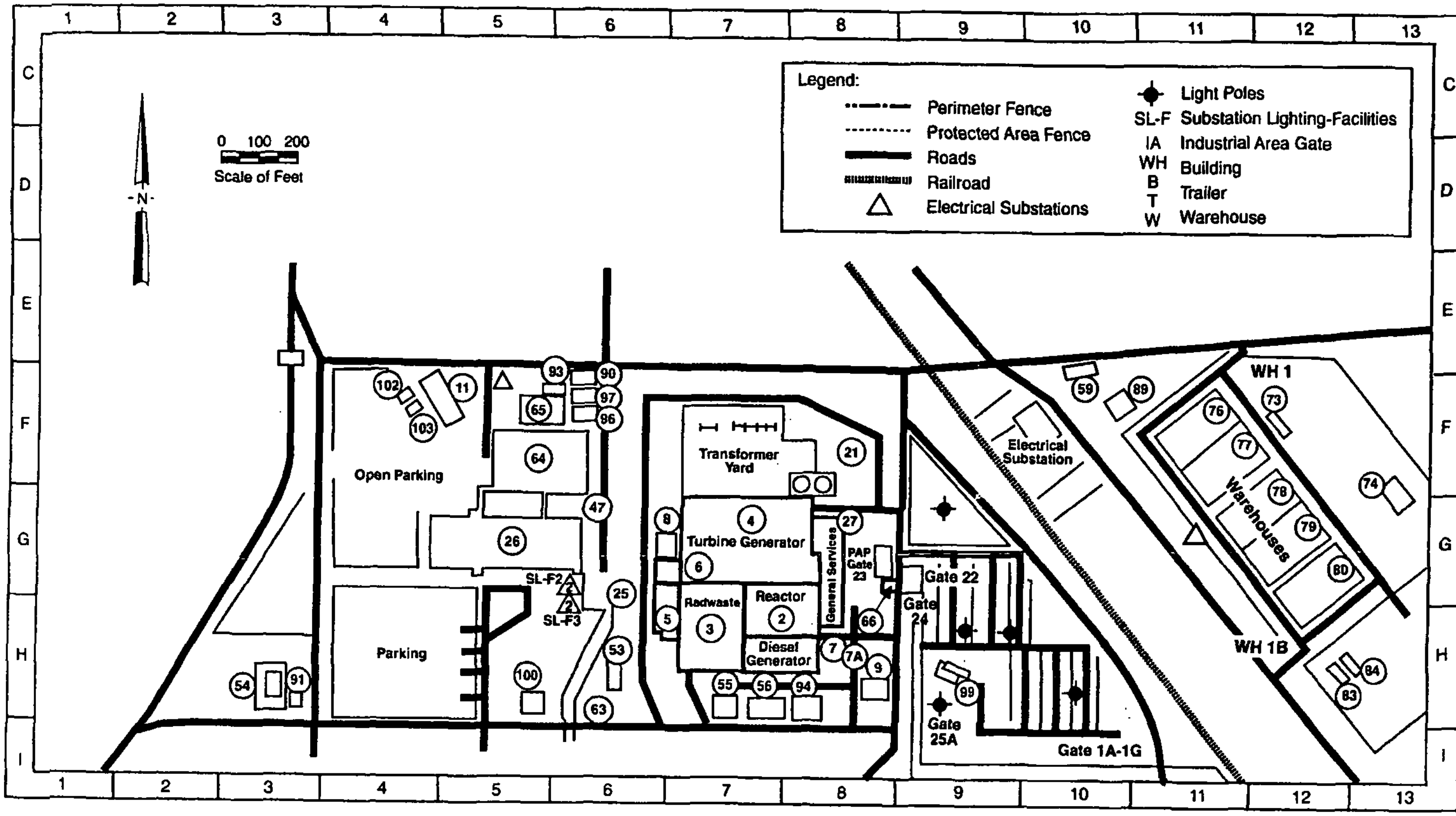
Figure B.2 Site layout of the reference BWR plant facilities, Sheet 2



Number	Loc.	Description
B 2	H-8	Reactor Building
B 3	H-7	Radwaste Building
B 4	G-7	Turbine Generator Building
B 5	H-7	Technical Building
W 6	G-7	Health Physics Access Point
B 7	H-8	Diesel Generator Building
B 7A	H-8	Diesel Fuel Polishing Building
B 8	G-6	R.R.C. Pump ASD Building
B 9	H-8	Plant Office
B 11	F-5	Trailer Maintenance/ Vehicle Maintenance/ Facilities Maintenance
B 21	F-8	Backflow Preventer Building
T 25	H-6	Alternate Access Point (A.A.P.)
B 26	G-5	Plant Engineering Center
B 27	H-8	General Services Building
B 47	G-6	Document Storage Facility
T 53	H-6	Project Managment/ Security Safegaurds
B 54	H-3	Columbia Exchange/ G.T.E.
T 55	I-7	Turbine Rebuild
T 56	I-8	Electrical Maintenance
B 59	F-10	Fire Brigade Training
B 62	G-9	Primary Access Point (P.A.P.)
B 63	I-6	Secondary Guardhouse
B 64	F-5	Document Storage/ Bechtel Site Office/ Records Management/ Microfilm
T 65	F-6	Drafting
T 66	H-9	Guard Booth
B 73	F-12	Gas Bottle Storage (Assorted Gases)
B 74	G-13	Oil and Solvent Storage
W 76	F-12	Warehouse/ Offices
W 77	G-12	Warehouse
W 78	G-12	Warehouse
W 79	H-12	Warehouse
W 80	H-12	Warehouse
B 83	H-13	Storage
B 84	H-13	Storage
T 89	F-11	Materials Management Office
B 90	F-6	Lunchroom
B 91	I-3	Vacant
B 93	F-6	Central Badging/ New Hires/ Visitors (Bechtel)
94	I-8	Plant Q.C.
T 96	F-6	Vacant
T 97	F-6	Safety System Functional Inspection
T 99	H-9	Visitors Center
B 100	I-5	Fitness for Duty Facility
T 102	F-4	Storage
T 103	F-4	Storage

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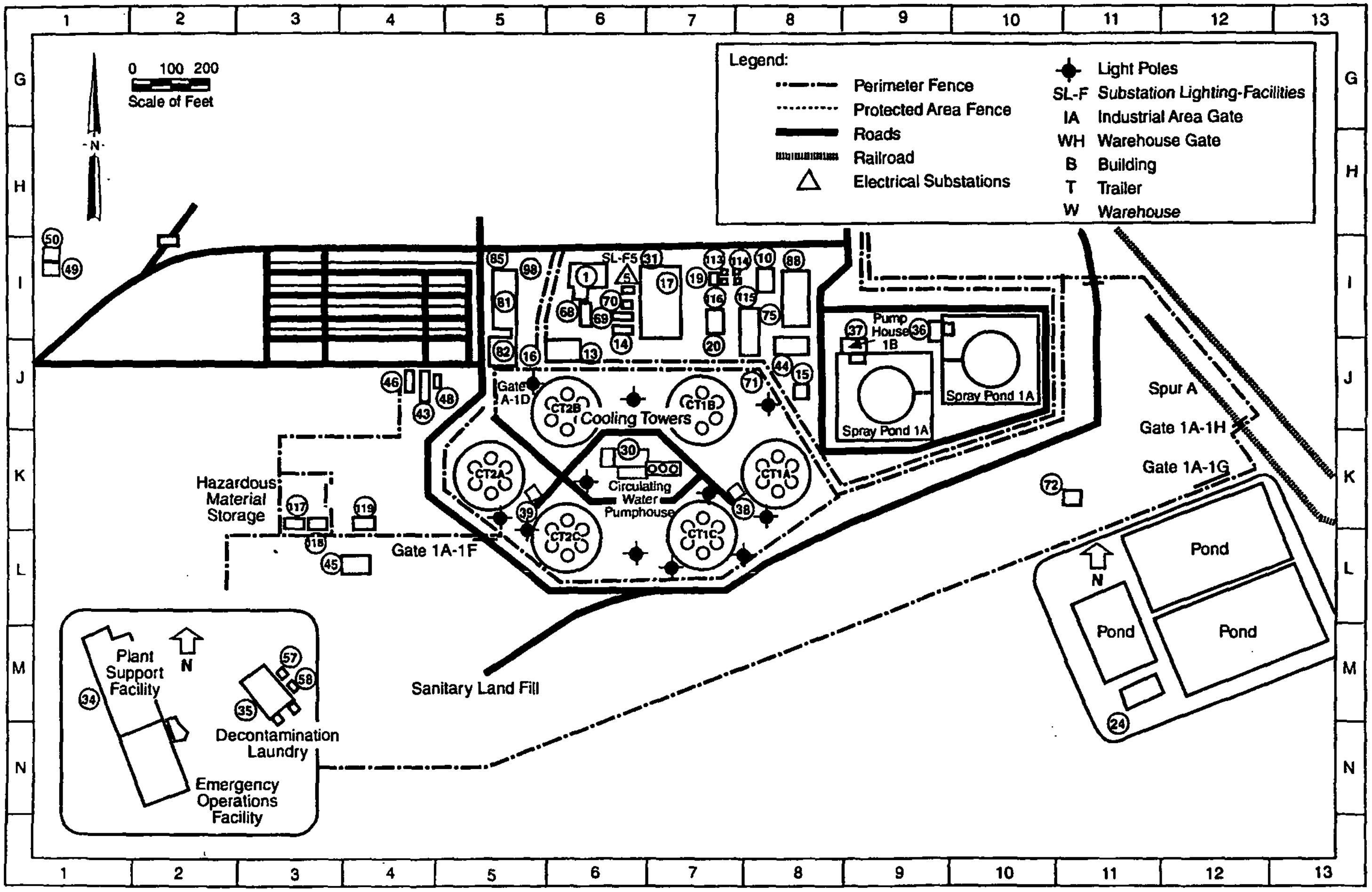
Figure B.3 Site layout of the reference BWR plant facilities, Sheet 3



Number	Loc.	Description
B 1	I-6	N.R.C. / N.D.E.
T 10	I-8	Site Cafeteria
B 13	J-6	Security
T 14	J-6	Lunchroom
B 15	J-8	Laborers Storage
B 16	J-6	Guard Booth
B 17	I-7	Records Management/ All Crafts Lunchroom/ Warehouse
B 19	I-7	Lube Storage/ Paint Shop
T 20	I-7	Lunchroom
B 30	K-7	Circulating Water Pumphouse
T 31	I-7	Latrine
B 34	M-2	Plant Support Facility/ Emergency Operations Facility (P.S.F./ E.O.F.)
B 35	M-3	Decontamination Laundry
B 36	J-10	Standby Service Water Pumphouse 1A
B 37	J-9	Standby Service Water Pumphouse 1B
B 38	K-8	Electrical Building #1
B 39	K-6	Electrical Building #2
T 43	J-4	Portable Switching Facility/ Tel/ Comm
T 44	J-8	Technical Support
T 45	L-4	MSR Tube Bundle Storage
T 46	J-4	Telecommunications
T 48	J-5	Telecommunications
B 49	I-1	Meteorological Tower Building
W 50	I-1	Meteorological Tower Building
B 57	L-3	North Pumphouse-Water Storage Tank
B 58	L-3	South Pumphouse-Water Storage Tank
T 68	I-6	First Aid
T 69	I-6	Lunchroom
T 70	I-7	Latrine
B 71	J-8	Guard Booth
B 72	K-11	Battery Shop/ Maintenance
B 75	J-8	Operations/ Carpenters
B 81	I-5	Bechtel, G.E., Supply System
B 82	J-5	Bechtel Admin./ Mgmt./ Setpoint/ Megawatt Improvement/ Human Resources/Tech. Services Management
B 85	I-5	Vacant
B 88	J-8	Planning/ Scheduling/ CIS-Core Integration Group -I&C- Spare Parts Eng.-Laborers
B 98	I-5	Guard Booth
B 113	I-7	Storage
B 114	I-7	Storage
B 115	I-7	Storage
B 116	I-7	Storage
B 117	L-3	Storage
B 118	L-3	Storage
B 119	L-4	Storage

Figure B.4 Site layout of the reference BWR plant facilities, Sheet 4

Table B.9 Summary of estimated costs for the termination survey

Entity	Cost element	Estimated cost ($)[a]
Licensee	Labor	
	Drafting grid maps to scale	33,904
	Layout of grid networks	213,837[b]
	Radiological survey	557,644[c]
	Report preparation	16,125[d]
	Office materials	2,500[e]
	Services	
	Drilling (auger, coring, restoration)	11,484[f]
	Land surveying	14,138[f]
	Analytical	33,712[g]
	Subtotal, Licensee	883,344
NRC	Confirmation survey	175,000[h]
Total		1,058,344

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Based on Tables B.10 and B.11.
(c) Includes the estimated direct labor costs of $389,038, per diem costs of $151,606 and $17,000 in travel costs.
(d) Based on Table B.14.
(e) Exclusive of instruments and equipment.
(f) Study estimate based on information contained in Reference 17.
(g) Instrumented mobile laboratory (see text for details).
(h) Study estimate based on information provided by industry contacts.

- Using the grid drawings, layout of grid networks (i.e., identification, measurement, painting, and associated paperwork) is completed for all floors, roofs, walls and ceilings, as applicable, according to appropriate survey protocol. No radiation dose is anticipated for these tasks. Work on the upper walls and ceilings may require the use of special equipment, such as manlifts or scaffolding, while work on the floors and roofs is not anticipated to require such equipment. For the purpose of this study, it is assumed that the clean scaffoldings used for previous decommissioning operations have been left in place for layout of grid networks and for subsequent use by the survey contractor.

Table B.10 gives the postulated crew size and cost for layout of grid networks for **affected** and **unaffected** areas[17] that are used in this study. Based upon NUREG/CR-5849, no scans are necessary for unaffected upper walls and ceilings. Only direct measurements (DMs) are taken, at the rate of one DM per 50 m^2 of surface area, with a minimum of 30 DMs per building recommended. Therefore, for the purpose of this study, it is estimated that a crew can accomplish grid marking of these surfaces for subsequent DMs at an average rate of 10 grid locations per hour, during an 8-hour shift.

Table B.10 Staffing and labor rates for survey gridding crews

Pers-hrs/crew-hr	Category	Labor rate ($/pers-hr)	Cost[(a)] ($/crew-hr)
2.0	Laborer	26.37	52.74
1.0	H. P. Tech.	36.82	--[(b)]
0.5	Crew Leader	54.84	27.42
3.5			80.16
Average labor cost, 2-shift operations			$84.17[(c)]

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

Analysis of Work Durations and Available Time

The basic assumptions about lost work time per shift are as follows:

- The crews work 8-hour shifts,
- The crew members take two 15-minute breaks per shift, together with an estimated 15 minutes each break allowed for travel time to and from the work-place, and
- The crew members devote 25 minutes per shift to work-related activities, e.g., the days' activities, industrial safety protection guidance, etc.

Thus, a total of 30 + 30 + 25 = 85 crew-minutes are lost from each 8 hr. shift, leaving a total of 480 - 85 = 395 crew-minutes available for productive work. These non-production time factors are:

[17]**Affected areas** are areas that have potential radioactive contamination (based on plant operating history) or known radioactive contamination (based on past or preliminary radiological surveillance). This would normally include areas where radioactive materials were used or stored, where records indicate spills or other unusual occurrences that could have resulted in spread of contamination, and where radioactive materials were buried. Areas immediately surrounding or adjacent to locations where radioactive materials were used or stored, spilled, or buried are included in this classification because of the potential for inadvertent spread of contamination. **Unaffected areas** are areas not classified as affected. These areas are not expected to contain residual radioactivity, based on a knowledge of site history and previous survey information.[(16)]

$$[\ 1 + (30/395) + (30/395) + (25/395)]\ \times 395 = 480$$
$$[\ 1 + 0.0759 + 0.0759 + 0.0633]\ \times 395 = 480$$

and the non-productive time adjustment factor becomes 480/395 = 1.215.
Worker efficiency while working on scaffolding or manlifts is assumed to be 91% of normal, or a work adjustment factor of 1.1 x work duration.

Total crew-minutes per activity for:

(floors, lower walls, and roofs)	=	estimated work duration x work difficulty adjustment x lost time adjustment
	=	estimated work duration x 1.0 x 1.215
	=	estimated work duration x 1.215
(upper walls and ceilings)	=	estimated work duration x work difficulty adjustment x lost time adjustment
	=	estimated work duration x 1.1 x 1.215
	=	estimated work duration x 1.337

Based on 4 m^2 units of surface area, the gridding operations and associated time durations for the **floors, lower walls, and roofs** are listed below.

- Layout of grid network — 1 min.
- Paperwork — 1 min.
- Move to next location — 1 min.

Crew-minutes for gridding of 4 m^2	(actual duration)	3 min.
Work Difficulty Adjustments:		None required.
Adjusted Work Duration:	1.0 x actual duration	= 3 min.
Non-productive time adjustments:		1.215
Total Work Duration per 4 m^2	1.215 x adjusted duration	= 3.645 min.
Crew-Hours per 4 m^2		0.061 hrs.
Total Labor Cost per 4 m^2	0.061 x \$84.17/crew-hr	= \$5.13

Based on 4 m^2 units of surface area, the gridding operations and associated time durations for the **upper walls and ceilings** are listed below.

- Layout of grid network — 1 min.
- Paperwork — 1 min.
- Move to next location — 1 min.

Crew-minutes for gridding of 4 m^2	(actual duration)	3 min.
Work Difficulty Adjustments:		1.1
Adjusted Work Duration:	1.1 x actual duration	= 3.3 min.
Non-productive time adjustments:		1.215
Total Work Duration per 4 m^2	1.215 x adjusted duration	= 4.01 min.

Crew-Hours per 4 m^2		0.067 hrs.
Total Labor Cost per 4 m^2	0.067 x \$84.17/crew-hr	= \$5.62

It is assumed that the ½-inch-wide paint strips used in gridding will cost \$0.05 per 4 m^2, based upon R. S. Means[2]. Thus, the total gridding cost per 4 m^2 of surface area (floors, lower walls, and roofs) is estimated to be:

$$\$5.13 \text{ (labor)} + \$0.05 \text{ (paint)} = \$5.18/4 \text{ m}^2$$

Similarly, the total gridding cost per 4 m^2 of surface area (upper walls and ceilings is estimated to be:

$$\$5.62 \text{ (labor)} + \$0.05 \text{ (paint)} = \$5.67/4 \text{ m}^2$$

Summary

Unit cost factor (floors, lower walls, and roofs) = \$1.30/m^2
Unit cost factor (upper walls and ceilings) = \$1.42/m^2

As described later in this section, it is postulated that the termination survey is conducted in four survey groups. The estimated schedule and costs for layout of survey grid networks for Group 1, consisting of the power block structures -- Turbine Generator Building, Radwaste and Control Building, Reactor Building, and Primary Containment -- are presented in Table B.10.

Assuming a gridding rate of 65.84 m^2/hour for the floors, lower walls, and roofs, about 527 m^2 can be gridded in one crew-shift (an 8-hour shift). Assuming two crews per shift, two shifts per day, it can be seen from Table B.11 that the duration of the gridding effort for the floors, lower walls, and roofs of the Group 1 structures would be about 23 days, based upon an estimated total surface area of 47,136 m^2.

In a similar manner, assuming a gridding rate of 59.85 m^2/hour for the upper walls and ceilings, about 479 m^2 can be gridded in one crew-shift. Assuming two crews per shift, two shifts per day, it can be seen from Table B.11 that the duration of the gridding effort for the upper walls and ceilings of the Group 1 structures would be about 38 days, based upon an estimated total surface area of 72,334 m^2. The estimated schedule and costs for layout of survey grid networks for Group 2, consisting of the remaining structures on site (approximately 95 unaffected structures of various sizes), are presented in Table B.12.

In NUREG/CR-0672, the termination surveys for DECON were conducted intermittently over a period of about 15-1/2 months, starting with a survey of the Turbine Generator Building and ending with a survey of the support facilities and the Radwaste and Control Building. For this analysis, it is postulated that the surveys are conducted in four survey activity groups, in the order shown in Table B.13.

The rationale for the structures surveys sequences shown in Groups 1 and 2 in Table B.13 is based upon an estimated diminishing order-of-difficulty of conducting the surveys and upon segregation of the site into two classifications of areas - affected and unaffected areas. This scenario will consolidate survey activities and reduce mobilization costs for the instrumented mobile laboratory postulated to be used by the radiological contractor.

Based upon a detailed analysis of the survey areas associated with the thirteen Group 2 structures given in Table B.13, a parametric analysis of the survey requirements for the remaining miscellaneous structures on the reference site -- i.e., approximately 80 buildings, trailers and warehouses shown in Figures B.2, B.3, and B.4 -- resulted in an estimated total survey time of approximately 591 hours for those entities.

Table B.11 Estimated cost and schedule for layout of survey grid networks for the power block (Group 1) structures at the reference BWR[a]

	Floors, lower walls/roofs			Upper walls & ceilings			Totals	
	Area (m^2)	Cost ($)	Time (days)	Area (m^2)	Cost ($)	Time (days)	Cost ($)	Time (days)
Turbine Gen. Bldg.	26,175	34,028	12.417	37,584	53,370	19.616	87,398	32.03
Radwaste/Control Bldg.	10,559	13,727	5.009	14,909	21,171	7.781	34,898	12.79
Reactor Bldg.	9,984	12,979	4.736	15,880	22,550	8.288	35,529	13.02
Containment Vessel	418	544	0.198	3,961	5,625	2.067	6,169	2.07
Totals	47,136	61,278	22.360	72,334	102,716	37.752	163,994	60.11

(a) The number of significant figures shown for area, cost, and time is for computational accuracy and does not imply precision to that many significant figures.

The license termination survey process is labor-intensive, requiring an estimated total of 4,682 hours of direct labor for the termination survey. This number is increased by 20% in this study to account for work breaks, and set-up and calibration checks, etc., resulting in total clock time of about 5,618 hours (see Table B.13).

Two crews, working a single shift, conduct the survey protocol. Each crew is postulated to consist of the staff listed in Table B.14.

The total hours of the two crews equals 136 hours per day and the combined salaries of the crews comes to $5,557.76 per day. Based upon the total hours given in Table B.13 for the 10 survey technicians, the estimated time to complete the termination survey is derived as follows:

5,618 hours/80 hrs per day = ~70 work days
or,
~70 work days/5 work days per week = ~ 14 wks (or, ~ 3.2 months)

Thus, the direct labor cost is: $5,557.76/day x ~70 work days = $389,038. Per diem (7 days/wk) for 17 full-time equivalent (FTE) staff, calculated using Federal Travel Rates of $91/day, amounts to $151,606.

Travel costs (postulated to be about $1,000/person) add another $17,000, resulting in a total labor cost of:

$389,038 + 151,606 + 17,000 = $557,644.

Table B.12 Estimated cost and schedule for layout of survey grid networks for Group 2 structures at the reference BWR[a]

	Floors, lower walls, & roofs[b]			Upper walls & ceilings[c]			Totals	
	Surface area, m^3	Cost, $	Time, days	Surface area, m^3	Cost, $	Time,days	Cost, $	Time, days
Cooling Towers (6)	19,830	2,577.90	0.941	N/A	N/A	N/A	2,577.90	0.941
Plant Engineering Center	15,792	2,052.96	0.749	10,903	1,834.23	0.681	3,887.19	1.430
Spray Pond Complex (2)	12,156	1,580.28	0.578	1,530	258.57	0.096	1,838.85	0.674
Service Building	7,674	997.62	0.364	6,152	1,036.97	0.385	2,034.59	0.749
Diesel Generator Bldg.	4,427	575.51	0.210	3,214	525.22	0.195	1,100.73	0.405
Electric Buildings (2)	1,152	149.76	0.055	684	252.51	0.094	402.27	0.149
Spray Pond Complex Pumphouses (2)	1,140	148.20	0.054	1,204	252.51	0.094	400.71	0.148
Circulating Water Pumphouse	2,988	388.44	0.142	3,526	592.56	0.220	981.00	0.362
Warehouse	4,320	561.60	0.205	2,160	363.61	0.135	925.21	0.340
Guard House	1,440	187.20	0.068	825	252.51	0.094	439.71	0.162
Office Building	1,600	208.00	0.076	800	252.51	0.094	460.51	0.170
Gas Bottle Storage	296	38.48	0.014	140	252.51	0.094	290.99	0.108
Makeup Water Pumphouse	749	97.37	0.036	480	252.51	0.094	349.88	0.130
Misc. Structures[d]	80,091	10,411.83	3.799	69,824	23,741.83	8.815	34,153.66	12.164
Totals	153,655	19,975.15	7.291	101,442	29,868.05	11.091	49,843.20	18.382

(a) The number of significant figures shown for area, cost, and time is for computational accuracy and does not imply precision to that many significant figures.
(b) Cost and time values are based on grid networks laid out on 10% of surface areas.
(c) Based on NUREG/CR-5849, no scans are necessary for unaffected upper walls and ceilings. Only direct measurements (DMs) are taken at the rate of one DM per 50 m^2 of surface area, with a minimum of 30 DMs recommended. Therefore, for the purpose of this study, it is estimated that a crew can accomplish grid marking of these surfaces for subsequent DMs at an average rate of 10 grid locations per hour, during an 8-hour shift.
(d) Layout of grid networks is postulated on approximately 80 unaffected structures of various sizes.

Table B.13 Summary of estimated times for the termination surveys of the structures and sites

	Estimated Survey Time, hours[a]
Group 1 - Structures	
Turbine Generator Building	1,757
Radwaste and Control Building	719
Reactor Building	684
Primary Containment	259
Group 2 - Structures	
Cooling Towers (6)	47
Plant Engineering Center	43
Spray Pond Complex (2)	30
Service Building	22
Diesel Generator Building	13
Electric Buildings (2)	13
Spray Pond Complex Pumphouses (2)	13
Circulating Water Pump House	11
Warehouse	11
Guard House	8
Office Building	8
Gas Bottle Storage	7
Makeup Water Pump House	7
Miscellaneous Structures	591[b]
Group 3 - Site Soil	
Survey Unit 1[c]	309
Survey Unit 2[d]	48
Survey Unit 3[e]	22
Group 4 - Sampling	
Subsurface soil, logging, water	60
Subtotal, hours	4,682[f]
Work Adjustments (20%)	936
Total, hours	5,618

(a) Based on the methodology presented in Reference 16.
(b) Approximately 80 unaffected structures of various sizes are surveyed; see text for details.
(c) A survey in the affected area 10 m beyond the Group 1 structures foundations.
(d) A survey of the plant facilities within the fenced area outside the affected survey area.
(e) A survey over the remainder of the site.
(f) The number of hours shown is for computational accuracy and does not imply precision to that many significant figures.

Table B.14 Staffing and labor rates postulated for survey crews

Person-hrs/crew-hr	Category	Labor rate ($/person-hr)	Cost ($/crew-hr)[a]
1.0	H. P. Leader/Supervisor	70.99	70.99
5.0	H. P./Survey Technician	36.82	184.10
1.0	Laborer[b]	26.37	26.37
0.5	Radiochemist[c]	54.40	27.20
0.5	Sr. Instrument Tech.[c]	54.40	27.20
0.5	Secretary/Clerk	22.99	11.50
8.5			347.36

(a)Based on Table B.1, except as noted otherwise.
(b)Included as part of the survey crew(s) in preparation for accessing the surfaces of interest, as required (e.g., removing wall and floor coverings, including paint and wax or sealer, and opening drains and ducts to enable representative measurements of the contaminant).
(c)Study estimate.

It is further assumed that the radiological contractor uses an instrumented mobile laboratory[18] for the duration of the survey. Assuming a 5-year lifetime, straight-line depreciation, and a 25% utilization factor, the mobile laboratory cost of about $156,500 would be amortized at a rate of about $2,408/week, resulting in a total mobile laboratory cost for the survey of:

$2,408/wk x 14 wks = $33,712

After the site has been surveyed, samples collected and analyzed, the data must be evaluated and presented in a report which documents the findings of the survey. The estimated labor associated with report preparation, shown in Table B.15, is taken from Reference 17, and the labor costs are based upon the DOC costs presented previously in Table B.1.

Table B.15 Estimated labor costs for preparation of termination survey report

Labor category	Person-weeks	$/person-wk	Cost (1993 $)
Engineer	4	2,363.44	9,454
Graphic Arts	1	1,304.10	1,304
Tech. writer/editor	3	1,304.10[a]	3,912
Clerical	2	919.79	1,840
Total	10		16,510

(a) Study estimate

[18]For a large, complex site such as the reference nuclear power plant, the following instrumentation and equipment are anticipated to be required: portable survey instruments, laboratory detectors and electronics, sample analysis systems, sample preparation equipment, and miscellaneous supplies and equipment.[17]

When the licensee has completed the cleanup and documented the radiological condition of the site, the NRC (or its agent) is ready for the certification process. Based upon discussion with NRC staff and upon information provided by industry contacts, it is postulated that this confirmatory/verification survey of selected points will take about one month and is estimated to cost about $175,000. These costs are ultimately paid by the licensee under the NRC's full-cost recovery policy.

According to 10 CFR 50.82, "Application for Termination of License," the Commission will terminate the license if it determines that 1) the decommissioning has been performed in accordance with the approved decommissioning plan and the order authorizing decommissioning; and, 2) the terminal radiation survey and associated documentation demonstrates that the facility and site are suitable for release for unrestricted use.

B.12 Cascading Costs

An extensive literature search revealed that cascading costs[19] have not been given any selective or distinctive consideration in decommissioning cost estimates until recently. This is not surprising because the history of decommissioning cost estimating has been an evolutionary and iterative process. This highly subjective cost category was not considered as a separate entity in NUREG/CR-0672 in 1980. In this reevaluation of the reference BWR study, cascading costs were specifically searched for, but no significant cascading costs were identified. Thus, no cascading costs are included in the cost for decontamination and decommissioning of the reference BWR power station.

B.13 Regulatory Costs

The reference nuclear power plant (WNP-2) has been operating since 1984. WNP-2 is operated by Washington Public Power Supply System (WPPSS). WNP-2 was licensed to operate by the NRC. Federal law gives the NRC sole authority over safety regulation for nuclear power plants. The NRC regulates WNP-2's operation and inspects WNP-2 to ensure that its safety requirements are followed. The NRC uses a combination of inspectors assigned to the site (Resident Inspectors), inspectors that operate out of the NRC's Regional Office in California, and technical specialists from the NRC headquarters in Maryland, to oversee WNP-2's operations.

The Omnibus Budget Reconciliation Act of 1990 (Public Law 101-508) was signed into law November 5, 1990. It requires that the NRC recover 100% of its budget authority from fees assessed against licensees for services rendered, except for the amount appropriated to the NRC from the Nuclear Waste Fund[20] by the Department of Energy (DOE) for FYs 1991 through 1995 for purposes of licensing support to the Nuclear Waste Policy Act (NWPA) activities. Subsection (c)(3) directs the NRC to establish a schedule of annual charges that fairly and equitably allocates the aggregate amount of charges among licensees and, to the maximum extent practicable, reasonably reflects the cost of providing services to such licensees or classes of licensees. The schedule may assess different annual charges for different licensees or classes of licensees based upon the allocation of the NRC's resources among licensees or classes of licensees, so that the licensees who require the greatest expenditures of the NRC's resources will pay the greatest annual charge.

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[19]Cascading costs are defined as those costs associated with the removal of noncontaminated and releasable material in support of the decommissioning process (e.g., if it is considered necessary to remove portions of the top floors or a roof to get at a bottom-floor nuclear component).
[20]The Nuclear Waste Fund (NWF) was established by section 302(c) of the Nuclear Waste Policy Act of 1982, 42 U.S.C. 10222(c). In general, the NWF is for functions or activities necessary or incident to the disposal of high-level radioactive waste or spent nuclear fuel.

With revision to 10 CFR Part 170, *Fees for Facilities and Materials Licenses and Other Regulatory Services Under the Atomic Energy Act of 1954, as Amended*, the NRC has established a policy of full-cost recovery for all NRC licensing services and inspections, including those activities associated with the renewal, dismantling/decommissioning, and termination of reactor licenses. NRC licensees are now expected to provide 100% of the agency's budget through user fees. For example, 10 CFR Part 170.20, as amended, changes the cost per professional staff hour for all full cost fees from $92 per hour for FY 1990 to $115 per hour for FY 1991 (a 25% increase over FY 1990) and to $123 per hour for FY 1992 (a 7% increase over FY 1991).[20] The professional staff-hour rate for FY 1993 is $132 per hour (a 7% increase over FY 1992). The professional staff-hour rates through FY 1995 will be published as a Notice in the Federal Register during the first quarter of each fiscal year.

Title 10 CFR Part 171, *Annual Fee for Power Reactor Operating Licenses*, has been expanded to include additional regulatory costs that are attributable to power reactors other than those costs that have previously been included in the annual fee for operating power reactors. These additional costs include the costs of generic activities that provide a potential future benefit to utilities currently operating power reactors. These generic activities are associated with **reactor decommissioning** (emphasis added), license renewal, standardization, and Construction Permits and Operating License reviews. By modifying Part 171, the base annual fee for an operating power reactor is expected to increase from approximately $1 million to approximately $2.8 million. Exactly what fraction of this annual fee is attributable to the future benefits of generic activities associated with reactor decommissioning was not determined in this study, but the entire annual fee is apparently considered an operations-related cost. Thus, Part 171 fees are not applicable to reactors with possession-only licenses and these fees are not included in the decommissioning cost estimates associated with this report.

Thus, the NRC charges fees in proportion to its cost (i.e., full-cost recovery) for providing individually identifiable services to specific applicants for, and holders of, NRC licenses and approvals.

In addition, WNP-2 operates under a Site Certification Agreement (SCA) issued on May 17, 1972, by the State of Washington Energy Facility Site Evaluation Council (EFSEC). This agreement specifies the conditions of construction and operation of the plant (mostly environmental conditions such as erosion control, monitoring programs, water discharge permits, etc.). EFSEC rules provide a means of funding each state agency for the purpose of 1) compliance monitoring or 2) to provide emergency response services. Funds are paid quarterly to EFSEC, who in turn pays each agency according to an interagency contract agreement. Funding for the state compliance monitoring program is expected to continue following final shutdown of the reference BWR. The estimated cost of this program, together with a summary of estimated regulatory costs, is given in Table B.16.

Funding for emergency response services (i.e., Emergency Management Division, Department of Health, Department of Agriculture, and Washington State Patrol) is not anticipated to continue after final plant shutdown.[21]

B.14 Contingency

Some state utility rate commissions have expressed concerns about the size of the contingency allowances in decommissioning cost estimates. Following is a brief discussion of the nature of a contingency allowance, the variation in the size of the contingency allowance as a function of the degree of knowledge about the project, the size of the allowance generally assigned to decommissioning projects, and the size of the allowance used in this study. The discussion is derived from a report prepared by Northeast Utilities Service Company for decommissioning of the Millstone Units 1 and 2.[21]

[21]Letter, William A. Kiel, Washington Public Power Supply System, to George J. Konzek, Battelle Northwest, transmitting State of Washington regulatory fees, dated October 7, 1993.

Table B.16 Summary of estimated regulatory costs

Entity	Cost Element	Estimated Cost, $ [a]
Licensee	State Compliance Monitoring:[b]	
	• Department of Health	178,000/yr[c]
	• Department of Ecology	2,000/yr[c]
	• Mixed Waste Fee (Ecology)	37,200/yr[d]
	• Department of Wildlife	14,800/yr[d]
	• Fire Protection Services Division	2,000/yr[d]
	• Labor and Industries	5,000/yr[d]
	• EFSEC Staff	5,000/yr[c]
	Resolution & Response to NRC	103,500[c]
	Review of the Decom. Plan	
NRC	Environmental Assessment	23,230[e]
	Decommissioning Plan[f]	230,600
	Regional Inspections during periods of safe storage:	
	• Two General Inspections/yr; 1-wk/inspection by 1 person	11,652[g]
	• One Security Inspection/yr; 3-days by 1 person	3,532[g]
	Resident Inspector (during periods of active decommissioning)[h]	115,300/yr
	Certification Survey[i]	175,000

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) See text for details.
(c) Study estimate based upon engineering judgment and discussions with industry contacts.
(d) Dollar values represent budget amounts for FY-94 (July 1, 1993 to June 30, 1994) for WNP-2.
(e) Based upon discussions with the NRC, this task is estimated to require about 1 man-month (a Period 1 cost).
(f) Discussions with NRC staff suggest that review, evaluation, and approval of a decommissioning plan for power reactors may require about a year (a Period 1 cost).
(g) Includes Federal Travel Rates of $91/day/person.
(h) 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.
(i) Already included in Table B.9, but included here for completeness.

A common element of engineering cost estimates is contingency. The American Association of Cost Engineers (AACE) in its Cost Engineers Notebook[22] defines contingency as:

> The specific provision for unforeseeable elements of cost within the defined project scope; particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events which will increase cost are likely to occur...

The inclusion of contingency in project estimates (construction, deconstruction or otherwise) is an industry-wide practice. In the U.S. Department of Energy Publication *DOE Uniform Contractor Reporting System, Volume 1*, September 1978, Form DOE533P illustrates specific use of project contingency. This form contains an item called "Management Reserve," which is defined as "Amount of Contingency...Available for Use..." As another example, the State of Connecticut's Department of Transportation employs contingency as an integral part of project estimates on budgeted construction jobs. This is done primarily to adequately allow for the "Unforeseeable Elements of Cost" such as:

- unexpected minor changes in scope
- allowance for uncertainties in estimating methods
- allowance for untried process
- unexpected job conditions.

These definitions and examples highlight the importance of including a provision for unforeseeable events that are likely to occur and that will increase costs. Virtually every nuclear and fossil fuel facility owner, architect-engineer, consultant, construction and demolition company in the country (and probably in the world) abides by the aforementioned contingency principle, either expressed or implied. Their experience in their respective fields has led them to recognize the propriety of a contingency provision in cost estimates.[14]

Because of the varying circumstances that make a contingency necessary, a single standard rate is not appropriate for all situations. The rate could be as high as 100% of the cost for an untried process where no engineering is complete and the job is to take place in the distant future. Contingency amounts of 20 to 35% are not uncommon for projects in the proposal stages. Contingency amounts of 5% are not uncommon for projects that have been fully engineered and designed and are entering the construction phase.

Contingency size is time-related. At the initial project stages when small amounts of engineering or design work have been completed, a larger contingency is needed, since more uncertainties exist. As the job approaches completion, lesser contingency amounts are appropriate.

Considering the state of knowledge available for a decommissioning project that is to take place 20 to 30 years in the future, a contingency of 25% is considered by professionals in the field to be a reasonable and realistic value for use in developing estimates of the possible financial exposure that will result from decommissioning. Therefore, a 25% contingency is used in this study for the decommissioning of the reference BWR power station.

B.15 References

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Appendix C

Cost Estimating Computer Program

Appendix C

Cost Estimating Computer Program

The Cost Estimating Computer Program (CECP), 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 CECP 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 CECP 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 CECP.

The CECP uses a data base, but it is not a commercial data base product. For this reason, data may be entered and information extracted only through the CECP program itself. The detailed and summary output files produced by the CECP are in ASCII format and may be accessed and printed using any IBM PC-compatible word processing system.

The CECP main menu is shown in Figure C.1. The first task for the user is to enter certain general data which the CECP will need later in calculating site-specific costs. This is done by selecting 1, 2, and 3 from the main menu. When the user types 1, for example, a portion of the data base is opened up permitting the user to enter labor costs, burial costs, overhead costs, consumables costs, physical constants (e.g., the density of reinforced concrete) and so on. When the user

```
CECP (BWR) MAIN MENU

GENERAL COSTS AND UNIT COST FACTORS
    1  Labor Rates, Burial Costs, Constants
    2  Unit Cost Factors for Decontamination
    3  Unit Cost Factors for Contam. Systems

SITE-SPECIFIC COSTS AND PARAMETERS
    A  Site Information
    B  Decommissioning Schedules
    C  Special Equipment Costs
    D  Building Decontamination Costs
    E  Contaminated System Costs
    F  Nuclear Steam Supply Systems Costs
    G  Staffing Costs
    H  Undistributed Costs
    I  Final Summary Report

*** Press Alt-X to Exit; V,P to View/Print Files ***
```

Figure C.1 CECP main menu

selects 1 for the first time, the default file is loaded into memory. The user may then modify whatever values he or she desires and save this new information to a file. In fact the user may save data to several files during the same session. The next time the user accesses item 1 he or she will have several files to choose from: the default file (which is always available) and the files he or she created. Any of these files may be loaded into memory and used as a basis for creating a new file. Data for items 2 and 3 are entered in the same way. If the user does not supply his or her own files for 1, 2, and 3, the CECP will still have the default files available.

Having entered general information into the data base, the user must now enter site-specific data. Data for menu items A and B are entered first, in either order, then data for items C through H, in any order. For each of the items C through H, the CECP calculates cost and exposure information in detail and then writes the results to appropriate output files. To get a complete site summary, combining data from items A through H, the user selects item I. The overall method for entering data is outlined in Figure C.2.

As an example of the data entry process, Figures C.3a and C.3b show the two input screens the user will see when he or she selects Item E from the main menu. These screens cover inventory information for a single system. The user enters the system name at the top and then enters information for each component in the system which will be removed in the decommissioning process. On Screen I, the user supplies the following information for each component: name, equipment category, disposal category, and quantity. On Screen II, the user supplies the following: volume, weight, radiation dose rate in millirem/hour, and, in the case of tanks, tank diameter and tank height.

The equipment category and disposal category parameters require further explanation. The user selects the equipment category from the following list: Lg Pipe, Sm Pipe, Lg Valve, Sm Valve, Tank, Lg Pump, Sm Pump, Lg HX,

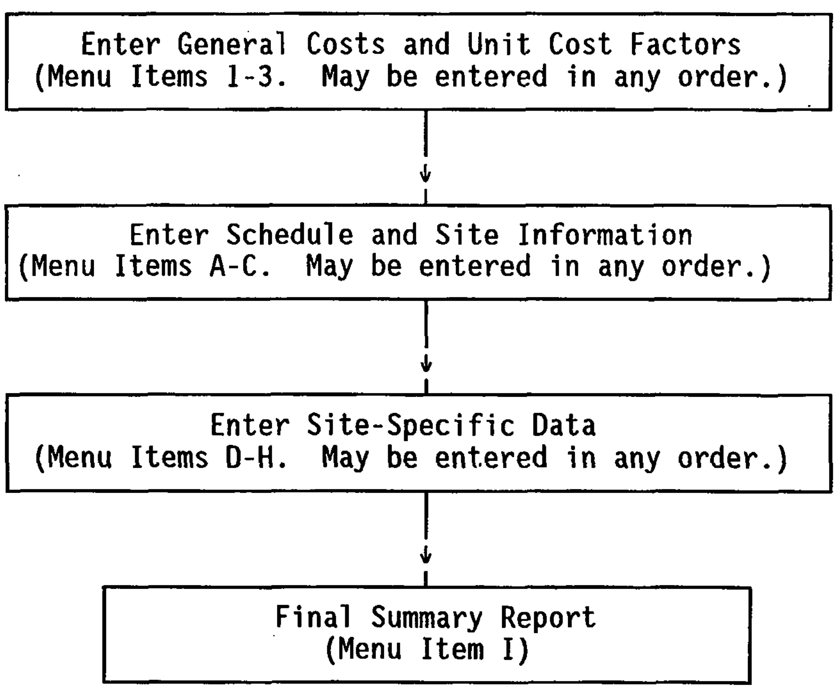

Figure C.2 Flow diagram for entering data into the CECP

MENU ITEM E: CONTAMINATED SYSTEMS COSTS

System Name: Control Rod Drive System

	Component Description	Category	Disposal	Quantity*
1	CRD Blade	Lg Misc.	Sea-Van	460
2	CRD Mechanism	Lg Misc.	Sea-Van	225
3	Direction Control Set	Sm Misc.	Sea-Van	185
4	Scram Valve	Sm Valve	Sea-Van	370
5	Scram Accumulator	Lg Misc.	Sea-Van	210
6	CRD Pump	Lg Pump	Sea-Van	2
7	Scram Discharge Volume	Lg Misc.	Sea-Van	2
8	Pump Suction Filter	Lg Misc.	Sea-Van	2
9	CRD Drive Water Filter	Sm Misc.	Sea-Van	2
10	3/4 Inch Valve	Sm Valve	Sea-Van	2042
11	1 Inch Valve	Sm Valve	Sea-Van	185
12	2 Inch Valve	Sm Valve	Sea-Van	379
13	4 Inch Valve	Lg Valve	Sea-Van	7
14	2 Inch Restricting Orifice	Sm Misc.	Sea-Van	1
15	2 Inch Flow Control Valve	Lg Misc.	Sea-Van	2

*NOTE: For piping, Quantity refers to feet of piping. For other categories, Quantity refers to the number of items of equipment.

Number of records: 20 ‖ File in use: REACTOR1.BD

F1 F2 Select System Change System Name Ctrl F10 Delete System
↑↓→← Home End PgUp PgDn Select Item ↵ Enter Data Insert Item
Ctrl End Insert Item at End Delete Item Save Data to a File Alt-X Quit

Figure C.3a System inventory information (Screen I)

MENU ITEM E: CONTAMINATED SYSTEMS COSTS

System Name: Control Rod Drive System

	Volume (ft3)	Weight (lb)	Diameter*	Length*	Millirem/Hr
1	9	400	N/A	N/A	25
2	6.3	480	N/A	N/A	25
3	0.32	80	N/A	N/A	25
4	1.6	70	1	24	3
5	1.05	140	N/A	N/A	3
6	9	4000	2	6	2
7	7.85	2000	N/A	N/A	2
8	4.7	400	N/A	N/A	80
9	1.6	100	N/A	N/A	80
10	0.2	30	0.75	5	3
11	0.3	50	1	7	3
12	1	90	2	11.5	3
13	3.1	268	4	17	3
14	0.31	60	N/A	N/A	3
15	1	160	N/A	N/A	3

*NOTE: Diameters and lengths of valves and diameters of piping are in inches. Diameters and lengths of other equipment (if applicable) are in feet.

Number of records: 20 ‖ File in use: DEFAULT.BD

F1 F2 Select System Change System Name Ctrl F10 Delete System
↑↓→← Home End PgUp PgDn Select Item ↵ Enter Data Insert Item
Ctrl End Insert Item at End Delete Item Save Data to a File Alt-X Quit

Figure C.3b System inventory information (Screen II)

Sm HX, Lg Elec, Sm Elec, Lg Misc, Sm Misc, Lg Hngr, and Sm Hngr. The last two categories refer to large and small pipe hangers. Lg Pipe refers to piping greater than 2.5 inches in diameter and Sm Pipe is piping 2 inches or less in diameter. The other categories are similarly defined. The equipment category parameter is important because it provides the CECP with the correct unit cost factor to be used in determining removal costs. The disposal category parameter is either Sea-Van (maritime container) or Metal Box (B-25 container). This parameter enables the CECP to apply the proper disposal cost algorithm to each component. Other sizes of maritime containers and special steel boxes are also used by the CECP for the applications shown in Table B.3.

Examples of typical output reports are illustrated in Figures C.4 through C.6, for the reference BWR. Tables C.1 through C.4 are complete summary tables for the four cases discussed in Chapters 3 and 4. Table C.1 is the DECON Case with Hanford selected as the low-level burial site; Table C.2 is the same as C.1 but with the burial site at Barnwell. Tables C.3 and C.4 are the SAFSTOR1 and SAFSTOR2 versions of C.1.

C.1 Plant Inventory

The CECP requires that the user supply information on the inventory of the plant. This includes information on building names and wall surface areas, reactor pressure vessel size, system names, number and sizes of pumps and valves, lengths and diameters of pipes, radiation levels in the vicinity of components, and so on. A discussion of the reference BWR plant inventory, which the CECP uses as the default BWR inventory, is presented below.

C.1.1 Inventories of Process System Components

Inventories of process system components and the inventory of steel piping that will have to be removed during decommissioning are compiled and presented in this section. These inventories are used in the CECP, together with appropriate unit cost factors and algorithms, to estimate the costs of removal, packaging, transport, and disposal for this material. The Reactor Coolant System, because of its complexity and large physical size, is treated separately in detailed analyses. See Chapter 3 for discussions of the RCS pumps and piping; Appendix E for the pressure vessel and internals, and sacrificial shield; and Appendix F for the turbine, turbine condenser, moisture separator reheaters, feedwater heaters, feed pump and turbine assembly, and drywell structural members.

Analysis Approach

Each major system that will require removal during decommissioning is identified and its components listed, together with the physical characteristics of the components where known. The numbers of valves of each size are also given. Valves 3 inches in diameter and smaller will probably be removed while attached to a length of piping and packaged together with its piping. Because of their size and weight, most of the larger and heavier valves will be removed and packaged separate from their associated 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, and is segregated according to size and material, a conservative approach. 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.

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+ **POTENTIALLY RADIOACTIVE SYSTEMS: PHYSICAL CHARACTERISTICS** +
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* **Condensate Demineralizers**

Component Description	Category	Disposal	Qty	Vol(ft^3)	Wgt(lb)	Tanks Dia(ft)	Tanks Hgt(ft)
Filter Demineralizers	Tank	Sea-Van	6	28	11,675	7.00	10.60
Resin Trap (with basket)	Lg Misc.	Sea-Van	6	23	2,100		
Demineralizer Hold Pump	Lg Pump	Sea-Van	6	8	350		
Condensate Backwash Receiving Tank	Tank	Sea-Van	1	59	15,224	12.20	21.10
Sludge Discharge Mixing Pump	Lg Pump	Sea-Van	1	16	924		
Condensate Decant Pump	Lg Pump	Sea-Van	1	16	924		
Condensate Backwash Pump	Lg Pump	Sea-Van	1	16	924		
Condensate Phase Separator Tank	Tank	Sea-Van	2	60	7,001	15.20	17.20
34 Foot Loop Seal	Lg Pipe	Sea-Van	150	0	19		
36 Inch Flow Element	Lg Valve	Sea-Van	1	200	1,800		
20 Inch Butterfly Valve	Lg Valve	Sea-Van	2	65	3,900		
18 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	1	61	3,100		
12 Inch Butterfly Valve	Lg Valve	Sea-Van	6	24	1,120		
12 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	12	24	1,120		
12 Inch Flow Element	Lg Valve	Sea-Van	6	24	1,000		
8 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	22	14	530		
8 Inch Butterfly Valve	Lg Valve	Sea-Van	2	15	530		
8 Inch Air Operated Valve	Lg Valve	Sea-Van	1	15	750		
8 Inch Check Valve	Lg Valve	Sea-Van	5	11	430		
8 Inch Flow Element	Lg Valve	Sea-Van	2	11	400		
6 Inch Air Operated Valve	Lg Valve	Sea-Van	12	7	375		
6 Inch Valve	Lg Valve	Sea-Van	2	7	375		
6 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	21	7	350		
6 Inch Check Valve	Lg Valve	Sea-Van	3	6	270		
4 Inch Air Operated Valve	Lg Valve	Sea-Van	5	3	180		
4 Inch Check Valve	Lg Valve	Sea-Van	1	3	130		
3 Inch Air Operated Valve	Sm Valve	Sea-Van	2	1	130		
3 Inch Air Operated Butterfly Valve	Sm Valve	Sea-Van	6	1	120		
3 Inch Butterfly Valve	Sm Valve	Sea-Van	1	1	120		
3 Inch Restricting Orifice	Sm Valve	Sea-Van	1	1	80		
2 Inch Air Operated Butterfly Valve	Sm Valve	Sea-Van	6	1	55		
2 Inch Butterfly Valve	Sm Valve	Sea-Van	2	1	55		
2 Inch Valve	Sm Valve	Sea-Van	43	1	75		
2 Inch Check Valve	Sm Valve	Sea-Van	5	1	50		
2 Inch Relief Valve	Sm Valve	Sea-Van	3	1	65		
1 1/2 Inch Valve	Sm Valve	Sea-Van	1	1	58		
1 Inch Air Operated Valve	Sm Valve	Sea-Van	13	1	45		
1 Inch Valve	Sm Valve	Sea-Van	18	1	45		
1 Inch Check Valve	Sm Valve	Sea-Van	5	1	30		
1 Inch Relief Valve	Sm Valve	Sea-Van	6	1	42		
Instrument Root Valve (typ. 3/4" globe)	Sm Valve	Sea-Van	149	0	32		

* **Equipment Drain Processing**

Component Description	Category	Disposal	Qty	Vol(ft3)	Wgt(lb)	Tanks Dia(ft)	Tanks Hgt(ft)
Waste Demineralizer	Tank	Sea-Van	1	33	1,998	5.00	10.20
Waste Collector Filter	Lg Misc.	Sea-Van	1	138	3,991		
Waste Filter Hold Pump	Lg Pump	Sea-Van	1	9	700		
Waste Collector Tank and Eductor	Tank	Sea-Van	1	66	22,530	16.20	18.10
Waste Collector Pump	Lg Pump	Sea-Van	1	20	625		
Spent Resin Tank	Tank	Sea-Van	1	18	1,448	5.90	5.90

Figure C.4a. Partial CECP output file for contaminated systems, Example 1

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+ POTENTIALLY RADIOACTIVE SYSTEMS: CREW-HOURS, PERSON-HOURS, ETC. +

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* **Condensate Demineralizers**

Component Description	Category	Disposal	Qty	Crew-Hrs	Pers-Hrs	Exp Hrs	Pers-Rem	Curies
Filter Demineralizers	Tank	Sea-Van	6	100.0	549.7	349.3	0.0	0.615
Resin Trap (with basket)	Lg Misc.	Sea-Van	6	18.4	73.7	46.8	0.0	0.000
Demineralizer Hold Pump	Lg Pump	Sea-Van	6	18.4	73.7	46.8	0.0	0.071
Condensate Backwash Receiving Tank	Tank	Sea-Van	1	29.8	164.0	104.2	0.0	0.344
Sludge Discharge Mixing Pump	Lg Pump	Sea-Van	1	3.1	12.3	7.8	0.0	0.019
Condensate Decant Pump	Lg Pump	Sea-Van	1	3.1	12.3	7.8	0.0	0.019
Condensate Backwash Pump	Lg Pump	Sea-Van	1	3.1	12.3	7.8	0.0	0.019
Condensate Phase Separator Tank	Tank	Sea-Van	2	67.0	368.6	234.2	0.0	0.782
34 Foot Loop Seal	Lg Pipe	Sea-Van	150	29.7	163.2	103.7	0.0	0.079
36 Inch Flow Element	Lg Valve	Sea-Van	1	3.0	16.3	10.4	0.0	0.033
20 Inch Butterfly Valve	Lg Valve	Sea-Van	2	5.9	32.6	20.7	0.0	0.019
18 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	1	3.0	16.3	10.4	0.0	0.008
12 Inch Butterfly Valve	Lg Valve	Sea-Van	6	17.8	97.9	62.2	0.0	0.023
12 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	12	35.6	195.8	124.4	0.0	0.045
12 Inch Flow Element	Lg Valve	Sea-Van	6	17.8	97.9	62.2	0.0	0.023
8 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	22	65.3	359.0	228.1	0.0	0.042
8 Inch Butterfly Valve	Lg Valve	Sea-Van	2	5.9	32.6	20.7	0.0	0.004
8 Inch Air Operated Valve	Lg Valve	Sea-Van	1	3.0	16.3	10.4	0.0	0.002
8 Inch Check Valve	Lg Valve	Sea-Van	5	14.8	81.6	51.8	0.0	0.010
8 Inch Flow Element	Lg Valve	Sea-Van	2	5.9	32.6	20.7	0.0	0.004
6 Inch Air Operated Valve	Lg Valve	Sea-Van	12	35.6	195.8	124.4	0.0	0.015
6 Inch Valve	Lg Valve	Sea-Van	2	5.9	32.6	20.7	0.0	0.002
6 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	21	62.3	342.6	217.7	0.0	0.025
6 Inch Check Valve	Lg Valve	Sea-Van	3	8.9	48.9	31.1	0.0	0.004
4 Inch Air Operated Valve	Lg Valve	Sea-Van	5	14.8	81.6	51.8	0.0	0.003
4 Inch Check Valve	Lg Valve	Sea-Van	1	3.0	16.3	10.4	0.0	0.001
3 Inch Air Operated Valve	Sm Valve	Sea-Van	2	0.0	0.0	0.0	0.0	0.001
3 Inch Air Operated Butterfly Valve	Sm Valve	Sea-Van	6	0.0	0.0	0.0	0.0	0.002
3 Inch Butterfly Valve	Sm Valve	Sea-Van	1	0.0	0.0	0.0	0.0	0.000
3 Inch Restricting Orifice	Sm Valve	Sea-Van	1	0.0	0.0	0.0	0.0	0.000
2 Inch Air Operated Butterfly Valve	Sm Valve	Sea-Van	6	0.0	0.0	0.0	0.0	0.001
2 Inch Butterfly Valve	Sm Valve	Sea-Van	2	0.0	0.0	0.0	0.0	0.000
2 Inch Valve	Sm Valve	Sea-Van	43	0.0	0.0	0.0	0.0	0.008
2 Inch Check Valve	Sm Valve	Sea-Van	5	0.0	0.0	0.0	0.0	0.001
2 Inch Relief Valve	Sm Valve	Sea-Van	3	0.0	0.0	0.0	0.0	0.001
1 1/2 Inch Valve	Sm Valve	Sea-Van	1	0.0	0.0	0.0	0.0	0.000
1 Inch Air Operated Valve	Sm Valve	Sea-Van	13	0.0	0.0	0.0	0.0	0.001
1 Inch Valve	Sm Valve	Sea-Van	18	0.0	0.0	0.0	0.0	0.001
1 Inch Check Valve	Sm Valve	Sea-Van	5	0.0	0.0	0.0	0.0	0.000
1 Inch Relief Valve	Sm Valve	Sea-Van	6	0.0	0.0	0.0	0.0	0.000
Instrument Root Valve (typ. 3/4" globe)	Sm Valve	Sea-Van	149	0.0	0.0	0.0	0.0	0.005
				581.0	3,126.00	1,987.0	0.0	2.232

* **Equipment Drain Processing**

Component Description	Category	Disposal	Qty	Crew-Hrs	Pers-Hrs	Exp Hrs	Pers-Rem	Curies
Waste Demineralizer	Tank	Sea-Van	1	14.2	78.2	49.7	0.2	0.066
Waste Collector Filter	Lg Misc.	Sea-Van	1	3.1	12.3	7.8	0.0	0.000
Waste Filter Hold Pump	Lg Pump	Sea-Van	1	3.1	12.3	7.8	0.0	0.014
Waste Collector Tank and Eductor	Tank	Sea-Van	1	35.0	192.4	122.2	0.6	0.441
Waste Collector Pump	Lg Pump	Sea-Van	1	3.1	12.3	7.8	0.0	0.023

Figure C.4b Partial CECP output file for contaminated systems, Example 2

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+ POTENTIALLY RADIOACTIVE SYSTEMS: REMOVAL, TRANSPORTATION, DISPOSAL COSTS. +
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* Condensate Demineralizers

Component Description	Category	Disposal	Qty	Removal	Container	Transport	Disposal	Tot. Costs
Filter Demineralizers	Tank	Sea-Van	6	19,218	9,661	353	81,115	110,347
Resin Trap (with basket)	Lg Misc.	Sea-Van	6	2,571	1,738	63	14,590	18,963
Demineralizer Hold Pump	Lg Pump	Sea-Van	6	2,540	290	11	2,432	5,272
Condensate Backwash Receiving Tank	Tank	Sea-Van	1	5,791	2,100	77	17,629	25,596
Sludge Discharge Mixing Pump	Lg Pump	Sea-Van	1	427	127	5	1,070	1,629
Condensate Decant Pump	Lg Pump	Sea-Van	1	427	127	5	1,070	1,629
Condensate Backwash Pump	Lg Pump	Sea-Van	1	427	127	5	1,070	1,629
Condensate Phase Separator Tank	Tank	Sea-Van	2	12,995	1,931	70	16,214	31,211
34 Foot Loop Seal	Lg Pipe	Sea-Van	150	5,715	392	14	3,480	9,602
36 Inch Flow Element	Lg Valve	Sea-Van	1	572	248	9	2,084	2,913
20 Inch Butterfly Valve	Lg Valve	Sea-Van	2	1,143	1,076	39	9,032	11,290
18 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	1	572	428	16	3,590	4,604
12 Inch Butterfly Valve	Lg Valve	Sea-Van	6	3,429	927	34	7,782	12,171
12 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	12	6,859	1,854	68	15,563	24,343
12 Inch Flow Element	Lg Valve	Sea-Van	6	3,429	828	30	6,948	11,235
8 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	22	12,574	1,608	59	13,502	27,743
8 Inch Butterfly Valve	Lg Valve	Sea-Van	2	1,143	146	5	1,227	2,522
8 Inch Air Operated Valve	Lg Valve	Sea-Van	1	572	103	4	868	1,547
8 Inch Check Valve	Lg Valve	Sea-Van	5	2,858	297	11	2,490	5,655
8 Inch Flow Element	Lg Valve	Sea-Van	2	1,143	110	4	926	2,184
6 Inch Air Operated Valve	Lg Valve	Sea-Van	12	6,859	621	23	5,211	12,713
6 Inch Valve	Lg Valve	Sea-Van	2	1,143	103	4	868	2,119
6 Inch Air Operated Butterfly Valve	Lg Valve	Sea-Van	21	12,002	1,014	37	8,511	21,564
6 Inch Check Valve	Lg Valve	Sea-Van	3	1,715	112	4	938	2,768
4 Inch Air Operated Valve	Lg Valve	Sea-Van	5	2,858	124	5	1,042	4,029
4 Inch Check Valve	Lg Valve	Sea-Van	1	572	18	1	151	741
3 Inch Air Operated Valve	Sm Valve	Sea-Van	2	0	36	1	301	338
3 Inch Air Operated Butterfly Valve	Sm Valve	Sea-Van	6	0	99	4	834	937
3 Inch Butterfly Valve	Sm Valve	Sea-Van	1	0	17	1	139	156
3 Inch Restricting Orifice	Sm Valve	Sea-Van	1	0	11	0	93	104
2 Inch Air Operated Butterfly Valve	Sm Valve	Sea-Van	6	0	46	2	382	429
2 Inch Butterfly Valve	Sm Valve	Sea-Van	2	0	15	1	127	143
2 Inch Valve	Sm Valve	Sea-Van	43	0	445	16	3,734	4,195
2 Inch Check Valve	Sm Valve	Sea-Van	5	0	34	1	289	325
2 Inch Relief Valve	Sm Valve	Sea-Van	3	0	27	1	226	254
1 1/2 Inch Valve	Sm Valve	Sea-Van	1	0	8	0	67	75
1 Inch Air Operated Valve	Sm Valve	Sea-Van	13	0	81	3	677	761
1 Inch Valve	Sm Valve	Sea-Van	18	0	112	4	938	1,054
1 Inch Check Valve	Sm Valve	Sea-Van	5	0	21	1	174	195
1 Inch Relief Valve	Sm Valve	Sea-Van	6	0	35	1	292	328
Instrument Root Valve (typ. 3/4" globe)	Sm Valve	Sea-Van	149	0	658	24	5,521	6,203
				109,552	27,752	1,013	233,198	371,515

* Equipment Drain Processing

Component Description	Category	Disposal	Qty	Removal	Container	Transport	Disposal	Tot. Costs
Waste Demineralizer	Tank	Sea-Van	1	2,728	276	10	2,314	5,328
Waste Collector Filter	Lg Misc.	Sea-Van	1	452	550	20	4,621	5,644
Waste Filter Hold Pump	Lg Pump	Sea-Van	1	424	97	4	811	1,335
Waste Collector Tank and Eductor	Tank	Sea-Van	1	6,792	3,107	113	26,089	36,102

Figure C.4c Partial CECP output file for contaminated systems, Example 3

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+ BUILDING COMPONENTS TO BE DECONTAMINATED +
+++++++++++++++++++++++++++++++
* Reactor Bldg

Component Description	Activity	Length (ft.)	Width (ft.)	Depth (in.)	Orientation
Drywell Head Laydown	Conc Wash	45.0	45.0	N/A	Floor
Drywell Head Laydown	Conc Rmvl	31.8	31.8	1.000	Floor
RPV Head Laydown	Conc Wash	27.0	27.0	N/A	Floor
RPV Head Laydown	Conc Rmvl	27.0	27.0	1.000	Floor
Space Frame	Conc Wash	17.3	17.3	N/A	Floor
Refueling Floor Cavities	Mtl Rmvl	134.2	134.2	0.250	Floor
Refuel Floor Alcove Pit	Conc Wash	23.7	23.7	N/A	Floor
RHR "A" Heat Exchanger Rm	Conc Wash	23.5	23.5	N/A	Floor
RHR "A" Heat Exchanger Rm	Conc Rmvl	16.6	16.6	1.000	Floor
RHR "B" Heat Exchanger Rm	Conc Wash	23.5	23.5	N/A	Floor
RHR "B" Heat Exchanger Rm	Conc Rmvl	16.6	16.6	1.000	Floor
Fuel Pool Cooling HX/Pump	Conc Wash	27.1	27.1	N/A	Floor
Fuel Pool Cooling HX/Pump	Conc Rmvl	24.2	24.2	1.000	Floor
RWCU Heat Exchanger Rm	Conc Wash	39.7	39.7	N/A	Floor
RWCU Heat Exchanger Rm	Conc Rmvl	21.7	21.7	1.000	Floor
Standby Liquid Control	Conc Wash	25.1	25.1	N/A	Floor
Instrument Rack Trough (9)	Conc Wash	11.7	11.7	N/A	Floor
RWCU Pump Rm	Conc Wash	17.5	17.5	N/A	Floor
RWCU Pump Rm	Conc Rmvl	17.5	17.5	1.000	Floor
CRD HCU Area East	Conc Wash	33.7	33.7	N/A	Floor
CRD HCU Area East	Conc Rmvl	15.1	15.1	1.000	Floor
CRD HCU Area West	Conc Wash	32.0	32.0	N/A	Floor
CRD HCU Area West	Conc Rmvl	14.3	14.3	1.000	Floor
Scram Discharge Volume Area	Conc Wash	14.4	14.4	N/A	Floor
Recirc HPU Area (2)	Conc Wash	12.6	12.6	N/A	Floor
CRD Repair Room	Conc Wash	31.4	31.4	N/A	Floor
CRD Repair Room	Conc Rmvl	31.4	31.4	1.000	Floor
TIP Room	Conc Wash	15.0	15.0	N/A	Floor
TIP Room	Conc Rmvl	11.6	11.6	1.000	Floor
Main Steam Tunnel	Conc Wash	24.4	24.4	N/A	Floor
Main Steam Tunnel	Conc Rmvl	24.4	24.4	1.000	Floor
Drywell Floor	Conc Wash	63.6	63.6	N/A	Floor
Drywell Floor	Conc Rmvl	63.6	63.6	1.000	Floor
Under Vessel CRD Area	Conc Wash	15.9	15.9	N/A	Floor
Under Vessel CRD Area	Conc Rmvl	15.9	15.9	1.000	Floor
Instrument Racks (8 racks)	Conc Wash	7.5	7.5	N/A	Floor
North Valve Room	Conc Wash	14.5	14.5	N/A	Floor
South Valve Room	Conc Wash	15.8	15.8	N/A	Floor
Wetwell Floor	Conc Wash	70.8	70.8	N/A	Floor
Wetwell Floor	Conc Rmvl	70.8	70.8	1.000	Floor
Control Rod Drive Pump Rm	Conc Wash	39.8	39.8	N/A	Floor
Control Rod Drive Pump Rm	Conc Wash	30.8	30.8	N/A	Floor
RCIC Pump Rm	Conc Wash	29.2	29.2	N/A	Floor
RCIC Pump Rm	Conc Rmvl	16.0	16.0	1.000	Floor
RHR "A" Pump Room	Conc Wash	34.6	34.6	N/A	Floor
RHR "A" Pump Room	Conc Rmvl	10.9	10.9	1.000	Floor
RHR "B" Pump Room	Conc Wash	40.0	40.0	N/A	Floor
RHR "B" Pump Room	Conc Rmvl	12.6	12.6	1.000	Floor
RHC "C" Pump Room	Conc Wash	30.4	30.4	N/A	Floor
LPCS Pump Room	Conc Wash	24.2	24.2	N/A	Floor
HPCS Pump Room	Conc Wash	24.2	24.2	N/A	Floor

Figure C.5a Partial CECP output file for building decontamination, Example 1

++++++++++++++++++++++++++++++++++
+ BUILDING DECONTAMINATION: TIMES AND EXPOSURES +
++++++++++++++++++++++++++++++++++
* Reactor Bldg

Component Description	Activity	Time (hours)	Pers-hours	Exposure Pers-hours	Man Rem
Drywell Head Laydown	Conc Wash	8.4	33.7	8.4	0.01
Drywell Head Laydown	Conc Rmvl	121.3	424.7	242.7	0.40
RPV Head Laydown	Conc Wash	3.0	12.1	3.0	0.00
RPV Head Laydown	Conc Rmvl	87.4	305.7	174.7	0.29
Space Frame	Conc Wash	1.2	5.0	1.2	0.00
Refueling Floor Cavities	Mtl Rmvl	54.1	297.3	188.9	0.31
Refuel Floor Alcove Pit	Conc Wash	2.3	9.3	2.3	0.00
RHR "A" Heat Exchanger Rm	Conc Wash	2.3	9.2	2.3	0.00
RHR "A" Heat Exchanger Rm	Conc Rmvl	33.0	115.5	66.0	0.11
RHR "B" Heat Exchanger Rm	Conc Wash	2.3	9.2	2.3	0.00
RHR "B" Heat Exchanger Rm	Conc Rmvl	33.0	115.5	66.0	0.11
Fuel Pool Cooling HX/Pump	Conc Wash	3.1	12.3	3.1	0.01
Fuel Pool Cooling HX/Pump	Conc Rmvl	70.6	247.0	141.1	0.23
RWCU Heat Exchanger Rm	Conc Wash	6.6	26.3	6.6	0.01
RWCU Heat Exchanger Rm	Conc Rmvl	56.8	198.7	113.5	0.19
Standby Liquid Control	Conc Wash	2.6	10.5	2.6	0.00
Instrument Rack Trough (9)	Conc Wash	0.6	2.3	0.6	0.00
RWCU Pump Rm	Conc Wash	1.3	5.1	1.3	0.00
RWCU Pump Rm	Conc Rmvl	37.0	129.4	73.9	0.12
CRD HCU Area East	Conc Wash	4.7	18.9	4.7	0.01
CRD HCU Area East	Conc Rmvl	27.3	95.4	54.5	0.09
CRD HCU Area West	Conc Wash	4.3	17.1	4.3	0.01
CRD HCU Area West	Conc Rmvl	24.6	86.1	49.2	0.08
Scram Discharge Volume Area	Conc Wash	0.9	3.5	0.9	0.00
Recirc HPU Area (2)	Conc Wash	0.7	2.7	0.7	0.00
CRD Repair Room	Conc Wash	4.1	16.4	4.1	0.01
CRD Repair Room	Conc Rmvl	118.1	413.3	236.2	0.39
TIP Room	Conc Wash	0.9	3.8	0.9	0.00
TIP Room	Conc Rmvl	16.2	56.6	32.4	0.05
Main Steam Tunnel	Conc Wash	2.5	9.9	2.5	0.00
Main Steam Tunnel	Conc Rmvl	71.3	249.4	142.5	0.23
Drywell Floor	Conc Wash	16.9	67.5	16.9	0.03
Drywell Floor	Conc Rmvl	486.0	1,701.0	972.0	1.59
Under Vessel CRD Area	Conc Wash	1.1	4.2	1.1	0.00
Under Vessel CRD Area	Conc Rmvl	30.5	106.7	61.0	0.10
Instrument Racks (8 racks)	Conc Wash	0.2	0.9	0.2	0.00
North Valve Room	Conc Wash	0.9	3.5	0.9	0.00
South Valve Room	Conc Wash	1.0	4.2	1.0	0.00
Wetwell Floor	Conc Wash	20.9	83.5	20.9	0.03
Wetwell Floor	Conc Rmvl	601.3	2,104.7	1,202.7	1.97
Control Rod Drive Pump Rm	Conc Wash	6.6	26.4	6.6	0.01
Control Rod Drive Pump Rm	Conc Wash	4.0	15.9	4.0	0.01
RCIC Pump Rm	Conc Wash	3.5	14.2	3.5	0.01
RCIC Pump Rm	Conc Rmvl	30.6	107.1	61.2	0.10
RHR "A" Pump Room	Conc Wash	5.0	19.9	5.0	0.01
RHR "A" Pump Room	Conc Rmvl	14.4	50.4	28.8	0.05
RHR "B" Pump Room	Conc Wash	6.7	26.7	6.7	0.01
RHR "B" Pump Room	Conc Rmvl	19.2	67.2	38.4	0.06
RHC "C" Pump Room	Conc Wash	3.9	15.4	3.9	0.01
LPCS Pump Room	Conc Wash	2.5	9.8	2.5	0.00
HPCS Pump Room	Conc Wash	2.5	9.8	2.5	0.00

Figure C.5b Partial CECP output file for building decontamination, Example 2

+++++++++++++++++++++++++
+ BUILDING DECONTAMINATION: COSTS +
+++++++++++++++++++++++++
* Reactor Bldg

Component Description	Activity	Removal	Container	Transport	Disposal
Drywell Head Laydown	Conc Wash	1,163	0	0	2,527
Drywell Head Laydown	Conc Rmvl	17,278	545	60	7,258
RPV Head Laydown	Conc Wash	419	0	0	910
RPV Head Laydown	Conc Rmvl	12,437	392	43	5,224
Space Frame	Conc Wash	173	0	0	375
Refueling Floor Cavities	Mtl Rmvl	10,383	25,889	945	217,364
Refuel Floor Alcove Pit	Conc Wash	322	0	0	700
RHR "A" Heat Exchanger Rm	Conc Wash	316	0	0	687
RHR "A" Heat Exchanger Rm	Conc Rmvl	4,697	148	16	1,973
RHR "B" Heat Exchanger Rm	Conc Wash	316	0	0	687
RHR "B" Heat Exchanger Rm	Conc Rmvl	4,697	148	16	1,973
Fuel Pool Cooling HX/Pump	Conc Wash	423	0	0	920
Fuel Pool Cooling HX/Pump	Conc Rmvl	10,048	317	35	4,221
RWCU Heat Exchanger Rm	Conc Wash	906	0	0	1,969
RWCU Heat Exchanger Rm	Conc Rmvl	8,083	255	28	3,395
Standby Liquid Control	Conc Wash	362	0	0	786
Instrument Rack Trough (9)	Conc Wash	79	0	0	173
RWCU Pump Rm	Conc Wash	177	0	0	385
RWCU Pump Rm	Conc Rmvl	5,263	166	18	2,211
CRD HCU Area East	Conc Wash	652	0	0	1,417
CRD HCU Area East	Conc Rmvl	3,880	122	13	1,630
CRD HCU Area West	Conc Wash	590	0	0	1,282
CRD HCU Area West	Conc Rmvl	3,504	111	12	1,472
Scram Discharge Volume Area	Conc Wash	120	0	0	260
Recirc HPU Area (2)	Conc Wash	92	0	0	200
CRD Repair Room	Conc Wash	566	0	0	1,230
CRD Repair Room	Conc Rmvl	16,814	530	58	7,063
TIP Room	Conc Wash	129	0	0	281
TIP Room	Conc Rmvl	2,303	73	8	967
Main Steam Tunnel	Conc Wash	342	0	0	742
Main Steam Tunnel	Conc Rmvl	10,147	320	35	4,263
Drywell Floor	Conc Wash	2,329	0	0	5,063
Drywell Floor	Conc Rmvl	69,200	2,183	239	29,068
Under Vessel CRD Area	Conc Wash	146	0	0	318
Under Vessel CRD Area	Conc Rmvl	4,341	137	15	1,824
Instrument Racks (8 racks)	Conc Wash	32	0	0	70
North Valve Room	Conc Wash	121	0	0	262
South Valve Room	Conc Wash	144	0	0	312
Wetwell Floor	Conc Wash	2,882	0	0	6,264
Wetwell Floor	Conc Rmvl	85,623	2,701	295	35,967
Control Rod Drive Pump Rm	Conc Wash	911	0	0	1,980
Control Rod Drive Pump Rm	Conc Wash	547	0	0	1,189
RCIC Pump Rm	Conc Wash	489	0	0	1,062
RCIC Pump Rm	Conc Rmvl	4,358	137	15	1,830
RHR "A" Pump Room	Conc Wash	688	0	0	1,495
RHR "A" Pump Room	Conc Rmvl	2,049	65	7	861
RHR "B" Pump Room	Conc Wash	920	0	0	1,999
RHR "B" Pump Room	Conc Rmvl	2,734	86	9	1,149
RHC "C" Pump Room	Conc Wash	531	0	0	1,155
LPCS Pump Room	Conc Wash	338	0	0	735
HPCS Pump Room	Conc Wash	338	0	0	735

Figure C.5c Partial CECP output file for building decontamination, Example 3

++
+ SUMMARY OF BUILDING DECONTAMINATION COSTS (ALL COSTS IN DOLLARS) +
++

* Reactor Bldg

Concrete Washing--

Surface Area:	30,537 ft2
Decon Costs:	17,562
Crew Hours:	127
Pers-Hours:	509
Pers-Rem:	0.21

Metal Washing--

Surface Area:	33,906 ft2
Decon Costs:	22,497
Crew Hours:	163
Pers-Hours:	653
Pers-Rem:	0.27

Concrete Removal--

Surface Area:	15,653 ft2
Weight Removed:	187,840 lb
Removal Costs:	267,457
Container Costs:	8,437
Shipping Costs:	922
Burial Costs:	112,348
Burial Volume:	2,317 ft3
Number of Drums:	313.07
Crew Hours:	1,878
Pers-Hours:	6,574
Pers-Rem:	6.15

Metal Removal--

Surface Area:	51,926 ft2
Weight Removed:	540,900 lb
Removal Costs:	31,769
Container Costs:	74,599
Shipping Costs:	2,723
Burial Costs:	626,342
Burial Volume:	9,616 ft3
Number of Vans:	15.02
Crew Hours:	165
Pers-Hours:	910
Pers-Rem:	0.95

Figure C.5d Partial CECP output file for building decontamination, Example 4

++
COSTS (IN DOLLARS) FOR REACTOR PRESSURE VESSEL AND INTERNALS
++

RPV Internal Components	Labor	Containers	Transport	Disposal	Total
Equipment Setup, Testing, Removal	77,974				77,974
Core Shroud	63,577	13,000	418,233	1,365,000	1,859,811
Top Fuel Guide	170,336	2,080	87,668	218,400	478,484
Shroud Support	20,562	6,570	544	30,535	58,210
Jet Pumps & Support Ring	64,962	16,695	145,651	663,367	890,676
Core Support Plate	83,476	14,085	36,757	36,804	171,122
Orif. Fuel Supports	0	4,695	29,347	14,783	48,825
CRD Guides	48,290	9,390	32,436	36,921	127,037
Limiters, Housings, Inst. Guides	89,879	14,895	544	125,060	230,378
Steam Separator	150,304	33,945	37,142	241,798	463,189
Steam Dryer	12,060	14,895	544	125,060	152,559
Totals for RPV Internals	781,421	130,250	788,867	2,857,727	4,558,265

Reactor Pressure Vessel	Labor	Containers	Transport	Disposal	Total
Equipment Setup, Testing, Removal	51,983				51,983
Insulation	0	7,300	181	131,906	139,387
Upper Flange	6,136	4,300	604	33,928	44,967
Upper Head	7,404	2,800	317	17,306	27,827
Lower Flange	5,727	4,000	604	30,048	40,379
Non-Act. RPV Wall	28,585	25,550	3,171	174,659	231,965
Act. RPV Wall	48,492	86,400	111,040	138,411	384,343
Lower Head	11,337	6,020	1,268	69,864	88,489
Nozzles	11,999	19,860	725	166,747	199,330
Studs & Nuts	0	4,380	362	20,357	25,099
Skirt, Base Ring, & Collar	11,453	19,860	725	166,747	198,785
Totals for RPV	183,115	180,470	118,998	949,971	1,432,553

RPV Internals

Crew Hours	Pers Hours	Exposure Hours	Pers-Rem
2,405.18	21,646.61	1,615.79	112.22

Pressure Vessel

Crew Hours	Pers Hours	Exposure Hours	Pers-Rem
563.62	5,072.58	416.47	35.05

Figure C.6 CECP output file for RPV internals

Table C.1 Final summary report for DECON

	Cost (dollars)										
	Decon	**Remove**	**Package**	**Ship**	**Bury**	**Undist**	**Total**	**Cu Ft**	**C-Hrs**	**Pers-Hrs**	**Pers-Rem**
Period 1: Planning and Preparation (Year -2.5000 to Year 0.0000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	851,203	851,203	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,422,975	3,422,975	0	0	0	0.00
Totals	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 1.2000)											
Removal of NSSS											
RPV Internals	0	781,421	130,250	788,867	2,857,727	0	4,558,265	8,500	2,405	21,647	112.22
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	2,160	12,960	45.70
RFC & D/S Pool Decon Costs	6,628	0	0	0	0	0	6,628	0	48	192	0.10
Totals	13,256,628	781,421	130,250	788,867	3,324,029	0	18,281,194	13,100	4,613	34,799	158.02
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	7,770	687	104,869	0	113,327	2,162	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	16,660,453	16,660,453	0	0	165,734	165.73
Regulatory Costs	0	0	0	0	0	431,160	431,160	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	58,324	58,324	0	0	0	0.00
Laundry Services	0	0	0	0	0	526,400	526,400	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	15,628	15,628	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	238,000	238,000	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,135,296	1,135,296	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,195,120	3,195,120	0	0	0	0.00
Totals	0	0	0	0	0	22,260,381	22,260,381	0	0	165,734	165.73
Totals for Period 2	13,256,628	781,421	138,020	789,554	3,428,898	22,260,381	40,654,902	15,262	4,613	200,533	323.75
Period 3: Spent Fuel Pool Operations (Year 1.2000 to Year 4.6000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,435,261	1,435,261	0	0	12,022	10.27
DOC Staff	0	0	0	0	0	965,545	965,545	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	86,761	86,761	0	0	0	0.00

Table C.1 (Continued)

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Environmental Monitoring Costs	0	0	0	0	0	16,524	16,524	0	0	0	0.00
Laundry Services	0	0	0	0	0	31,559	31,559	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	18,361	18,361	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,040,000	2,040,000	0	0	0	0.00
Totals	0	0	0	0	0	4,594,011	4,594,011	0	0	12,022	10.27
Totals for Period 3	0	0	0	0	0	4,594,011	4,594,011	0	0	12,022	10.27
Period 4: Deferred Dismantlement (Year 4.6000 to Year 6.3000)											
Removal of NSSS											
Reactor Pressure Vessel and Insulation	0	183,115	180,470	118,998	949,971	0	1,432,553	13,152	564	5,073	35.05
Sacrificial Shield	0	750,000	63,000	10,872	1,112,261	0	1,936,133	9,759	720	3,600	24.95
Recirculation Pumps	0	16,224	0	600	252,852	0	269,676	5,214	33	180	1.87
RCS Piping	0	1,041,231	475,837	18,744	2,846,048	0	4,381,861	33,102	5,397	29,683	261.59
RCS Piping Insulation	0	0	23,175	1,151	418,753	0	443,078	8,635	0	0	0.00
Main Turbine	0	243,372	476,640	21,681	4,001,921	0	4,743,613	61,440	1,280	7,040	2.37
Main Turbine Condenser	28,927	465,637	283,250	13,180	4,799,854	0	5,590,848	85,800	2,315	12,564	4.36
Moisture Separator Reheaters	3,099	116,362	60,860	2,476	524,469	0	707,266	7,960	635	3,456	1.20
Feed Water Heaters	17,453	48,674	8,000	5,328	1,512,736	0	1,592,191	27,680	384	1,920	0.67
Turbine Feed Pumps	4,363	9,126	5,465	1,521	275,883	0	296,359	5,074	80	392	0.14
Structural Beams, Plates, & Cable Trays	0	440,350	151,800	5,980	863,555	0	1,461,685	10,560	2,316	12,738	4.42
Spent Fuel Racks	0	826,875	79,579	3,241	727,988	0	1,637,683	11,717	444	4,000	1.09
Spent Fuel Pool Decon Costs	5,539	0	0	0	0	0	5,539	0	40	161	0.04
Spent Fuel Pool Water Treatment Costs	450,000	0	23,475	18,988	40,554	0	533,018	600	432	2,592	1.20
Totals	509,382	4,140,966	1,831,551	222,760	18,326,843	0	25,031,503	280,693	14,639	83,399	338.95
Removal of Contaminated Plant Systems											
Control Rod Drive System	0	419,204	66,566	2,429	578,814	0	1,067,013	8,580	3,037	12,178	8.49
Feed and Condensate	0	67,607	181,919	6,639	1,527,412	0	1,783,578	23,450	343	1,812	0.24
Chemical Waste Processing	0	65,141	17,552	641	147,372	0	230,706	2,263	357	1,858	5.30
Containment Instrument Air	0	10,399	2,133	78	17,911	0	30,522	275	73	303	0.02
Fuel Pool Cooling and Cleanup	0	61,211	9,251	338	77,892	0	148,691	1,192	326	1,749	1.51
Condensate Demineralizers	0	109,552	27,752	1,013	233,198	0	371,515	3,577	581	3,126	0.22
Equipment Drain Processing	0	72,531	15,988	584	134,238	0	223,341	2,061	384	2,066	3.51
Extraction Steam	0	34,293	35,137	1,282	295,017	0	365,729	4,529	178	979	0.07
High/Low Pressure Core Spray	0	17,009	20,381	744	171,124	0	209,258	2,627	94	474	0.08
Miscellaneous Drains	0	9,721	2,321	85	19,484	0	31,610	299	51	278	0.05

Table C.1 (Continued)

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Main Steam and MS Leakage Control	0	100,597	80,604	2,942	676,761	0	860,904	10,390	587	2,826	2.94
Radioactive Floor Drain Processing	0	61,567	9,496	347	79,727	0	151,136	1,224	329	1,758	3.04
Turbine & Rad Waste Bldg. Drains	0	16,834	2,990	109	25,105	0	45,038	385	99	482	0.70
Offgas	0	68,531	19,982	729	167,772	0	257,015	2,576	372	1,954	3.10
Reactor Building Closed Cooling Water	0	39,925	12,704	464	106,668	0	159,761	1,638	215	1,137	0.31
Reactor Core Isolation Cooling	0	21,223	6,607	241	55,471	0	83,542	852	120	609	0.11
Residual Heat Removal	0	80,834	93,087	3,397	781,948	0	959,267	11,999	425	2,284	0.31
Misc. Recirculation System Components	0	3,429	10,120	369	84,971	0	98,890	1,305	18	98	0.20
Reactor Water Cleanup	0	51,494	14,435	527	121,198	0	187,654	1,861	277	1,470	39.45
Reactor Building Equipment & Floor Drains	0	27,813	2,769	101	23,245	0	53,928	357	152	794	0.14
Sample System	0	11,682	349	13	2,930	0	14,973	45	68	337	0.01
Standby Gas Treatment	0	10,974	12,328	450	103,510	0	127,263	1,589	73	303	0.02
Heater Vents and Drains	0	126,994	60,138	2,195	504,925	0	694,252	7,752	660	3,632	0.50
Miscellaneous Items	0	235,156	31,884	1,164	275,090	0	543,294	4,110	1,425	6,735	2.26
Other Piping	0	3,719,826	233,902	8,537	2,258,891	0	6,221,156	30,151	19,314	106,229	36.86
Small Hangers (2" pipe or less)	0	906,136	88,999	3,506	450,041	0	1,448,682	6,191	4,721	25,967	0.90
Large Hangers (> 2" pipe)	0	1,815,040	254,294	10,017	1,285,883	0	3,365,234	17,690	9,443	51,934	1.80
Totals	0	8,164,723	1,313,690	48,939	10,206,598	0	19,733,949	148,968	43,723	233,372	112.15
Decontamination of Site Buildings											
Reactor Bldg	40,059	237,506	83,036	3,644	738,689	0	1,102,935	11,933	1,901	7,129	6.16
Rad Waste/Control Bldg	13,363	63,380	4,701	354	51,810	0	133,608	971	538	1,955	1.63
Turbine Generator Bldg	5,503	21,665	2,990	167	29,031	0	59,356	502	188	701	0.58
Waste Water Solidification Costs	141,560	0	31,300	28,589	49,442	0	250,891	800	389	1,167	0.32
Removal of HVAC Ducts	0	289,831	40,150	1,993	761,531	0	1,093,505	14,960	3,443	10,330	4.38
Removal of HVAC Equipment	0	68,351	61,410	4,143	1,138,636	0	1,272,540	22,096	363	1,813	2.81
Building Cranes	72,399	131,622	10,950	544	221,821	0	437,336	4,080	588	3,132	0.16
Floor Drains	0	378,911	12,077	848	97,137	0	488,973	1,797	2,613	7,840	1.66
Totals	272,884	1,191,266	246,614	40,282	3,088,099	0	4,839,144	57,139	10,023	34,068	17.69
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	115,188	10,191	1,554,545	0	1,679,923	32,056	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,058,344	1,058,344	0	0	0	0.00

Table C.1 (Continued)

	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Cost (dollars)										
Undistributed Costs											
Utility Staff	0	0	0	0	0	4,897,730	4,897,730	0	0	29,328	16.01
DOC Staff	0	0	0	0	0	11,271,449	11,271,449	0	0	32,448	17.72
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	610,810	610,810	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	1,083,113	1,083,113	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	273,642	273,642	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,608,336	1,608,336	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	24,626,426	24,626,426	0	0	61,776	33.73
Totals for Period 4	782,266	13,496,955	3,507,042	322,172	33,176,085	25,684,770	76,969,290	518,856	68,386	412,615	502.53
Grand Totals	14,038,894	14,278,376	3,645,063	1,111,726	36,604,983	61,998,403	131,677,444	534,119	72,999	625,170	836.55
Grand Totals with 25% contingency	17,548,617	17,847,970	4,556,328	1,389,657	45,756,229	77,498,003	164,596,805	534,119	72,999	625,170	836.55

Listed below are the fractions of the total cost that are attributable to labor and materials (A), energy and transportation (B), and waste burial (C). Property taxes and nuclear liability insurance are not included.

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.673	83,688,002	104,610,003
B (energy and transportation):	0.033	4,111,719	5,139,648
C (waste burial):	0.294	36,604,983	45,756,229
	A + B + C ($)	124,404,704	155,505,880
	Taxes and Insurance ($)	7,272,740	9,090,925
	Grand Totals ($)	131,677,444	164,596,805

Burial Volumes by Waste Class

	Vol. (ft3)	Per Cent
Class A Waste:	514,723	96.37
Class B&C Waste:	19,152	3.59
GTCC Waste:	244	0.05
	534,119	100.00

Table C.2 Final summary report for BARNWELL

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Period 1: Planning and Preparation (Year -2.5000 to Year 0.0000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	851,203	851,203	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,422,975	3,422,975	0	0	0	0.00
Totals	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 1.2000)											
Removal of NSSS											
RPV Internals	0	781,421	130,250	1,327,288	5,388,107	0	7,627,065	8,500	2,405	21,647	112.22
Chemical Decontamination	13,250,000	0	0	0	2,105,580	0	15,355,580	4,600	2,160	12,960	45.70
RFC & D/S Pool Decon Costs	6,628	0	0	0	0	0	6,628	0	48	192	0.10
Totals	13,256,628	781,421	130,250	1,327,288	7,493,687	0	22,989,274	13,100	4,613	34,799	158.02
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	7,770	15,593	606,392	0	629,756	2,162	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	16,660,453	16,660,453	0	0	165,734	165.73
Regulatory Costs	0	0	0	0	0	431,160	431,160	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	58,324	58,324	0	0	0	0.00
Laundry Services	0	0	0	0	0	526,400	526,400	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	15,628	15,628	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	238,000	238,000	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,135,296	1,135,296	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,195,120	3,195,120	0	0	0	0.00
Totals	0	0	0	0	0	22,260,381	22,260,381	0	0	165,734	165.73
Totals for Period 2	13,256,628	781,421	138,020	1,342,881	8,100,079	22,260,381	45,879,410	15,262	4,613	200,533	323.75
Period 3: Spent Fuel Pool Operations (Year 1.2000 to Year 4.6000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,435,261	1,435,261	0	0	12,022	10.27
DOC Staff	0	0	0	0	0	965,545	965,545	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	86,761	86,761	0	0	0	0.00

Table C.2 (Continued)

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Environmental Monitoring Costs	0	0	0	0	0	16,524	16,524	0	0	0	0.00
Laundry Services	0	0	0	0	0	31,559	31,559	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	18,361	18,361	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,040,000	2,040,000	0	0	0	0.00
Totals	0	0	0	0	0	4,594,011	4,594,011	0	0	12,022	10.27
Totals for Period 3	0	0	0	0	0	4,594,011	4,594,011	0	0	12,022	10.27
Period 4: Deferred Dismantlement (Year 4.6000 to Year 6.3000)											
Removal of NSSS											
Reactor Pressure Vessel and Insulation	0	183,115	180,470	1,110,607	4,489,266	0	5,963,458	13,152	564	5,073	35.05
Sacrificial Shield	0	750,000	63,000	246,605	2,927,680	0	3,987,285	9,759	720	3,600	24.95
Recirculation Pumps	0	16,224	0	31,279	1,462,089	0	1,509,592	5,214	33	180	1.87
RCS Piping	0	1,041,231	475,837	425,160	9,611,720	0	11,553,948	33,102	5,397	29,683	261.59
RCS Piping Insulation	0	0	23,175	26,096	2,425,678	0	2,474,949	8,635	0	0	0.00
Main Turbine	0	243,372	476,640	778,628	17,693,874	0	19,192,514	61,440	1,280	7,040	2.37
Main Turbine Condenser	28,927	465,637	283,250	463,341	24,440,743	0	25,681,898	85,800	2,315	12,564	4.36
Moisture Separator Reheaters	3,099	116,362	60,860	63,125	2,277,516	0	2,520,963	7,960	635	3,456	1.20
Feed Water Heaters	17,453	48,674	8,000	303,898	7,971,515	0	8,349,541	27,680	384	1,920	0.67
Turbine Feed Pumps	4,363	9,126	5,465	50,112	1,458,656	0	1,527,722	5,074	80	392	0.14
Structural Beams, Plates, & Cable Trays	0	440,350	151,800	135,633	3,066,298	0	3,794,081	10,560	2,316	12,738	4.42
Spent Fuel Racks	0	826,875	79,579	105,067	3,344,534	0	4,356,055	11,717	444	4,000	1.09
Spent Fuel Pool Decon Costs	5,539	0	0	0	0	0	5,539	0	40	161	0.04
Spent Fuel Pool Water Treatment Costs	450,000	0	23,475	30,239	224,280	0	727,993	600	432	2,592	1.20
Totals	509,382	4,140,966	1,831,551	3,769,789	81,393,850	0	91,645,538	280,693	14,639	83,399	338.95
Removal of Contaminated Plant Systems											
Control Rod Drive System	0	419,204	66,566	55,104	2,448,810	0	2,989,684	8,580	3,037	12,178	8.49
Feed and Condensate	0	67,607	181,919	150,595	6,692,397	0	7,092,518	23,450	343	1,812	0.24
Chemical Waste Processing	0	65,141	17,552	14,530	645,713	0	742,936	2,263	357	1,858	5.30
Containment Instrument Air	0	10,399	2,133	1,766	78,479	0	92,777	275	73	303	0.02
Fuel Pool Cooling and Cleanup	0	61,211	9,251	7,658	340,310	0	418,429	1,192	326	1,749	1.51
Condensate Demineralizers	0	109,552	27,752	22,974	1,020,952	0	1,181,230	3,577	581	3,126	0.22
Equipment Drain Processing	0	72,531	15,988	13,235	588,167	0	689,922	2,061	384	2,066	3.51
Extraction Steam	0	34,293	35,137	29,087	1,292,623	0	1,391,140	4,529	178	979	0.07
High/Low Pressure Core Spray	0	17,009	20,381	16,872	749,784	0	804,047	2,627	94	474	0.08
Miscellaneous Drains	0	9,721	2,321	1,921	85,369	0	99,332	299	51	278	0.05

Table C.2 (Continued)

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Main Steam and MS Leakage Control	0	100,597	80,604	66,725	2,965,246	0	3,213,173	10,390	587	2,826	2.94
Radioactive Floor Drain Processing	0	61,567	9,496	7,861	349,326	0	428,249	1,224	329	1,758	3.04
Turbine & Rad Waste Bldg. Drains	0	16,834	2,990	2,475	109,997	0	132,296	385	99	482	0.70
Offgas	0	68,531	19,982	16,541	735,097	0	840,152	2,576	372	1,954	3.10
Reactor Building Closed Cooling Water	0	39,925	12,704	10,517	467,369	0	530,515	1,638	215	1,137	0.31
Reactor Core Isolation Cooling	0	21,223	6,607	5,469	243,048	0	276,347	852	120	609	0.11
Residual Heat Removal	0	80,834	93,087	77,058	3,424,451	0	3,675,431	11,999	425	2,284	0.31
Misc. Recirculation System Components	0	3,429	10,120	8,378	372,304	0	394,231	1,305	18	98	0.20
Reactor Water Cleanup	0	51,494	14,435	11,950	531,033	0	608,912	1,861	277	1,470	39.45
Reactor Building Equipment & Floor Drains	0	27,813	2,769	2,292	101,848	0	134,722	357	152	794	0.14
Sample System	0	11,682	349	289	12,836	0	25,156	45	68	337	0.01
Standby Gas Treatment	0	10,974	12,328	10,206	453,533	0	487,042	1,589	73	303	0.02
Heater Vents and Drains	0	126,994	60,138	49,783	2,212,343	0	2,449,258	7,752	660	3,632	0.50
Miscellaneous Items	0	235,156	31,884	26,394	1,172,949	0	1,466,383	4,110	1,425	6,735	2.26
Other Piping	0	3,719,826	233,902	193,627	8,604,744	0	12,752,099	30,151	19,314	106,229	36.86
Small Hangers (2" pipe or less)	0	906,136	88,999	79,521	1,597,998	0	2,672,654	6,191	4,721	25,967	0.90
Large Hangers (> 2" pipe)	0	1,815,040	254,294	227,211	4,565,893	0	6,862,438	17,690	9,443	51,934	1.80
Totals	0	8,164,723	1,313,690	1,110,038	41,862,620	0	52,451,071	148,968	43,723	233,372	112.15
Decontamination of Site Buildings											
Reactor Bldg	40,059	237,506	83,036	82,663	3,393,971	0	3,837,236	11,933	1,901	7,129	6.16
Rad Waste/Control Bldg	13,363	63,380	4,701	8,032	273,808	0	363,283	971	538	1,955	1.63
Turbine Generator Bldg	5,503	21,665	2,990	3,792	142,088	0	176,038	502	188	701	0.58
Waste Water Solidification Costs	141,560	0	31,300	82,244	293,300	0	548,404	800	389	1,167	0.32
Removal of HVAC Ducts	0	289,831	40,150	45,211	2,487,658	0	2,862,850	14,960	3,443	10,330	4.38
Removal of HVAC Equipment	0	68,351	61,410	78,351	6,230,757	0	6,438,869	22,096	363	1,813	2.81
Building Cranes	72,399	131,622	10,950	12,330	1,151,137	0	1,378,439	4,080	588	3,132	0.16
Floor Drains	0	378,911	12,077	19,239	526,501	0	936,727	1,797	2,613	7,840	1.66
Totals	272,884	1,191,266	246,614	331,863	14,499,221	0	16,541,847	57,139	10,023	34,068	17.69
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	115,188	231,145	8,988,992	0	9,335,325	32,056	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,058,344	1,058,344	0	0	0	0.00

Table C.2 (Continued)

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Undistributed Costs											
Utility Staff	0	0	0	0	0	4,897,730	4,897,730	0	0	29,328	16.01
DOC Staff	0	0	0	0	0	11,271,449	11,271,449	0	0	32,448	17.72
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	610,810	610,810	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	1,083,113	1,083,113	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	273,642	273,642	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,608,336	1,608,336	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	24,626,426	24,626,426	0	0	61,776	33.73
Totals for Period 4	782,266	13,496,955	3,507,042	5,442,836	146,744,683	25,684,770	195,658,551	518,856	68,386	412,615	502.53
Grand Totals	14,038,894	14,278,376	3,645,063	6,785,716	154,844,762	61,998,403	255,591,213	534,119	72,999	625,170	836.55
Grand Totals with 25% contingency	17,548,617	17,847,970	4,556,328	8,482,145	193,555,952	77,498,003	319,489,017	534,119	72,999	625,170	836.55

Listed below are the fractions of the total cost that are attributable to labor and materials (A), energy and transportation (B), and waste burial (C). Property taxes and nuclear liability insurance are not included.

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.337	83,688,002	104,610,003
B (energy and transportation):	0.039	9,785,709	12,232,136
C (waste burial):	0.624	154,844,762	193,555,952
	A + B + C ($)	248,318,473	310,398,092
	Taxes and Insurance ($)	7,272,740	9,090,925
	Grand Totals ($)	255,591,213	319,489,017

	Burial Volumes by Waste Class	
	Vol. (ft3)	Per Cent
Class A Waste:	514,723	96.37
Class B&C Waste:	19,152	3.59
GTCC Waste:	244	0.05
	534,119	100.00

Table C.3 Final summary report for SS1

	Cost (dollars)										
	Decon	**Remove**	**Package**	**Ship**	**Bury**	**Undist**	**Total**	**Cu Ft**	**C-Hrs**	**Pers-Hrs**	**Pers-Rem**
Period 1: Planning and Preparation (Year -2.5000 to Year 0.0000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	851,203	851,203	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,422,975	3,422,975	0	0	0	0.00
Totals	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 1.2000)											
Removal of NSSS											
RPV Internals	0	781,421	130,250	788,867	2,857,727	0	4,558,265	8,500	2,405	21,647	112.22
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	2,160	12,960	45.70
RFC & D/S Pool Decon Costs	6,628	0	0	0	0	0	6,628	0	48	192	0.10
Totals	13,256,628	781,421	130,250	788,867	3,324,029	0	18,281,194	13,100	4,613	34,799	158.02
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	7,770	687	104,869	0	113,327	2,162	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	16,660,453	16,660,453	0	0	165,734	165.73
Regulatory Costs	0	0	0	0	0	431,160	431,160	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	58,324	58,324	0	0	0	0.00
Laundry Services	0	0	0	0	0	526,400	526,400	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	15,628	15,628	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	238,000	238,000	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,135,296	1,135,296	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,195,120	3,195,120	0	0	0	0.00
Totals	0	0	0	0	0	22,260,381	22,260,381	0	0	165,734	165.73
Totals for Period 2	13,256,628	781,421	138,020	789,554	3,428,898	22,260,381	40,654,902	15,262	4,613	200,533	323.75

Table C.3 (Continued)

	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Cost (dollars)										
Period 3: Spent Fuel Pool Operations (Year 1.2000 to Year 4.6000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,435,261	1,435,261	0	0	12,022	10.27
Regulatory Costs	0	0	0	0	0	86,761	86,761	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	16,524	16,524	0	0	0	0.00
Laundry Services	0	0	0	0	0	31,559	31,559	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	18,361	18,361	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,040,000	2,040,000	0	0	0	0.00
Totals	0	0	0	0	0	3,628,466	3,628,466	0	0	12,022	10.27
Totals for Period 3	0	0	0	0	0	3,628,466	3,628,466	0	0	12,022	10.27
Period 4: Extended Safe Storage (Year 4.6000 to Year 58.3000)											
Layup Spent Fuel Pool											
Spent Fuel Pool Decon Costs	5,539	0	0	0	0	0	5,539	0	40	161	0.04
Spent Fuel Pool Water Treatment Costs	450,000	0	23,475	18,988	40,554	0	533,018	600	432	2,592	1.20
Totals	455,539	0	23,475	18,988	40,554	0	538,557	600	472	2,753	1.24
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	795	70	10,734	0	11,600	221	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	63,349,716	63,349,716	0	0	223,392	121.99
DOC Staff	0	0	0	0	0	1,931,092	1,931,092	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	14,168,423	14,168,423	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	2,609,981	2,609,981	0	0	0	0.00
Laundry Services	0	0	0	0	0	593,630	593,630	0	0	0	0.00
Maintenance Allowance	0	0	0	0	0	933,252	933,252	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	478,467	478,467	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	32,220,000	32,220,000	0	0	0	0.00
Totals	0	0	0	0	0	116,284,561	116,284,561	0	0	223,392	121.99
Totals for Period 4	455,539	0	24,270	19,059	51,288	116,284,561	116,834,717	821	472	226,145	123.23

Table C.3 (Continued)

	Cost (dollars)										
	Decon	**Remove**	**Package**	**Ship**	**Bury**	**Undist**	**Total**	**Cu Ft**	**C-Hrs**	**Pers-Hrs**	**Pers-Rem**
Period 5: Deferred Dismantlement (Year 58.3000 to Year 58.6100)											
Removal of NSSS											
Reactor Pressure Vessel and Insulation	0	183,115	180,470	118,998	942,394	0	1,424,976	13,152	564	5,073	1.47
Sacrificial Shield	0	750,000	63,000	10,872	1,112,261	0	1,936,133	9,759	720	3,600	0.02
Totals	0	933,115	243,470	129,870	2,054,654	0	3,361,109	22,911	1,284	8,673	1.49
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,150,656	1,150,656	0	0	5,803	0.00
DOC Staff	0	0	0	0	0	2,245,926	2,245,926	0	0	6,448	0.00
Consultant/Other Staff	0	0	0	0	0	75,082	75,082	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	111,383	111,383	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	15,067	15,067	0	0	0	0.00
Laundry Services	0	0	0	0	0	54,925	54,925	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	18,662	18,662	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	293,285	293,285	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	371,566	371,566	0	0	0	0.00
Totals	0	0	0	0	0	6,976,552	6,976,552	0	0	12,251	0.01
Totals for Period 5	0	933,115	243,470	129,870	2,054,654	6,976,552	10,337,661	22,911	1,284	20,924	1.50
Grand Totals	13,712,167	1,714,536	405,761	938,483	5,534,840	158,609,201	180,914,988	38,995	6,369	459,624	458.75
Grand Totals with 25% contingency	17,140,209	2,143,170	507,201	1,173,104	6,918,550	198,261,501	226,143,734	38,995	6,369	459,624	458.75

Listed below are the fractions of the total cost that are attributable to labor and materials (A), energy and transportation (B), and waste burial (C). Property taxes and nuclear liability insurance are not included.

Table C.3 (Continued)

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.940	134,451,570	168,064,463
B (energy and transportation):	0.022	3,101,891	3,877,364
C (waste burial):	0.039	5,534,840	6,918,550
	A + B + C ($)	143,088,302	178,860,377
	Taxes and Insurance ($)	37,826,686	47,283,358
	Grand Totals ($)	180,914,988	226,143,734

	Burial Volumes by Waste Class	
	Vol. (ft3)	Per Cent
Class A Waste:	20,399	52.31
Class B&C Waste:	18,352	47.06
GTCC Waste:	244	0.62
	38,995	100.00

Table C.4 Final summary report for SS2

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Period 1: Planning and Preparation (Year -2.5000 to Year 0.0000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	851,203	851,203	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,422,975	3,422,975	0	0	0	0.00
Totals	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,459,241	9,459,241	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 1.2000)											
Removal of NSSS											
RPV Internals	0	781,421	130,250	788,867	2,857,727	0	4,558,265	8,500	2,405	21,647	112.22
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	2,160	12,960	45.70
RFC & D/S Pool Decon Costs	6,628	0	0	0	0	0	6,628	0	48	192	0.10
Totals	13,256,628	781,421	130,250	788,867	3,324,029	0	18,281,194	13,100	4,613	34,799	158.02
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	7,770	687	104,869	0	113,327	2,162	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	16,660,453	16,660,453	0	0	165,734	165.73
Regulatory Costs	0	0	0	0	0	431,160	431,160	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	58,324	58,324	0	0	0	0.00
Laundry Services	0	0	0	0	0	526,400	526,400	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	15,628	15,628	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	238,000	238,000	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,135,296	1,135,296	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,195,120	3,195,120	0	0	0	0.00
Totals	0	0	0	0	0	22,260,381	22,260,381	0	0	165,734	165.73
Totals for Period 2	13,256,628	781,421	138,020	789,554	3,428,898	22,260,381	40,654,902	15,262	4,613	200,533	323.75
Period 3: Spent Fuel Pool Operations (Year 1.2000 to Year 4.6000)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,435,261	1,435,261	0	0	12,022	10.27
Regulatory Costs	0	0	0	0	0	86,761	86,761	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	16,524	16,524	0	0	0	0.00
Laundry Services	0	0	0	0	0	31,559	31,559	0	0	0	0.00

Table C.4 (Continued)

	Cost (dollars)										
	Decon	**Remove**	**Package**	**Ship**	**Bury**	**Undist**	**Total**	**Cu Ft**	**C-Hrs**	**Pers-Hrs**	**Pers-Rem**
Plant Power Usage	0	0	0	0	0	18,361	18,361	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,040,000	2,040,000	0	0	0	0.00
Totals	0	0	0	0	0	3,628,466	3,628,466	0	0	12,022	10.27
Totals for Period 3	0	0	0	0	0	3,628,466	3,628,466	0	0	12,022	10.27
Period 4: Extended Safe Storage (Year 4.6000 to Year 58.3000)											
Layup Spent Fuel Pool											
Spent Fuel Pool Decon Costs	5,539	0	0	0	0	0	5,539	0	40	161	0.04
Spent Fuel Pool Water Treatment Costs	450,000	0	23,475	18,988	40,554	0	533,018	600	432	2,592	1.20
Totals	455,539	0	23,475	18,988	40,554	0	538,557	600	472	2,753	1.24
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	795	70	10,734	0	11,600	221	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	63,349,716	63,349,716	0	0	223,392	121.99
DOC Staff	0	0	0	0	0	1,931,092	1,931,092	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	14,168,423	14,168,423	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	2,609,981	2,609,981	0	0	0	0.00
Laundry Services	0	0	0	0	0	593,630	593,630	0	0	0	0.00
Maintenance Allowance	0	0	0	0	0	933,252	933,252	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	478,467	478,467	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	32,220,000	32,220,000	0	0	0	0.00
Totals	0	0	0	0	0	116,284,561	116,284,561	0	0	223,392	121.99
Totals for Period 4	455,539	0	24,270	19,059	51,288	116,284,561	116,834,717	821	472	226,145	123.23
Period 5: Deferred Dismantlement (Year 58.3000 to Year 60.0000)											
Removal of NSSS											
Reactor Pressure Vessel and Insulation	0	183,115	180,470	118,998	942,394	0	1,424,976	13,152	564	5,073	1.47
Sacrificial Shield	0	750,000	63,000	10,872	1,112,261	0	1,936,133	9,759	720	3,600	0.02
Recirculation Pumps	0	16,224	0	600	252,852	0	269,676	5,214	33	180	0.00
RCS Piping	0	1,041,231	475,837	18,744	2,846,048	0	4,381,861	33,102	5,397	29,683	0.22
RCS Piping Insulation	0	0	23,175	1,151	418,753	0	443,078	8,635	0	0	0.00
Main Turbine	0	243,372	476,640	21,681	4,001,921	0	4,743,613	61,440	1,280	7,040	0.00
Main Turbine Condenser	28,927	465,637	283,250	13,180	4,799,854	0	5,590,848	85,800	2,315	12,564	0.00
Moisture Separator Reheaters	3,099	116,362	60,860	2,476	524,469	0	707,266	7,960	635	3,456	0.00
Feed Water Heaters	17,453	48,674	8,000	5,328	1,512,736	0	1,592,191	27,680	384	1,920	0.00

Table C.4 (Continued)

	Cost (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Turbine Feed Pumps	4,363	9,126	5,465	1,521	275,883	0	296,359	5,074	80	392	0.00
Structural Beams, Plates, & Cable Trays	0	440,350	151,800	5,980	863,555	0	1,461,685	10,560	2,316	12,738	0.00
Spent Fuel Racks	0	826,875	79,579	3,241	727,988	0	1,637,683	11,717	444	4,000	0.00
Totals	53,843	4,140,966	1,808,076	203,772	18,278,712	0	24,485,369	280,093	14,167	80,646	1.73
Removal of Contaminated Plant Systems											
Control Rod Drive System	0	419,204	66,566	2,429	558,894	0	1,047,093	8,580	3,037	12,178	0.01
Feed and Condensate	0	67,607	181,919	6,639	1,527,412	0	1,783,578	23,450	343	1,812	0.00
Chemical Waste Processing	0	65,141	17,552	641	147,372	0	230,706	2,263	357	1,858	0.00
Containment Instrument Air	0	10,399	2,133	78	17,911	0	30,522	275	73	303	0.00
Fuel Pool Cooling and Cleanup	0	61,211	9,251	338	77,669	0	148,469	1,192	326	1,749	0.00
Condensate Demineralizers	0	109,552	27,752	1,013	233,013	0	371,330	3,577	581	3,126	0.00
Equipment Drain Processing	0	72,531	15,988	584	134,238	0	223,341	2,061	384	2,066	0.00
Extraction Steam	0	34,293	35,137	1,282	295,017	0	365,729	4,529	178	979	0.00
High/Low Pressure Core Spray	0	17,009	20,381	744	171,124	0	209,258	2,627	94	474	0.00
Miscellaneous Drains	0	9,721	2,321	85	19,484	0	31,610	299	51	278	0.00
Main Steam and MS Leakage Control	0	100,597	80,604	2,942	676,761	0	860,904	10,390	587	2,826	0.00
Radioactive Floor Drain Processing	0	61,567	9,496	347	79,727	0	151,136	1,224	329	1,758	0.00
Turbine & Rad Waste Bldg. Drains	0	16,834	2,990	109	25,105	0	45,038	385	99	482	0.00
Offgas	0	68,531	19,982	729	167,772	0	257,015	2,576	372	1,954	0.00
Reactor Building Closed Cooling Water	0	39,925	12,704	464	106,668	0	159,761	1,638	215	1,137	0.00
Reactor Core Isolation Cooling	0	21,223	6,607	241	55,471	0	83,542	852	120	609	0.00
Residual Heat Removal	0	80,834	93,087	3,397	781,566	0	958,884	11,999	425	2,284	0.00
Misc. Recirculation System Components	0	3,429	10,120	369	84,971	0	98,890	1,305	18	98	0.00
Reactor Water Cleanup	0	51,494	14,435	527	121,198	0	187,654	1,861	277	1,470	0.03
Reactor Building Equipment & Floor Drains	0	27,813	2,769	101	23,245	0	53,928	357	152	794	0.00
Sample System	0	11,682	349	13	2,930	0	14,973	45	68	337	0.00
Standby Gas Treatment	0	10,974	12,328	450	103,510	0	127,263	1,589	73	303	0.00
Heater Vents and Drains	0	126,994	60,138	2,195	504,925	0	694,252	7,752	660	3,632	0.00
Miscellaneous Items	0	235,156	31,884	1,164	267,703	0	535,907	4,110	1,425	6,735	0.00
Other Piping	0	3,719,826	233,902	8,537	1,963,869	0	5,926,134	30,151	19,314	106,229	0.03
Small Hangers (2" pipe or less)	0	906,136	88,999	3,506	450,041	0	1,448,682	6,191	4,721	25,967	0.00
Large Hangers (> 2" pipe)	0	1,815,040	254,294	10,017	1,285,883	0	3,365,234	17,690	9,443	51,934	0.00
Totals	0	8,164,723	1,313,690	48,939	9,883,480	0	19,410,831	148,968	43,723	233,372	0.10
Decontamination of Site Buildings											
Reactor Bldg	40,059	237,506	83,036	3,644	738,689	0	1,102,935	11,933	1,901	7,129	0.01
Rad Waste/Control Bldg	13,363	63,380	4,701	354	51,810	0	133,608	971	538	1,955	0.00

Table C.4 (Continued)

	Cost (dollars)										
	Decon	**Remove**	**Package**	**Ship**	**Bury**	**Undist**	**Total**	**Cu Ft**	**C-Hrs**	**Pers-Hrs**	**Pers-Rem**
Turbine Generator Bldg	5,503	21,665	2,990	167	29,031	0	59,356	502	188	701	0.00
Waste Water Solidification Costs	141,560	0	31,300	28,589	49,442	0	250,891	800	389	1,167	0.32
Removal of HVAC Ducts	0	289,831	40,150	1,993	761,531	0	1,093,505	14,960	3,443	10,330	4.38
Removal of HVAC Equipment	0	68,351	61,410	4,143	1,138,636	0	1,272,540	22,096	363	1,813	2.81
Building Cranes	72,399	131,622	10,950	544	221,821	0	437,336	4,080	588	3,132	0.16
Floor Drains	0	378,911	12,077	848	97,137	0	488,973	1,797	2,613	7,840	1.66
Totals	272,884	1,191,266	246,614	40,282	3,088,099	0	4,839,144	57,139	10,023	34,068	9.33
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	114,392	10,120	1,543,811	0	1,668,324	31,835	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,058,344	1,058,344	0	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	5,841,789	5,841,789	0	0	29,328	0.01
DOC Staff	0	0	0	0	0	11,271,449	11,271,449	0	0	69,888	0.03
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	610,810	610,810	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	1,174,167	1,174,167	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	273,642	273,642	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	1,608,336	1,608,336	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	25,661,539	25,661,539	0	0	99,216	0.05
Totals for Period 5	326,727	13,496,955	3,482,772	303,113	32,794,102	26,719,883	77,123,551	518,035	67,914	447,302	11.20
Grand Totals	14,038,894	14,278,376	3,645,063	1,111,726	36,274,288	178,352,532	247,700,878	534,119	72,999	886,002	468.45
Grand Totals with 25% contingency	17,548,617	17,847,970	4,556,328	1,389,657	45,342,860	222,940,664	309,626,097	534,119	72,999	886,002	468.45

Listed below are the fractions of the total cost that are attributable to labor and materials (A), energy and transportation (B), and waste burial (C). Property taxes and nuclear liability insurance are not included.

Table C.4 (Continued)

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.804	167,343,664	209,179,581
B (energy and transportation):	0.022	4,590,185	5,737,732
C (waste burial):	0.174	36,274,288	45,342,280
	A + B + C ($)	208,208,138	260,260,172
	Taxes and Insurance ($)	39,492,740	49,365,925
	Grand Totals ($)	247,700,878	309,626,097

	Burial Volumes by Waste Class	
	Vol. (ft3)	Per Cent
Class A Waste:	514,723	96.37
Class B&C Waste:	19,152	3.59
GTCC Waste:	244	0.05
	534,119	100.00

Inventory Listings

The systems identified in this section for complete or partial removal during decontamination for license termination are:

- Chemical Waste Processing
- Containment Instrument Air
- Control Rod Drive System
- Condensate Demineralizers
- Equipment Drain Processing
- Extraction Steam
- Feed and Condensate
- Fuel Pool Cooling and Cleanup
- High Pressure Core Spray
- Low Pressure Core Spray
- Miscellaneous Drains
- Main Steam
- Main Steam Leakage Control
- Offgas (Augmented) System
- Turbine Bldg and Rad Waste Bldg Drains
- Radioactive Floor Drain Processing
- Reactor Bldg Closed Cooling Water
- Reactor Core Isolation Cooling
- Residual Heat Removal
- Recirculation
- Reactor Water Cleanup
- Reactor Bldg Equipment and Floor Drains
- Sample Systems
- Standby Gas Treatment
- Heater Vents and Drains
- Miscellaneous Items from Partial Systems
- Piping from RCS and Other Systems

The inventories of system components for each system and the stainless steel piping inventory are presented in Table C.5. The weights of the valves listed are based on typical 600 psig service-rated gate valves. For most of the valves, which are in systems rated for 150 psig service, these estimates are conservative. For the limited number of valves associated with the primary coolant system and the steam system, these estimates are non-conservative. On the average, the estimated weights should be conservative. The volumes of the valves are estimated using a crude approximation to calculate the space occupied by the valve body and the valve stem and operator. Again, the estimates are considered to conservatively overestimate the actual volumes occupied by the valves.

C.2 Unit Cost Factors and Work Difficulty Factors

The average time required to perform a particular decommissioning task will almost always be longer than expected because of unavoidable external factors: reduced efficiency while working in respiratory equipment or working on scaffolding; the number and length of each work break; and radiation protection/ALARA activities. Each of these work difficulty factors may be expressed as a percent increase in time. Thus, a 20% factor for working in a respirator means that

work duration in respirator = 1.2 x work duration not in respirator

The CECP permits the user to change work difficulty factors for any activity or to simply use the default values.

Table C.5 Reference BWR system components and piping inventories

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
Chemical Waste Processing System				
2	Chemical waste tank	11,066	Cyl. 18.1 x 12.2 dia.	2125
2	Detergent drain tank	4039	Cyl. 7.9 x 6 dia.	219
2	Detergent drain pump	385	3.3 x 1.3 x 1.7	7.2
2	Concentrator feed pump	559	3.6 x 1 x 2	7.2
2	Chemical waste pump	1054	4.3 x 1.3 x 1.7	9.3
1	Detergent drain filter	2495	Cyl. 3 x 1 dia.	2.3
2	Chemical addition tank	500	Cyl. 4 x 2.6 dia.	16.6
2	Tank agitators	80	Cyl. 8 x .4 dia.	1
2	Chemical addition pump	385	3.3 x 1.3 x 1.7	7.2
2	Distillate tank	11,066	Cyl. 18.1 x 12.2 dia.	2125
2	Distillate tank pump	508	4 x 1 x 1.3	5.2
1	Distillate polishing demin.	999	Cyl. 7.9 x 10.2 dia.	651
2	Decon sol. concentrator	7500	Cyl. 15.2 x 4 dia.	187
2	Decon sol. conc. tank	1566	Cyl. 5.6 x 5.6 dia.	139
2	Decon conc. recycle pump	1857	5.6 x 2 x 3.6	40.3
2	Decon concentrator condenser	5078	Cyl. 11.2 x 2.6 dia.	61.4
2	Decon concentrator pre heater	6923	Cyl. 15.2 x 3 dia.	105
1	Decon concentrator waste pump	559	3.6 x 1.3 x 1.7	7.9
2	Chemical waste stream mixer	245	1.8 x .8 x .8	1.1
2	Condensate receiver tank	2093	Cyl. 10.2 x 3.8 dia.	115.7
2	Condensate receiver tank pump	225	3.6 x 1.3 x 1.3	6.3
2	8 in. air operated valve	340		144.2
2	6 in. MOV	180		7.0
3	6 in. valve	180		7.0
4	4 in. MOV	100		2.9
5	4 in. valve	100		2.9
2	4 in. check valve	80		2.3
2	4 in. flow element	80		2.3
2	3 in. MOV	65		1.2
15	3 in. air operated valve	65		1.2
14	3 in. valve	65		1.2
5	3 in. check valve	60		1.0
1	3 in. restricting orifice	60		1.0
1	3 in. flow element	60		1.0
8	2 in. air operated valve	40		.9
25	2 in. valve	40		.9
7	2 in. check valve	35		.7
2	2 in. relief valve	40		.8
3	2 in. flow element	35		.7

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
3	1-1/2 in. air operated	35		.8
31	1-1/2 in. valve	35		.8
8	1-1/2 in. check valve	30		.4
4	1-1/2 in. restricting orifice	30		.4
7	1 in. air operated valve	30		.4
23	1 in. valve	30		.4
12	1 in. check valve	25		.4
6	1 in. restricting orifice	25		.4
96	Instr. root (typ. 3/4" globe)	32		.3
Containment Instrument Air				
3	3/4 in. valve	32		.3
48	1/2 in. valve	20		.3
2	3/4 in. relief valve	25		.3
62	1 1/4 in. three way valve	55		1.1
4	1 1/4 in. four way valves	60		1.2
2	2 in. check valve	35		.8
100	2 in. valve	40		1.0
1	2 in. relief valve	42		.9
1	6 in. check valve	150		6.2
1	6 in. valve	180		7.2
22	Instrument air accumulators	285	Cyl. 4.5 x .8 dia.	2.3
Control Rod Drive System				
460	CRD blade	400	Cyl. 16.5 x 10 in. Dia.	9.0
225	CRD mechanism	480	Cyl. 18 x 8 in. Dia.	6.3
185	Direction control set	80	Parallel piped 1 x.8 x.4	.32
370	Scram valve	70	Cyl. 2 x 1 Dia.	1.6
210	Scram accumulator	140	Cyl. 3 x 8 in. Dia.	1.05
2	CRD pump	4000	6 x 2 x 2	24.0
2	Scram discharge volume	2000	Cyl. 10 x 1 dia.	7.9
2	Pump suction filter	400	Cyl. 6 x 1 dia.	4.7
2	CRD drive water filter	100	Cyl. 2 x 1 dia.	1.6
2042	3/4 in. valve	30		.2
185	1 in. valve	50		.3
379	2 in. valve	90		1
7	4 in. valve	268		3.1
1	2 in. restricting orifice	60	Cyl. .4 x .5 dia.	.31
2	2 in. flow control valve	160		1

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
1	1 in. air operated vent	90		.7
1	2 in. air operated drain	145		.8
2	2 in. flow element	50		.35
1	1 in. flow element	30		.25
39	Instrument root valve	8		.02
Condensate Demineralizers				
6	Filter demineralizers	11,675	Cyl. 10.6 x 7 dia.	400
6	Resin trap (w/ basket)	2100	Cyl. 4.1 x 2.7 dia.	22.9
6	Demin hold pump	350	3.6 x 1.3 x 1.6	7.7
1	Condensate backwash receiving tank	15,224	Cyl. 21.1 x 12.2 dia.	2471
1	Sludge disc mixing pump	924	4.9 x 2 x 1.7	16.2
1	Condensate decant pump	924	4.9 x 2 x 1.7	16.2
1	Condensate backwash transfer pump	924	4.9 x 2 x 1.7	16.2
2	Condensate phase separator tank	7001	Cyl. 17.2 x 15.2 dia.	3113
2	34 bf loop seal (6 in. pipe)			
1	36 in. flow element	1180		
2	20 in. butterfly valve	3900		
1	18 in. air operated butterfly	3100		
6	12 in. butterfly valve	1120		
12	12 in. air operated butterfly	1120		
6	12 in. flow element	1000		
22	8 in. air operated butterfly	530		14.0
2	8 in. butterfly	530		14.6
1	8 in. air operated valve	750		14.6
5	8 in. check valve	430		10.9
2	8 in. flow element	400		10.9
12	6 in. air operated valve	375		7.2
2	6 in. valve	375		7.2
21	6 in. air operated bttrfly	350		
3	6 in. check valve	270		6.0
5	4 in. air operated valve	180		3.1
1	4 in. check valve	130		2.5
2	3 in. air operated valve	130		1.4
6	3 in. air operated bttrfly	120		1.4
1	3 in. butterfly valve	120		1.2
1	3 in. rest. orifice	80		1.1
6	2 in. air operated bttrfly	55		1
2	2 in. butterfly	55		

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
43	2 in. valve	75		1
5	2 in. check valve	50		.8
3	2 in. relief valve	65		.9
1	1-1/2 in. valve	58		.9
13	1 in. air operated valve	45		.5
18	1 in. valve	45		.5
5	1 in. check valve	30		.5
6	1 in. relief valve	42		.5
149	Inst root (typ 3/4" globe)	32		.3
Equipment Drain Processing				
1	Waste collector filter	3991	Cyl. 11.2 x 4 dia.	138
1	Waste filter hold pump	700	3.3 x 1.6 x 1.6	9
1	Waste collector tank & eductor	22,530	Cyl. 18.1 x 16.2 dia.	373
1	Waste collector pump	625	4.6 x 1.6 x 2.6	20.1
1	Spent resin tank	1,448	Cyl. 5.9 x 5.9 dia.	165
1	Spent resin pump	224	3.6 x 1.3 x 1.6	7.9
1	Waste surge tank & eductor	40,269	Cyl. 20.1 x 25 dia.	9,945
1	Waste surge pump	625	4.6 x 1.6 x 2.6	20.1
2	Waste sample tank & eductor	15,330	Cyl. 14.5 x 15 dia.	2,515
2	Waste sample pump	508	4.3 x 1.6 x 2.3	16.4
1	8 in. air operated valve	320		14.2
1	6 in. air operated Valve	180		7.0
2	6 in. check valve	150		5.7
1	6 in. flow element	150		5.7
1	6 in. flow site glass	120		5.0
27	4 in. air operated valve	100		2.9
14	4 in. valve	100		2.9
13	4 in. check valve	80		2.3
1	4 in. resin strainer	80		2.7
7	4 in. restricting orifice	80		2.2
1	4 in. flow element	80		2.2
5	4 in. resin screen	70		1.1
4	3 in. air operated valve	65		1.1
7	3 in. valve	65		1.1
2	3 in. check valve	60		.9
1	3 in. restricting orifice	60		.9
1	3 in. flow element	60		.9
4	2 in. air operated valve	40		.8

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
14	2 in. valve	40		.8
2	2 in. check valve	35		.7
1	2 in. relief valve	40		.8
3	2 in. flow element	35		.7
2	1-1/2 in. air operated	35		.8
5	1-1/2 in. valve	35		.8
3	1-1/2 in. check valve	30		.4
4	1 in. air operated valve	30		.4
6	1 in. valve	30		.4
10	1 in. check valve	25		.3
1	1 in. flow element	25		.3
55	Inst root (typ 3/4" globe)	32		.3
Extraction Steam				
6	24 in. MOV	7,100		88.6
6	24 in. stop check	5,690		70.9
10	20 in. MOV	5,800		76.9
10	20 in. stop check	4,640		61.3
5	18 in. MOV	4,900		60.5
5	18 in. stop check	3,920		48.4
2	16 in. MOV	4,230		50.2
2	16 in. stop check	3,384		40.2
6	8 in. AOV	1125		14.6
4	6 in. MOV	588		7.2
4	4 in. AOV	268		3.1
10	2 in. AOV	75		1
12	2 in. restricting orifice	55		.8
85	Inst root (typ 3/4" globe)	32		.3
Feed and Condensate				
2	Turbine and feed pump	120,750	31.3 x 13.2 x 12.2 (skid)	5,045
3	Condensate booster pump	26,444	18.2 x 6.0 x 6.0 (skid)	642
3	Condensate pump	48,200	Cyl. 19.5 x 8.6 dia.	1,128
1	Gland exhaust condenser	8,880	Cyl. 10.2 x 2.6 dia.	55.8
2	Air ejector condenders & ejectors	14,568	19.1 x 5.0 x 9.9	945
1	Off gas condenser	1975	Cyl. 15.5 x 4.6 dia.	260
2	#6 feedwater heater	161,660	Cyl. 41.3 x 8 dia.	2038
2	#5 feedwater heater	151,681	Cyl. 42.2 x 8 dia.	2082
3	#4 feedwater heater	77,836	Cyl. 46.2 x 6 dia.	1280

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
3	#3 feedwater heater	110,767	Cyl. 48.2 x 6.9 dia.	1818
3	#2 feedwater heater	112,763	Cyl. 48.2 x 6.9 dia.	1818
3	#1 feedwater heater	138,710	Cyl. 51.2 x 6 dia.	1419
2	Condensate storage tanks	111,179	Cyl. 44 x 45 dia.	7063
2	Seal steam evaporator	29,627	Cyl. 35.3 x 6 dia.	978
2	Seal steam evap blwdwn cooler	470	Cyl. 3.5 x 1 dia.	2.8
16	24 in. MOV	15,750		88.6
3	24 in. valve	15,750		88.6
2	24 in. stop-check valve	9450		80
1	24 in. air operated check	10,000		81
4	24 in. flow element	9200		80
14	20 in. MOV	9000		78
8	20 in. valve	9000		78
6	20 in. check valve	5400		72
1	20 in. air operated check	6000		73
3	20 in. flow element	5400		72
2	18 in. MOV	10,140		60.5
2	18 in. valve	10,140		60.5
3	16 in. MOV	6000		44
1	16 in. air control valve	6000		44
1	16 in. air operated check	3900		40
2	16 in. flow element	3600		40
3	16 in. valve	6000		44
1	16 in. check	3600		40
2	12 in. air operated valve	3200		24.2
3	12 in. valve	3000		24.2
1	12 in. flow element	1800		21
1	10 in. air operated valve	1640		18.2
10	10 in. valve	1610		18.2
3	10 in. flow element	880		14.0
2	8 air operated control	1125		14.6
1	8 in. valve	1125		14.6
3	6 in. air operated	640		10.2
1	3 in. air operated valve	153		1.4
4	3 in. valve	153		1.4
1	3 in. flow element	100		1.1
5	2-1/2 MOV	120		1.2
5	2-1/2 in. valve	120		1.2
4	2-1/2 in. check valve	70		1

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
5	2 in. air operated valve	75		1
21	2 in. valve	75		1
16	1-1/2 in. valve	62		.9
3	1-1/2 in. relief valve	50		.7
2	1 in. MOV	50		.5
3	1 in. air operated valve	50		.5
79	1 in. valve	50		.5
2	1 in. check valve	38		.5
20	1 in. relief valve	42		.5
2	1 in. restricting orifice	38		.5
7	3/4 in. relief valve	40		.5
3	1/2 in. valve	25		.3
3	1/2 in. check	15		.2
3	1/2 in. restricting orifice	18		.2
119	Inst root (typ 3/4" globe)	32		.3
Fuel Pool Cooling and Cleanup				
2	FPCC pumps	1161	5 x 2 x 2	20
2	FPCC demin	3450	Cyl. 13.2 x 3 dia.	91.5
2	Skimmer surge tank	11,793	Cyl. 25 x 5.9 dia.	695
1	Resin eductor	80	Cyl. 1.6 x .6 dia.	.5
2	FPCC heat exchanger	4490	Cyl. 20.1 x 2 dia.	62
1	Supp. pool cleanup pump	1161	5 x 2 x 2	19.4
2	Resin tank agitator	80	Cyl. 8 x .4	3.2
1	Fuel pool precoat pump	625	4 x 1.6 x 2	12.7
1	(Precoat) dust evacuator	230	1.8 x 1.2 x 1.2	2.6
2	FPCC hold pump	429	3.6 x 1 x 1.7	5.9
2	FPCC output diffusers (120 feet of 8 in. pipe with holes)			
1	FPCC precoat tank	500	Cyl. 4 x 2.6 dia.	16.6
1	FPCC resin tank	500	Cyl. 4 x 2.6 dia.	16.6
2	10 in. valve (no internals)	305		17.6
4	10 in. valve	500		17.6
3	10 in. check valve	370		13.8
3	10 in. flow element	370		13.8
2	8 in. MOV	320		14.2
5	8 in. valve	320		14.2
1	8 in. check valve	240		10.6
10	6 in. MOV	180		7.0

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
14	6 in. valve	180		7.0
3	6 in. check valve	150		5.8
9	6 in. AOV	180		5.8
1	6 in. flow element	150		5.8
1	4 in. air operated valve	100		2.9
1	4 in. check valve	80		2.3
1	4 in. flow element	80		2.3
2	3 in. air operated valve	65		1.3
1	3 in. valve	65		1.3
2	3 in. check valve	60		1.0
3	2 in. air operated valve	40		.9
5	2 in. valve	40		.9
1	2 in. check valve	35		.7
1	2 in. relief valve	45		.8
1	1-1/2 in. valve	35		.8
10	1 in. valve	35		.4
1	1 in. check valve	30		.4
2	1 in. relief valve	38		.4
1	1 in. flow element	30		.4
75	Inst root (typ 3/4" globe)	32		.3
High Pressure Core Spray				
2	24" suction strainer	378.4		12.56
1	18" MOV	4900		60.5
1	24" check valve	7,100		88.6
1	3" valve	153		1.4
1	3" check valve	100		1.4
1	14" MOV	2,760		31.1
1	20" check valve	6,000		70.0
1	12 x 24" pump	60,374	4.9 dia. x 14.1	1071
1	16" check valve	1,600		31.1
1	2" valve	90		1.0
1	1 x 2" pump	181	4.9 x 1.9 x 1.9	18.9
1	1" check valve	50		0.3
1	1" valve	50		0.3
1	1 1/2 x 2" relief valve	90		2.0
2	6" valve	588		7.2
3	12" valve	2240		20.6
1	10" MOV	1610		16.1

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
2	12" MOV	2240		20.6
42	3/4" valve	90		0.2
Low Pressure Core Spray				
2	24" suction strainer	378.4		12.56
1	Vent strainer	94.6		3.14
28	3/4" valve	30		0.2
1	24" MOV	7,100		88.6
1	3/4" check valve	30		0.2
4	1 1/2" valve	62		0.6
1	14 x 24 pump	21,200	11.8 x 3.8 dia.	134
1	Pump pit	400	5.0 x 3.0 x 0.25	3.75
1	16" check valve	1600		31.1
1	12" MOV	2240		21.0
2	12" valve	2240		21.0
1	16" flow control valve	4030		45.0
1	6" flow control valve	588		7.2
1	6" valve	588		7.2
1	1 x 2" pump	181	4.9 x 1.9 x 1.9	18.9
1	1 1/2" check valve	50		0.3
1	3" valve	153		1.4
1	12" check valve	1200		14.6
1	3/4" AOV	30		0.2
Miscellaneous Drains				
1	Misc. drain tank #1	1073	8.9 x 4.0 dia.	112
1	Misc. drain tank #2 w/pumps	1441	15.1 x 5.6 dia.	372
2	6 in. valve	588		7.2
5	4 in. valve	268		3.1
8	3 in. MOV	153		1.4
3	3 in. air operated valve	153		1.4
3	3 in. valve	153		1.4
2	3 in. check valve	100		1.1
8	3 in. strainer	130		1.2
4	3 in. restricting orifice	100		1.1
2	3 in. flow element	100		1.1
1	2 in. MOV	75		1
11	2 in. air operated valve	75		1
11	2 in. valve	75		1

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
26	2 in. restricting orifice	55		.8
3	1-1/2 in. air operated	62		.9
2	1-1/2 in. valve	62		.9
8	1 in. air operated valve	50		.5
7	1 in. valve	50		.5
2	1 in. steam trap	90		.75
47	Inst root (typ 3/4" globe)	32		.3
14	1/2 in. valve	90		.75
2	2 1/2 in. AOV	131		1.2
3	2 1/2 in. valve	131		1.2
Main Steam				
1	72 in. MOV	100,000		2300
6	Stop valves	40,000		1800
6	Interceptor valves	10,000		1000
8	30 in. MSIV	1,400		170
1	24 in. MOV	7.100		88.6
4	24 in. relief valve	9,230		90.1
2	20 in. relief valve	7,700		86.1
1	16 in. MOV	4,230		50.2
2	16 in. check valve	3,380		40.1
2	14 in. check valve	2,220		29.4
2	14 in. MOV	2,760		31.1
2	12 in. MOV	2,500		28.0
2	12 stop check	1,970		31.1
4	30 in. flow restrictor	3,000		51.6
18	8 in. AO SRV	2,030		29.0
36	10 in. vacuum breakers	900		15.0
18	24 x 12 in. quenchers	1,650	7.0 x 8.0 x 8.0	448
8	10 in. MOV	1610		18.2
2	10 in. valve	1610		18.2
5	8 in. valve	1125		14.6
1	8 in. check valve	740		10.9
9	6 in. MOV	588		7.2
2	6 in. valve	588		7.2
1	6 in. check valve	420		6.0
4	6 in. relief valve	500		7.0
2	4 in. MOV	268		3.1
2	4 in. valve	268		3.1

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
11	3 in. MOV	153		1.4
6	3 in. air operated valve	153		1.4
4	3 in. valve	153		1.4
2	3 in. flow element	100		1.1
2	2 in. MOV	75		1
5	2 in. air operated valve	75		1
393	2 in. valve	75		1
7	1-1/2 in. air operated	62		.9
4	1-1/2 in. valve	62		.9
7	1 in. air operated valve	50		.5
75	1 in. valve	50		.5
195	Inst root (typ 3/4" globe)	32		.3
163	1/2 in. valve	25		.4
35	1 in. steam traps	90		.75
2	RFW turbine	40,000		1000
1	Moisture separator	2,000		200
4	2 in. strainer	95		1.2
2	4 in. strainer	220		4.0
2	8 in. relief valve	1,029		14.6
4	8 in. strainer	520		4.5
1	Gland steam condenser	4,000		200
2	Ejector condenser	4,000		200
1	HP turbine			
2	LP turbine			
1	Bypass valve assembly	11,600	17.3 x 3.0 x 11.0	571
2	Moisture separator reheater	459,000	12.7 dia. x 92.8	11,755
2	Steam evaporator	29,674	5.9 dia. x 35	3809
8	28 in. HOV governor valves	8000		
Main Steam Leakage Control				
8	1/2 in. valve	25		.3
28	3/4 in. valve	32		.3
2	1 in. flow element	38		.5
14	1 in. valve	50		.5
4	1 in. check valve	38		.5
4	1 1/2 in. flow element	46		.5
20	1 1/2 in. MOV	50		.5

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
2	1 1/2 in. check valve	46		.5
2	MSLC Fan (3 in.)	450		8
4	MSLC heater	125		2.4
Offgas (Augmented) System				
2	Catalytic recombiner vessel	999	Cyl. 6.9 x 4.6 dia.	116
2	Preheater heat exchanger	1185	Cyl. 12.2 x 4 dia.	150
1	Offgas condenser	1976	Cyl. 15.5 x 4.6 dia.	260
1	Water separator	598	Cyl. 5.6 x 1 dia.	4.3
2	Lab vacuum pump (P-11/1,/2)	<100	.8 x .8 x .8	.5
2	Lab vacuum pump (P-14/1, 4/1)	<100	.8 x .8 x .8	.5
2	Water separator	2994	Cyl. 6 x 1 dia.	4.6
8	Charcoal ads. vessel	8,980	Cyl. 22.8 x 4 dia.	281
2	Cooler condenser	1995	Cyl. 7.9 x 2 dia.	24.4
5	Seal water trap			
2	Pre-filter vessel	2495	Cyl. 10.6 x 3 dia.	73
2	After-filter vessel	2495	Cyl. 10.6 x 3 dia.	73
4	Dessicant dryers	1371	Cyl. 4 x 3.3 dia.	28
2	Dryer heater	7984	10.2 x 8.9 x 5.9	54
2	Dryer chiller	4990	12.2 x 1.7 x 18.2	366
2	Regen. blower	1400	2.2 x 2.6 x 3.6	20.6
9	6 in. air operated valve	180		6.8
18	6 in. valve	180		6.8
2	4 in. MOV	100		2.9
4	4 in. air operated valve	100		2.9
2	3 in. air operated valve	65		1.2
6	3 in. valve	65		1.2
4	2 in. air operated valve	40		.8
10	2 in. valve	40		.8
3	1-1/2 in. air operated	35		.7
4	1-1/2 in. valve	35		.7
1	1-1/2 in. relief valve	37		.7
2	1-1/2 in. flow element	30		.4
16	1 in. air operated valve	30		.4
30	1 in. valve	30		.4
2	1 in. relief valve	32		.4
89	Inst root (typ 3/4" globe)	32		.3

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
Turbine Bldg. and Rad Waste Bldg. Drains				
4	EDR sump pump	1289	Cyl. 7.9 x 1.7 dia.	16.9
4	FDR sump pump	1065	Cyl. 7.9 x 1.7 dia.	16.9
1	Chemical drain sump pump	1467	Cyl. 7.9 x 1.7 dia.	16.9
2	EDR sump pump	1289	Cyl. 7.9 x 1.7 dia.	16.9
3	FDR sump pump	1065	Cyl. 7.9 x 1.7 dia.	16.9
19	6 in. restricting orifice	150		5.7
6	3 in. valve	65		1.2
6	3 in. check valve	60		.9
3	2 in. MOV	40		.8
8	2 in. valve	40		.8
8	2 in. check valve	35		.6
22	Inst root (typ 3/4" globe)	32		.3
Radioactive Floor Drain Processing				
1	Floor drain demineralizer	1997	Cyl. 10.2 x 5 dia.	19.6
1	Floor drain sample tank	15,330	Cyl. 14.5 x 14.9 dia.	2511
1	Floor drain sample pump	508	4.3 x 1.7 x 2.3	16.9
1	Floor drain filter aid pump	260	2.2 x 1.3 x 1.3	3.7
1	Floor drain filter hold pump	699	3.3 x 5 x 5	8.1
1	Floor drain filter	3991	Cyl. 11.2 x 4 dia.	13.8
1	Floor drain collector pump	625	4.6 x 1.7 x 2.6	20.6
1	Floor drain collector tank	22,530	Cyl. 18.1 x 16.2 dia.	37.2
1	Waste decant pump	224	3.6 x 1.3 x 1.7	8.1
1	Waste sludge dsch mixing pump	634	4.6 x 1.6 x 1.7	12.5
1	Waste sludge phase sep tank	12,093	Cyl. 11.2 x 14.2 dia.	1771
2	Eductor	(Internal to two of the tanks, included in the tank volume and mass)		
2	8 in. air operated valve	320		9.9
3	6 in. air operated valve	180		5.4
2	6 in. check valve	150		5.4
1	6 in. flow site glass	100		1.2
1	4 in. MOV	100		2.8
21	4 in. air operated valve	100		2.8
18	4 in. valve	100		2.8
11	4 in. check valve	80		2.2
4	4 in. restricting orifice	80		2.2
1	4 in. resin strainer	250	2.3 x 1.6 x .5	1.8
5	3 in. air operated valve	65		1.2
3	3 in. valve	65		1.2

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
3	3 in. check valve	60		1.0
1	3 in. flow element	55		.9
2	3 in. flow site glass	40		.7
4	2 in. air operated valve	40		.9
9	2 in. valve	40		.9
3	2 in. check valve	35		.7
1	2 in. relief valve	40		.8
1	2 in. stop check	40		.7
2	2 in. flow site glass	30		.4
1	2 in. restricting orifice	35		.7
2	1-1/2 in. air operated	35		.8
1	1-1/2 in. valve	35		.8
1	1 in. relief valve	30		.6
1	1-1/2 in. flow element	30		.4
4	1 in. air operated valve	30		.4
3	1 in. check valve	25		.4
1	1 in. solenoid valve	30		.4
1	1 in. ball valve	30		.4
1	1 in. flow site glass	20		.4
50	Inst root (typ 3/4" globe)	15		.2
2	1/2 in. solenoid	15		.2
5	1/2 in. check	15		.2
Reactor Bldg. Closed Cooling Water				
3	RBCCW heat exchanger	16432	Cyl. 35.3 x 3 dia.	245
2	RBCCW pump	3518	5.3 x 2 x 2.6	27.6
1	RBCCW surge tank	1170	Cyl. 6 x 4 dia.	75
5	Drywell cooler & fans	1640	2.4 x 4 x 3	28.8
1	14 in. MOV	990		26
3	12 in. valve	730		23
7	10 in. MOV	550		17.5
6	10 in. valve	550		17.5
4	10 in. check valve	370		13.5
1	10 in. flow element	370		13.5
5	8 in. MOV	340		13.5
2	8 in. valve	340		13.5
2	8 in. air operated valve	340		10.4
4	8 in. flow element	240		10.4
6	6 in. valve	210		7.0

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
4	6 in. check valve	150		5.8
1	6 in. air operated valve	210		6.8
1	6 in. flow element	150		5.8
7	4 in. MOV	120		2.9
1	4 in. air operated valve	120		2.9
3	4 in. valve	120		2.9
9	3 in. valve	80		1.2
3	3 in. electro-hydraulic valve	80		1.0
1	2 in. air operated valve	45		.8
10	2 in. valve	45		.8
1	2 in. relief valve	48		.7
6	1 in. valve	30		.4
7	1 in. relief valve	32		.4
149	Inst root (typ 3/4" globe)	32		.3
Reactor Core Isolation Cooling				
1	Pelton wheel turbine/pump	13790	10.2 x 3.9 x 3.9	158
1	Barometric condenser	1219	Cyl. 6.9 x .66 dia.	2.3
1	Condenser pump	1496	Cyl. 2 x 1 dia.	1.5
1	Water leg pump	876	4.9 x 2 x 2	19
1	Vacuum pump	999	Cyl. 2 x .66 dia.	.7
1	Vacuum tank	898	2 x 2 x 3	11.8
1	Steam condensate drip pot	240	Cyl. 2.5 x .7 dia.	1
2	8 in. suction strainers	145	Cyl. 1.6 x 1 dia.	1.3
4	3/4 in. steam trap	55		.5
1	10 in. exhaust drip chamber	680	Cyl. 2 x 1 dia.	1.6
1	Turbine exhaust sparger	530	Cyl. 3 x 1 dia.	2.4
3	10 in. MOV	1610		18.2
1	10 in. check valve	880		14.0
2	8 in. MOV	1125		14.6
1	8 in. valve	1125		14.6
2	8 in. check valve	740		10.9
3	6 in. MOV	588		7.2
2	6 in. valve	588		7.2
1	6 in. check valve	420		6.0
2	6 in. air operated check	490		6.3
2	6 in. restricting orifice	420		6.0
3	4 in. MOV	268		3.1
1	4 in. hydraulic control valve	450		6.2

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
2	3 in. restricting orifice	100		1.1
4	2 in. MOV	75		1
1	2 in. air operated valve	75		1
4	2 in. valve	75		1
6	2 in. check valve	55		.8
1	2 in. relief valve	64		.9
2	2 in. restricting orifice	55		.8
1	1-1/2 in. MOV	62		.9
2	1-1/2 in. valve	62		.9
1	1-1/2 in. check valve	46		.5
1	1-1/2 in. relief valve	50		.7
1	1-1/2 in. restricting orifice	46		.5
5	1 in. air operated valve	50		.5
1	1 in. pressure control valve	60		.6
5	1 in. valve	50		.5
9	1 in. restricting orifice	38		.5
1	3/4 in. air solenoid	32		.3
2	3/4 in. pressure control valve	50		.5
8	Dragon valve (excess flow check)	50		.5
204	Inst root (typ 3/4" globe)	32		.3
Residual Heat Removal				
3	RHR pump	17,164	Cyl. 12.2 x 5 dia.	235
1	Water leg pump	875	5 x 2 x 2	19.4
1	Drywell upper spray ring header	18,860	135 Ft of 12 in. Class I pipe	144.5
1	Drywell lower spray ring header	28,774	206 Ft of 12 in. Class I pipe	220.4
1	Wetwell spray ring header	11,778	260 Ft of 6 in. Class I pipe	62.4
6	Suppression pool suction strnrs	430	Cyl. 2.7 x 2.3 dia.	11.2
2	RHR heat exchanger	64,295	Cyl. 29.4 x 5 dia.	565.8
3	24 in. MOV	15,750		88.6
2	20 in. MOV	9,000		78
1	20 in. valve	9,000		78
11	18 in. MOV	10,140		60.5
8	18 in. valve	10,140		60.5
5	18 in. check	6084		54.5
3	18 in. flow element	6084		54.5
2	18 in. restricting orifice	6084		54.5
4	16 in. MOV	6000		44
4	14 in. MOV	3400		34

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
2	14 in. valve	3400		34
3	14 in. air operated check	2140		31
2	14 in. restricting orifice	2080		31
3	12 in. MOV	2240		25
3	12 in. valve	2240		25
3	12 in. air operated check	1280		22
1	12 in. restricting orifice	1200		22
2	10 in. valve	1610		18.2
1	10 in. check valve	880		14.0
2	8 in. MOV	1125		14.6
1	8 in. air operated control valve	740		10.9
3	6 in. MOV	588		7.2
3	6 in. valve	588		7.2
4	6 in. check valve	420		6.0
3	6 in. ganged restricting orifice	680		8.0
2	6 in. restricting orifice	400		6.0
2	6 in. relief valve	500		7.0
1	6 in. flow element	420		6.0
4	4 in. MOV	268		3.1
2	4 in. valve	268		3.1
1	4 in. check valve	180		2.5
3	3 in. MOV	153		1.4
11	3 in. valve	153		1.4
1	3 in. check valve	100		1.1
1	2-1/2 in. AOV	90		1.3
1	2 in. MOV	75		1
8	2 in. valve	75		1
4	2 in. check valve	55		.8
2	2 in. relief valve	64		.9
2	1-1/2 in. MOV	62		.9
3	1-1/2 in. valve	62		.9
3	1-1/2 in. check valve	46		.5
2	1-1/2 in. stop check	50		.7
1	1-1/2 in. restricting orifice	46		.5
2	1 in. MOV	50		.5
8	1 in. valve	50		.5
1	1 in. check valve	38		.5
8	1 in. relief valve	42		.5
4	Dragon valve (excess flow check)	50		.5

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
4	3/4 in. solenoid valve	40		.5
227	Inst root (typ 3/4" globe)	32		.3
Recirculation				
2	Recirculation pump w/motor	96,072	10.7 x 11.9 x 20.5	2607
2	Seal water injection heat exchanger	(Included in the motor assembly)		
2	24 in. HOV	10,500		88.6
4	24 in. MOV	10,500		88.6
2	3/4 in. check valve	25		.3
76	3/4 in. valve	32		.3
28	3/4 restricting orifice	25		.3
12	3/4 in. flow element	25		.3
2	3/4 in. relief valve	27		.3
2	3/4 in. MOV	32		.3
92	1 in. valve	50		.5
10	1 in. restricting orifice	38		.8
4	2 in. valve	75		1.2
30	Dragon valve (excess flow check)	50		.5
Reactor Water Cleanup System				
2	RWCU Pump	1300	5 x 2 x 2	20
2	Clean up hold pump	1177	4.3 x 1.6 x 2.3	15.9
1	Clean up precoat pump	1000	4.3 x 1.3 x 2.3	12.9
1	Sludge discharge pump	625	4 x 1.6 x 2	12.7
1	Decant pump	225	3.6 x 1.3 x 1.3	6.3
2	Non-regenerative HX	9000	Cyl. 26 x 2.7 dia.	149
2	Regenerative HX	9100	Cyl. 21 x 2.7 dia.	120
	Filter demineralizer	7000	Cyl. 8.9 x 3 dia.	62.9
1	Batch tank	500	Cyl. 4 x 2.6 dia.	16.6
2	Phase separator tank	4500	Cyl. 8.9 x 10.2 dia.	73.2
1	Precoat agitator	60	Cyl. 8 x .4 dia.	1
7	6 in. MOV	588		7.2
2	6 in. valve	588		7.2
1	6 in. check valve	588		7.2
2	6 in. flow element	588		7.2
1	6 in. restricting orifice	588		7.2
6	4 in. MOV	268		3.1
16	4 in. air operated valve	268		3.1
1	4 in. flow element	268		3.1

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
11	4 in. valve	268		3.1
4	4 in. check valves	268		3.1
1	4 in. relief valve	268		3.1
1	4 in. restricting orifice	268		3.1
16	3 in. air operated valve	153		1.4
4	3 in. valve	153		1.4
2	3 in. check valve	153		1.4
2	3 in. flow element	153		1.4
6	2 in. air operated valve	90		1
10	2 in. valve	90		1
1	2 in. check valve	90		1
1	1 in. air operated valve	50		.3
21	1 in. valve	50		.3
5	1 in. relief valve	50		.3
3	Excess flow check valve	35		.2
129	Inst root (typ 3/4" globe)	30		.2
2	1/2 in. air operated valve	20		.1
2	1/2 in. valve	20		.1
2	1/2 in. check valve	15		.1
Reactor Building Equipment and Floor Drains				
4	Drain sump pump	1153	Cyl. 9.9 x 1.7 dia.	21.2
3	Drain sump pump	1432	Cyl. 10.2 x 1.7 dia.	21.9
1	Equipment drain heat exchanger	1496	Cyl. 7.9 x 1 dia.	60.8
1	Drywell equipment drain HX	1496	Cyl. 7.9 x 1 dia.	60.8
4	6 in. air operated valve	180		5.6
24	6 in. restricting orifice	150		5.6
7	4 in. valve	100		2.9
1	4 in. check valve	80		2.3
6	4 in. restricting orifice	80		2.3
18	3 in. air operated valve	65		1.2
9	3 in. valve	65		1.2
5	2 in. valve	40		.8
5	2 in. check valve	35		.7
1	1-1/2 in. air operated	35		.7
1	1-1/2 in. valve	35		.7
1	1-1/2 in. restricting orifice	25		.5
1	1-1/2 in. flow element	25		.5
4	1 in. valve	28		.5

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
2	1 in. flow element	20		.5
12	Inst root (typ 3/4" globe)	16		.3
Sample Systems				
4	Sample rack	180	Typical: 2 x 1 x 6	12
4	Fume hood with sink	260	Typical: 2 x 3 x 3	18
4	Constant temperature bath	140	Typical: 2 x 1 x 2	4
1	1 in. air operated valve	40		.4
4	3/4 in. solenoid valve	30		.4
2	1/2 in. air operated valve	25		.3
Standby Gas Treatment				
42	2" check valve	55		0.8
2	18" valves	4,900		60.5
14	18" damper, MOV	1,240		88.6
2	18" damper, AOV	1,240		88.6
2	SGT filter unit	19,600	6.08 x 46.25	
8	3/4" valve	30		0.2
4	Blower	4,500		121
Heater Vents and Drains				
2	Steam evap drain tank (5A&B)	1,977	4.0 x 3.0 dia.	28.3
2	Heater drain tank (4A&B)	13,820	7.9 x 4.0 dia.	99.3
2	Moisture separator drain tank	3,777	8.9 x 4.6 dia.	147.9
4	Reheater drain tank	2,497	7.8 x 3.0 dia.	55.1
4	Reheater drain tank	13,820	7.9 x 4.0 dia.	99.3
2	20 in. valve	5,800		76.6
1	18 in. AOV	4,900		60.5
2	18 in. flow element	4,160		50.8
2	18 in. valve	4,900		76.6
5	16 in. flow element	2,791		33.1
4	16 in. check valve	2,791		33.1
5	16 in. MOV	4,230		50.2
9	16 in. AOV	4,230		50.2
7	16 in. valve	4,230		50.2
7	12 in. AOV	2,500		28.0
12	12 in. MOV	2,500		28.0
6	12 in. valve	2,500		28.0
2	12 in. flow elements	2,100		23.5

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
9	10 in. MOV	1610		18.2
13	10 in. AOV	1610		18.2
6	8 in. MOV	1125		14.6
2	8 in. AOV	1125		14.6
8	8 in. check valve	740		10.9
6	8 in. flow element	740		10.9
6	6 in. MOV	588		7.2
4	6 in. valve	588		7.2
2	6 in. check valve	420		6.0
13	6 in. AOV	588		7.2
4	6 in. flow element	420		6.0
12	4 in. MOV	268		3.1
8	4 in. air operated valve	268		3.1
6	4 in. valve	268		3.1
1	4 in. flow element	180		2.5
12	3 in. MOV	153		1.4
8	3 in. air operated valve	153		1.4
10	3 in. valve	153		1.4
1	3 in. restricting orifice	100		1.1
4	3 in. flow element	100		1.1
2	2 in. air operated valve	75		1
152	2 in. valve	75		1
319	1 in. valve	50		.5
160	Inst root (typ 3/4" globe)	32		.3
2	1/2 in. valve	25		.4
3	2 1/2 in. valve	131		1.2
1	1 1/2 in. MOV	62		.9
2	1 1/2 in. valve	62		.9
1	1 1/2 in. check valve	50		.7
Miscellaneous Items from Partial Systems				
5	TIP drive unit	796	4 x 2.6 x 3	31
8	TIP indexing unit	20	Cyl. 2.5 x .8 dia.	1.3
5	TIP ball valve	50		.9
5	Explosive shear valve	50		.9
5	TIP shield pig	340	Cyl. 1.5 x .8 dia.	.8
1 set	TIP tubing	650	Bent and crushed	45
2	Hogger (mechanical vacuum pump)	6,985	2. x 2.6 x 2.6	13.8
1	Refueling bridge	54,886		800

Table C.5 (Continued)

Number	Component	Weight (lb)	Physical Dimensions (ft)	Volume ft^3
1	Reactor service platform	11,475	3.5 x 23 dia.	728
2	Refueling mast	650	Cyl. 21 x 2 dia.	.22
1	CRD removal turntable	5489	20 x 8 x 2	160
1	CRD removal trolley	380	1.8 x 2 x 16	40
1	Incore instrument grapple	80	Cyl. 2.8 x .7 dia.	1.1
1	Fuel support piece grapple	90	1.5 x 1 x 1	1.5
1	Control blade grapple	130	Cyl. 14 x .5 plus cyl. 3 x .9 dia.	4.7
1	Spent fuel pool work table	980	Stainless table 3 x 20 x .3	25
2	Fuel prep machine	840		30
1	Channel measurement machine	930	2.2 x 3 x 22	25
185	Blade guide (aluminum)	160	5 x .5 x 14	7
1	In core instrument strongback	220	Cyl. 18 x .9 dia.	11.5
1	Manipulators, crows feet, etc.	300	1.5 x 1.5 x 2	4.5
20	In-vessel manipulator poles	30	Cyl. 15 x .2 dia.	.5
9	Drywell recirculation fan	560	Cyl. 2.4 x 2.8 dia.	14.8
4	Stud tensioner	2300	Cyl. 3.2 x 1.5 dia.	5.6
1	RPV head strongback	4700	3 x 10 x 10	8
1	Dryer/separator strongback	1333		15
18	SRV tailpipe and sparger	--	2761 Ft of 10" pipe	
84	24" suppression pool downcomer	--	47 Ft each of 24" pipe	
18	28" suppression pool downcomer	--	47 Ft each of 28" pipe	
1	Portions of rx head space frame	1240		18
1	Upper drywell spray header	--	147 Ft of 12" pipe	
1	Lower drywell spray header	--	222 Ft of 12" pipe	
1	Suppression pool spray header	--	267 Ft of 6" pipe	

Piping from RCS and Other Systems		
Piping Size	Total Length (ft)	Total Weight (lb)
1/2 - 2"	66,160	150,279
3 - 10"	41,515	848,576
12 - 16"	9,757	697,113
18 - 24"	13,419	2,412,700
26 - 30"	2,933	883,745
36 - 72"	2,159	582,664

Table C.5 (Continued)

Pipe Hangers	
Hanger Size	**Number**
1 - 2" pipe size	7,500
> 2" pipe size	5,000

Using labor costs, equipment and consumables costs, and the work difficulty factors, the CECP calculates the unit cost factor for each decommissioning activity. Unit cost factors are in dollars per unit (e.g., dollars per cut in the case of piping). The unit cost factor is thus defined as the estimated amount of money required to perform some operation on one unit of a component or material. The CECP calculates unit cost factors for removing, decontaminating, transporting, and disposing of a variety of equipment and material.

General work difficulty factors are presented in Section C.2.1. Labor rates, crew staffing levels and consumables costs for the cutting and packaging crews are discussed in Section C.2.2. In Sections C.2.3 through C.2.21, the assumptions of C.2.1 and C.2.2 are applied to specific system components to arrive at the reference BWR unit cost factors.

C.2.1 Analysis of Work Durations and Available Time

The basic assumptions about lost work time per shift are as follows:

- The crews work 8-hour shifts,
- The crew members take two 15-minute breaks per shift,
- The crew members suit-up or un-suit in anti-contamination clothing 8 times per shift, @ 15 minutes each time, including travel time to and from the work-place, and
- The crew members devote 25 minutes per shift to ALARA-related activities, e.g., radiation protection guidance, etc.

Thus, a total of 30 + 120 + 25 = 175 crew-minutes are lost from each 8 hr. shift, leaving a total of 480 - 175 = 305 crew-minutes available for productive work. These non-production time factors are:

$$[\,1 + (30/305) + (120/305) + (25/305)] \times 305 = 480$$
$$[\,1 + 0.098 + 0.393 + 0.082] \times 305 = 480$$

and the non-productive time adjustment factor becomes 480/305 = 1.574. Worker efficiency while working in respiratory equipment is assumed to be 83% of normal, or a work adjustment factor of 1.2 x work duration. Worker efficiency while working on scaffolding is assumed to be 91% of normal, or a work adjustment factor of 1.1 x work duration. These default factors may be changed if the CECP user so desires.

Total crew-minutes per activity = estimated work duration x work difficulty adjustment x non-productive time adjustment
= estimated work duration x 1.3 x 1.574
= estimated work duration x 2.046

Radiation Exposure time = estimated work duration x 1.3

C.2.2 Labor and Materials Costs per Hour of Cutting Crew Time

The postulated staffing for crews engaged in cutting and packaging piping and tanks within the reference BWR is given below, together with appropriate labor rates for each type of crew member. Multiplying the hourly rate for each labor type by the number of crew members of that type and summing over all labor types yields the labor rate per crew hour.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[(a)] ($/crew-hr)
3.0	Laborer	26.37	79.11
1.5	Crafts	49.70	74.55
0.5	H. P. Tech.	36.82	--[(b)]
0.5	Crew Leader	54.84	27.42
5.5			181.08
Average labor cost, 2 shift operation			$190.13[(c)]

(a) These values include 110% overhead and 15% DOC profit.
(b) Part of DOC overhead staff. Labor costs appear in undistributed cost.
(c) A 10% shift differential is included for second shift

Material costs are a function of the piping/tank size. Principal components are absorbent materials, plastic sheeting and bags, and gases for torches. The quantities and unit costs used in these analyses are listed below.

		Piping						Tanks
Material		0-2 in. dia		2-14 in. dia.		32-47 in. dia.		1/2 in. tank wall
Abs. Matl.	@$0.32/ft^2	10 ft^2	$3.20	15 ft^2	$4.80	20 ft^2	$6.40	length x dia. x $0.32
Plastic	@$0.04/ft^2	25 ft^2	$1.00	37.5 ft^2	$1.50	50 ft^2	$2.00	length x dia. x $0.04
Gases	@$6.75/hr	0.017 hr	$0.11	0.033 hr	$0.22	0.33 hr	$2.23	Hours of cut x $6.75
Including 15% DOC profit:			$4.97/cut		$7.50/cut		$12.22/cut	1.15 x As calculated per tank

C.2.3 Removal and Packaging of Contaminated Piping 0.5 in. Dia. to 2 in. Dia.

All contaminated piping is assumed to be stainless steel, Schedule 140 to 160. Cutting is accomplished using a plasma arc torch mounted on a mechanically-driven track system. The piping is cut into nominal 15 ft lengths, for packaging into maritime containers. The basic operations are listed below, together with the estimated clock times required to accomplish each operation.

- Install scaffolding at cut location — 15 min.
- Remove insulation at cut location — 5 min.
- Attach track-mounted torch system — 5 min.

•	Install contamination control system	5 min.
•	Cut pipe	1 min.[a]
•	Remove track-mounted torch system	5 min.
•	Bag ends of piping section	5 min.
•	Remove contamination control system	5 min.
•	Transfer the piping section to a maritime container	5 min.[b]
•	Remove scaffolding and move to next location	15 min.

Crew-minutes for making one cut (actual duration)	61 min.
Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration	1.3 x actual duration = 79.3 min.
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per cut	1.574 x adjusted duration = 125 min.
Crew-Hours per cut	= 2.08 hrs.
Total Labor Cost per cut	2.08 x $190.13/crew-hr = $395.47
Crew Exposure Hours per cut (adjusted duration)	= 1.32 hrs.
Exposure person-hours per cut @ 5.5 pers-hours/crew-hour	= 7.3 hrs.

(a) Nominal time for cutting rate of 30 in./min.
(b) This activity is in parallel with scaffold removal/next installation.

C.2.4 Removal and Packaging of Contaminated Piping 2.5 in. Dia. to 14 in. Dia.

All contaminated piping is assumed to be stainless steel, Schedule 140 to 160. Cutting is accomplished using a plasma arc torch mounted on a mechanically-driven track system. The piping is cut into nominal 15 ft lengths, for packaging into maritime containers. The basic operations are listed below, together with the estimated clock times required to accomplish each operation.

•	Install scaffolding at cut location	15 min.
•	Remove insulation at cut location	10 min.
•	Install track-mounted torch system	10 min.
•	Attach lifting devices to pipe section	10 min.
•	Install contamination control system	10 min.
•	Cut pipe	2 min.[a]
•	Remove track-mounted torch system	5 min.

•	Bag ends of piping section	5 min.
•	Remove contamination control system	5 min.
•	Transfer the piping section to a maritime container	10 min.[b]
•	Remove scaffolding and move to next location	15 min.

Crew-minutes for making one cut(actual duration) 87 min.

Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration	1.3 x actual duration = 113 min.
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per cut	1.574 x adjusted duration = 178 min.
Crew-Hours per cut	= 2.96 hrs.
Total Labor Cost per cut	2.96 x $190.13/crew-hr = $562.78
Crew Exposure Hours per cut (adjusted duration)	= 1.88 hrs.
Exposure person-hours per cut @ 5.5 pers-hours/crew-hour	= 10.36 hrs.

(a) Nominal time for cutting rate of 30 in./min.
(b) This activity is in parallel with scaffold removal/next installation.

C.2.5 Removal and Packaging of Contaminated RCS Piping

All contaminated piping is assumed to be stainless steel, Schedule 140 to 160. Cutting is accomplished using a plasma arc torch mounted on a mechanically-driven track system. The piping is cut for packaging into maritime containers, with the relatively straight sections between the RPV and the steam generator and between the RPV and the primary pump removed in one piece, and the curved section between the steam generator and the primary pump cut into two sections. The basic operations are listed below, together with the estimated clock times required to accomplish each operation.

•	Install scaffolding at cut location	30 min.
•	Remove insulation at cut location	20 min.
•	Attach lifting devices to piping section	20 min.
•	Install track-mounted torch system	20 min.
•	Install contamination control system	15 min.
•	Cut pipe	20 min.[a]
•	Remove track-mounted torch system	15 min.
•	Bag ends of piping section	10 min.
•	Remove contamination control system	10 min.

- Transfer the piping section to a maritime container — 30 min.(b)
- Remove scaffolding and move to next location — 30 min.

Crew-minutes for making one cut (actual duration)	190 min.
Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per cut	1.3 x actual duration = 247 min.
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per cut	1.574 x adjusted duration = 389 min.
Crew-Hours per cut	= 6.48 hrs.
Total labor cost per cut	6.48 x $190.13/crew-hr = $1,232.04
Crew Exposure Hours per cut (adjusted duration)	= 4.12 hrs.
Exposure Pers-hours per cut @ 5.5 pers-hours/crew-hour	= 22.6 hrs.

(a) Based on 30 inch pipe and assuming a nominal cutting rate of 8 in./min.
(b) This activity is in parallel with scaffold removal/next installation.

C.2.6 Removal and Packaging of Contaminated Tanks, Tank Diameters between 3 ft and 15 ft

All contaminated tanks are assumed to be stainless steel, approximately 0.5 inches in wall thickness. Cutting is accomplished using a plasma arc torch mounted on a mechanically driven track system. The cutting rate is 4 ft/min., which includes the torch changeout time of 15 min. for every 30 min. of torch operation. The tank is cut into nominal 3.5 ft x 7.5 ft segments for packaging in maritime containers, which are limited in contents weight to less than 35,000 lb. The basic operations are listed below, together with the estimated clock times required to accomplish each operation.

- Install scaffolding around the tank location — 15 min.
- Remove insulation from the tank — 30 min.
- Install contamination control system — 15 min.
- Install track-mounted torch system — 10 min.
- Attach lifting devices to tank section — 10 min.
- Make major cut in tank wall (a) — A min.
- Remove track-mounted torch system — 10 min.
- Place the tank section in the disposal container — 10 min.(b)
- Remove contamination control system — 15 min.
- Remove scaffolding and move to next location — 15 min.

The number of major cuts per tank is given by:

$$N = [1 + (h/7.5)\text{next integer}] + [(\pi \times D/3.5)\text{next integer}] + 6\ (>7.5\text{ ft dia.}) \text{ or } + 2\ (<7.5\text{ ft dia.}),$$

where D is the tank diameter and h is the tank height, in feet. Major cuts are defined as circumferential cuts, longitudinal cuts, and cuts across tank ends.

The cumulative length of cut, L, is given by:

$$L = \pi \times D \times [1 + (h/7.5)\text{next integer}] + h \times [(\pi \times D/3.5)\text{next integer}] + 6 \times D\ (>7.5\text{ ft dia.}) \text{ or } + 2 \times D\ (<7.5\text{ ft dia.})$$

(a) These operations are repeated for each major cut.
(b) This activity is conducted in parallel with torch track removal and reinstallation for next cut.

The average time (minutes) per cut, A, is given by:

$$A = [L/(\text{cutting rate in ft/min.})]/N$$

Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration	1.4 x actual duration
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Cumulative crew-hours per tank	1.3 x 1.574 x actual duration
or	1.3 x 1.574 x [90 + N x (30 + A)]/60

Other Calculations:
Total Labor Cost per Tank: (Crew-hours/tank)(Dollars/crew-hour)
One crew-hour = 5.5 person-hours. The cost per crew-hour is defined to be $190.13
Crew Exposure Hours per Tank (adjusted duration) = 1.3 x [90 + N x (30 + A)]/60
Exposure pers-hours per tank @ 5.5 pers-hours/crew-hour = 5.5 x [1.3 x [90 + N x (30 + A)]/60

Example Calculation:
Diameter = 10.7 ft, height = 27 ft
N, the number of major cuts is given by:
N = [1 + (27/7.5){rounded to next integer}] + [π x 10.7/3.5]{rounded to next integer} + 6 = 1 + 4 + 10 + 6 = 21
L, the total length of cut in sectioning the tank is given by:
L = π x 10.7 x (1 + 4) + 27 x 10 + 6 x 10.7 = 503 ft
A, the average cutting time, is given by:
A = L/N/(cutting rate) = 503 ft / 21 cuts / 4 ft/min. = 6 min./cut
Crew-hours = 1.3 x 1.574 x [90 + N x (30 + A)]/60 = 2.046 x [90 + 21 x (30 + 6)]/60 = 28.85 crew-hours
Labor Costs = 28.85 crew-hours x $190.13/crew-hour = $5485.25

Person-hours = 28.85 x 5.5 pers-hours/crew-hour = 158.7 pers-hours
Exposure pers-hours = 1.3 x (14.1 exp. crew-hours) x 5.5 pers-hours/crew = 100.8 exposure person-hours

C.2.7 Labor and Materials Costs per Hour of Equipment Removal Time

The postulated staffing for crews engaged in removing and packaging pumps and miscellaneous equipment within the reference BWR is given below, together with appropriate labor rates for each type of crew member. Multiplying the hourly rate for each labor type by the number of crew members of that type and summing over all labor types yields the labor rate per crew hour.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)
2.0	Laborer	26.37	52.74
1.0	Crafts	49.70	49.70
0.5	H. P. Tech.	36.82	--[b]
0.5	Crew Leader	54.84	27.42
4.0			129.86
Average labor cost, 2-shift operations			$136.35[c]

(a) These values include 110% overhead and 15% DOC profit.
(b) Part of DOC overhead staff. Labor costs appear in undistributed cost.
(c) A 10% shift differential is included for second shift.

Material costs depend on pump/equipment size. For this analysis, it is assumed that the average pump or item of miscellaneous equipment is a cylinder whose height is twice its diameter. To be conservative, it is further assumed that this cylinder is oriented with its axis horizontal to the floor and that the area of the absorbent material should be twice the projected area of the cylinder on the floor. Under these assumptions, the area of required absorbent material is

$$\text{area} = 3 \times \text{vol}^{2/3},$$

where vol is the volume of the item. The costs of plastic and absorbent material, including 15% DOC profit are then:

Abs. Matl. @ $0.32/ft^2 = 3 x vol$^{2/3}$ x $0.32 x 1.15
Plastic @ $0.04/ft^2 = 3 x vol$^{2/3}$ x $0.04 x 1.15

C.2.8 Removal and Packaging of Pumps and Miscellaneous Equipment Weighing Less than 100 Pounds

For items weighing less than 100 pounds, it is assumed that scaffolding will not be required and that the attached piping has already been severed from the item (accounted for in Sections C.2.4 or C.2.5). The basic removal operations are listed below, together with the estimated clock times required to accomplish each operation.

- Disconnect power/instrument/sensor lines 20 min.
- Unbolt item from its mounting 10 min.
- Rig and move item to packaging area 10 min.

Crew-minutes for removing one item (actual duration)	40 min.
Work Difficulty Adjustments:	
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per item	1.2 x actual duration = 48 min.
Non-productive-time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per item	1.574 x adjusted duration = 75.6 min.
Crew-Hours per item	= 1.26 hrs.
Total labor cost per item (1.26 x $136.35/crew-hr)	= $171.69
Crew Exposure Hours per item (adjusted duration)	= 0.80 hrs.
Exposure Person-hours per item @ 4.0 pers-hours/crew-hour	= 3.20 hrs.

C.2.9 Removal and Packaging of Pumps and Miscellaneous Equipment Weighing More than 100 Pounds

The assumptions here are similar to the ones made in the preceding section, except that it is now assumed that scaffolding may be required and that the removal operation will be more time consuming. The basic removal operations are listed below, together with the estimated clock times required to accomplish each operation.

- Install scaffolding at equipment location — 30 min.
- Disconnect power/instrument/sensor lines — 30 min.
- Unbolt equipment from its mounting — 20 min.
- Rig and move item to packaging area — 10 min.

Crew-minutes for removing one item (actual duration)	90 min.
Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per item	1.3 x actual duration = 117 min.
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per item	1.574 x adjusted duration = 184 min.
Crew-Hours per item	= 3.07 hrs.
Total labor cost per item (3.07 x $136.35/crew-hr)	= $418.59
Crew Exposure Hours per item (adjusted duration)	= 1.95 hrs.
Exposure Pers-hours per item @ 4.0 pers-hours/crew-hour	= 7.80 hrs.

C.2.10 Removal and Packaging of Electrical Equipment Weighing Less than 100 Pounds

For electrical items weighing less than 100 pounds, it is assumed that scaffolding will not be required. The basic removal operations are listed below, together with the estimated clock times required to accomplish each operation.

• Disconnect electrical power	20 min.
• Unbolt item from its mounting	10 min.
• Rig and move item to packaging area	10 min.
Crew-minutes for removing one item (actual duration)	40 min.
Work Difficulty Adjustments:	
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per item	1.2 x actual duration = 48 min.
Non-productive-time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per item	1.574 x adjusted duration = 75.6 min.
Crew-Hours per item	= 1.26 hrs.
Total labor cost per item (1.26 x $136.35/crew-hr)	= $171.69
Crew Exposure Hours per item (adjusted duration)	= 0.80 hrs.
Exposure Person-hours per item @ 4.0 pers-hours/crew-hour	= 3.20 hrs.

C.2.11 Removal and Packaging of Electrical Equipment Weighing More than 100 Pounds

The assumptions here are similar to the ones made in the preceding section, except that the removal operation will be more time consuming. The basic removal operations are listed below, together with the estimated clock times required to accomplish each operation.

• Disconnect electrical power	30 min.
• Unbolt equipment from its mounting	20 min.
• Rig and move item to packaging area	10 min.
Crew-minutes for removing one item (actual duration)	60 min.
Work Difficulty Adjustments:	
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per item	1.2 x actual duration = 72 min.
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per item	1.574 x adjusted duration = 113 min.

Crew-Hours per item	= 1.88 hrs.
Total labor cost per item (1.88 x $136.35/crew-hr)	= $256.34
Crew Exposure Hours per item (adjusted duration)	= 1.2 hrs.
Exposure Pers-hours per item @ 4.0 pers-hours/crew-hour	= 4.80 hrs.

C.2.12 Removal and Packaging of RCS Pumps

The attached piping is presumed severed from the pump body previously (accounted for under RCS Piping Removal). The pump ports are sealed with steel plates welded in place, lifting attachments are connected to the pump/motor assembly, the supports and stabilizers are removed, and the unit is lifted to the operating deck and placed in a horizontal shipping cradle. The basic operations are listed below, together with the estimated clock times required to accomplish each operation.

• Install scaffolding at cut location	60 min.
• Remove pump cooling system ducts	30 min.
• Remove insulation from pump body	30 min.
• Disconnect lubrication and seal cooling lines	20 min.
• Disconnect instrument/sensor lines	10 min.
• Cap inlet and outlet pump ports	30 min.
• Attach lifting devices to pump assembly	60 min.
• Disconnect pump supports and stabilizer units	90 min.
• Lift the pump assembly to the operating deck	60 min.
• Secure the pump assembly to the shipping cradle	30 min.
• Remove scaffolding and move to next location	60 min.
Crew-minutes for removing one pump (actual duration)	480 min.
Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per pump	1.3 x actual duration = 624 min.
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per pump	1.574 x adjusted duration = 982 min.
Crew-Hours per pump	= 16.4 hrs.
Total labor cost per pump (16.37 x $190.13/crew-hr)	= $3,112.43
Crew Exposure Hours per pump (adjusted duration)	= 10.4 hrs.
Exposure Person-hours per pump @ 5.5 pers-hours/crew-hour	= 57.2 hrs.

C.2.13 High-Pressure Water Wash/Vacuuming of Surfaces

All contaminated horizontal surfaces are washed using a manually operated cleaning system which washes the surface using high-pressure (250 psig) jets and collects the water and removed material simultaneously using a vacuum collection system. This system permits excellent cleansing while avoiding recontamination due to dispersion of the water. The same system, employing modified cleansing heads, is used to wash vertical or overhead surfaces and stairs. An additional 20% of labor time is postulated to be required for the vertical and overhead surfaces cleaning and an additional 5% of labor time is required for stairs. The costs per square foot of surface cleaned are developed below.

A crew consisting of 2 laborers, 1 crafts, 0.5 crew leader, and 0.5 health physics technician is required for the cleansing operation. Normally, there will be two crews working per shift, with two-shift operations. The crew labor costs and exposure levels are:

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Doses rate (mrem/crew-hr)
2.0	Laborer	26.37	52.74	2
1.0	Crafts	49.70	49.70	0
0.5	H. P. Tech.	36.82	--[b]	0
0.5	Crew Leader	54.84	27.42	0
4.0			129.86	2
Average labor cost, 2 shift operation			$136.35[c]	

(a) These values include 110% overhead and 15% DOC profit.
(b) Part of DOC overhead staff. Labor costs appear in undistributed cost.
(c) A 10% shift differential is included for second shift

During an 8-hour (480 minute) shift, the actual cleansing time is estimated to be 4 hours, based on the following:

480 - 120 (suit-up) - 30 (breaks) - 25 (ALARA) - 15 (warmup) - 50 (cleanup), or 240 minutes net working time using the cleansing system. Assuming a cleansing rate of 8 ft^2/minute, about 1,920 ft^2 can be cleansed in one shift.

Thus, the cost per square foot of surface cleansed is given by:

$$8\ (\$136.35)\ /\ 1920\ ft^2 = \$0.568/ft^2$$

Material costs to support system operation include:

Vacuum hose replacement (4 times/yr)	$1,180
HEPA filter replacement (once/yr)	300
Misc. parts (steam hose,filters) per yr	2,000
Total material costs/yr	$3,480

With a system operating time of 1040 hr/yr, the material costs per ft^2 are:

$$[\$3{,}480/yr]\ /[1040\ hr/yr \times 60\ min/hr \times 8\ ft^2/min] = \$0.007/ft^2$$

and the total operating costs for the system are $\$0.575/ft^2$ for horizontal surfaces. For vertical and overhead surfaces, an additional 20% is added to the operations time and the labor costs to account for the time used in maneuvering the bucket crane, fork-lift basket, etc., to reach the elevated surfaces. Then, the unit cost factor for elevated surfaces is:

$$\$0.575/ft^2 \times 1.2 = \$0.690/ft^2$$

For stairs, an additional 5% is added to the operations time and the labor costs to account for the time used in maneuvering the equipment on the stairs. Then, the unit cost factor for stairs is:

$$\$0.575/ft^2 \text{ X } 1.05 = \$0.604/ft^2$$

The water usage, and hence liquid radwaste generation, at the rate of 1 gallon per minute of system operation is:

$$1 \text{ gallon}/8 \text{ ft}^2 = 0.125 \text{ gallons/ft}^2$$

Summary

Unit cost factor (horizontal surfaces)	= $\$0.575/ft^2$
Unit cost factor (vertical/overhead)	= $\$0.690/ft^2$
Unit cost factor (stairs)	= $\$0.604/ft^2$
Liquid radwaste generation	= 0.125 gallons/ft^2
Radiation Exposure	= 0.004 mrem/ft^2

C.2.14 Cutting Uncontaminated Concrete Walls and Floors

All concrete walls and floors are assumed to be uncontaminated or to have been decontaminated before sawing operations begin. Thus, the costs of cutting uncontaminated concrete to provide access to other components are considered to be cascading costs.

Material and labor costs for cutting uncontaminated concrete walls and floors are based on the cut measured in inch-feet (i.e., a cut 1-inch deep, 1 foot long, equals 1 inch-foot). Based on discussions with an industry source, a cutting rate of 60 inch-feet per hour is used in this study. The unit cost for blade material is estimated at $0.44 per in-ft of cut.

The postulated staffing for crews engaged in cutting the uncontaminated concrete within the reference BWR is given below, together with appropriate labor rates for each type of crew member. Multiplying the hourly rate for each labor type by the number of crew members of that type and summing over all labor types yields the labor rate per crew hour.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)
1.0	Laborer	26.37	26.37
1.0	Crafts	49.70	49.70
0.5	Crew Leader	54.84	27.42
2.5			108.66
Average labor cost, 2 shift operations			$108.66[b]

(a) These values include 110% overhead and 15% DOC profit.
(b) A 10% shift differential is included for second shift

Cutting of concrete walls is accomplished using a wall-saw on a mechanically driven track system. Cutting of concrete floors is done with a slab-saw. Scaffolding will be used as needed for installing and removing the track system when sawing openings in walls. The concrete pieces are cut into various shapes and sizes, depending upon the size of the openings desired. No packaging is contemplated, since the removed material is uncontaminated. The removed pieces of concrete are transferred to nearby storage areas. The basic operations for cutting concrete walls and concrete floors follow, together with the estimated clock times required to accomplish each operation are shown below.

Cutting Concrete Walls

• Install scaffolding at cut location	15 min.
• Install track-mounted cutting system	10 min.
• Install vacuum/water-spray dust control system	5 min.
• Cut concrete @ 1 in-ft/min.	[thickness of cut (in) x length of cut (ft)]
• Remove track-mounted cutting system	5 min.
• Remove vacuum/water-spray dust control system	5 min.
• Transfer the concrete section to a storage area	5 min.[a]
• Remove scaffolding and move to next location	15 min.

Crew-minutes for making one cut (actual duration) $60\ \text{min} + \dfrac{N^{(b)}}{1\ \text{in-ft/min}}\ \text{min}$

Work Difficulty Adjustments:

Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	10% of actual duration
Adjusted Work Duration	1.2 x actual duration

Non-productive Time Adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in protective clothing	39.4% of adjusted duration[c]
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per cut	1.574 x adjusted duration

Crew Exposure Hours per in-ft of cut (adjusted duration)	0
Exposure Person-hours per in-ft of cut	0
Total materials cost per in-ft of cut	$0.44

(a) This activity is in parallel with scaffold removal/next installation.
(b) N = [thickness of cut (in) x length of cut (ft)].
(c) A conservative estimate since no contamination is postulated to be involved in the cutting operations; however, protective clothing is assumed to be worn during industrial-type cutting operations.

Cutting Concrete Floors

• Install floor slab holding device	30 min.[(a)]
• Install cutting system	5 min.
• Install vacuum/water-spray dust control system	5 min.
• Cut concrete @ 1 in-ft/min.	[thickness of cut (in) x length of cut (ft)]
• Remove cutting system	5 min.
• Remove vacuum/water-spray dust control system	5 min.
• Transfer the concrete section to a storage area and disengage floor slab holding device	10 min.

Crew-minutes for making one cut (actual duration) $60 \text{ min} + \dfrac{N^{(b)}}{1 \text{ in-ft/min}} \text{ min}$

Work Difficulty Adjustments:

Height/Access adjustment for scaffold work	0% of actual duration
Respiratory protection adjustment	10% of actual duration
Adjusted Work Duration	1.1 x actual duration

Non-productive Time adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in protective clothing	39.4% of adjusted duration[(c)]
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per cut	1.574 x adjusted duration

Crew Exposure Hours per in-ft of cut (adjusted duration)	0
Exposure Person-hours per in-ft of cut	0
Total materials cost per in-ft of cut	$0.44

(a) Building crane is used for this operation.
(b) N = [thickness of cut (in) x length of cut (ft)].
(c) A conservative estimate since no contamination is postulated to be involved in the cutting operations; however, protective clothing is assumed to be worn during industrial-type cutting operations.

C.2.15 Removal of Contaminated Concrete Surfaces

Those contaminated horizontal surfaces which are not sufficiently decontaminated using the high-pressure washing system are removed using a commercially available pneumatically operated surface removal system. Commercial systems which use very high-pressure water jets for surface removal are also available. For this analysis, a specific commercial system manufactured by Pentex, Inc. is assumed (the Moose™ and associated smaller units) which chips off the surface and collects the dust and chips into a waste drum, and filters the air to prevent recontamination of the cleaned surfaces.

It is postulated that the depth of concrete to be removed will vary from location to location, but that on the average, removal of about one inch will be sufficient to remove the residual radioactive contamination. Because the removal system selected removes about 0.125 inch of material per pass, an average of 8 passes will be required over the contaminated areas. Because the Moose™ cannot get closer to walls than about 6 inches, smaller units of the same type (Squirrel III™, and Corner Cutter™) are used to clean the perimeter areas of rooms.

The effective scabbling rate in the buildings will be a composite one, reflecting that both the large area scabbler (Moose™, 115 ft^2/hr) and the smaller area scabblers (Squirrel™, 30 ft^2/hr) can be operated in parallel, thus increasing the effective rate for the combination. For a 10 ft. x 10 ft. room, where the perimeter area represents about 20% of the total floor area, the effective rate would be ~ 142 ft^2/hr. For a 20 ft. x 20 ft. room, where the perimeter represents about 10% of the total floor area, the effective rate would be ~ 127 ft^2/hr, and for a 30 ft. x 30 ft. room, where the perimeter represents about 6.5% of the total floor area, the effective rate would be ~ 123 ft^2/hr. For this analysis, a nominal value of 130 ft^2/hr per layer removed is postulated for all floor surfaces. For the 8 layers postulated to be removed in these analyses, the effective nominal removal rate would be ~16.25 ft^2/hr.

Staffing of this crew is postulated to consist of 3 laborers (one on the Moose™, one on the Squirrel™, one watching the compressor and handling the filled waste drums), about 1/4 each of a crew leader and a health physics technician.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Doses rate (mrem/crew-hr)
3.0	Laborer	26.37	79.11	3
0.25	H. P. Techs	36.82	--[b]	0
0.25	Crew Leader	54.84	13.71	0
3.50			92.82	3
Average labor cost, 2 shift operation			$97.46[c]	

(a) These values include 110% overhead and 15% DOC profit.
(b) Part of DOC overhead staff. Labor costs appear in undistributed cost.
(c) A 10% shift differential is included for second shift.

During an 8-hour (480 minute) shift, the actual cleansing time is estimated to be 5.33 hours (320 minutes), based on the following:

$$480 - 120 \text{ (suit-up)} - 30 \text{ (breaks)} - 10 \text{ (ALARA)}$$

or 320 minutes net working time using the cleansing system. Assuming a cleansing rate of 16.25 ft^2/hour, about 87 ft^2 can be cleansed in one shift. Thus, the labor cost per square foot of surface cleansed is given by:

$$(\$97.46/\text{crew-hr}) / (320/480 \times 16.25)\ ft^2/hr = \$9.00/ft^2$$

The cutting bits for the units are assumed to be replaced every 80 hours of operation, for an equivalent cost of about $13 per hour of operation. Principal additional costs would be filter replacements at about $2.50 per hour of operation, and waste drums for the collected debris at about $0.07 per square foot per pass (or $0.539 per square foot for eight passes).

The duration of the removal effort would be about 25 weeks, based on 21,600 ft^2 to be removed, the 16.25 ft^2/hr removal rate, two shifts per day, and a daily operating time of 5.33 hours per shift. Because of the relatively short time that the equipment is needed, rental would be preferable to purchase. Assuming a 5-yr lifetime, straight-line depreciation, and a 25% utilization factor, the equipment cost of about $148,000 would be amortized at a rate of about $2,300/wk, or about $43.12 per hour of operation.

Rental of a 365-cfm capacity compressor sufficient to supply the main unit and the edger unit simultaneously would be about $2,025/month, or about $8.76 per hour of operation.

The total material and rental cost per square foot for the eight passes is then given by:

[$13/hr. (bits) + $2.50/hr. (filters) + $43.12/hr. (system) + $8.76/hr. (compressor)]/16.25 ft^2/hour + $0.539/$ft^2$ (drums) = $5.93/$ft^2$

Thus, the total cost per square foot of horizontal surface removal is estimated as $9.00 (labor) + $4.69 (material and rental) = $13.69/$ft^2$.

The smaller units (Squirrel III™ and Corner Cutter™) could be utilized on vertical surfaces. The cost per square foot of vertical surface removed would be approximately four times the horizontal cost, due to the lower removal rates of the smaller units:

4 x [$9.00 (labor) + $4.69 (material)] + $0.539 (drums) = $55.30/$ft^2$

Summary

Unit cost factor (horizontal surfaces)	= $17.63/$ft^2$
Unit cost factor (vertical/overhead)	= $55.30/$ft^2$
Waste volume generated (1 in. removed)	= 0.083 ft^3/ft^2
Radiation Exposure	= 0.24 mrem/ft^2

C.2.16 Removal and Packaging of Contaminated Metal Surfaces

All contaminated metal surfaces are assumed to be stainless steel, approximately 0.125 inches in wall thickness. Cutting is accomplished using a plasma arc torch mounted on a mechanically driven track system. The cutting rate is 4 ft/min., which includes the torch changeout time of 15 min. for every 30 min. of torch operation. The surfaces are cut into nominal 7.5 ft x 18 ft segments for packaging in modified maritime containers. Crew size and composition, work difficulty adjustments and non-productive time adjustments are assumed to be the same as for tank cutting operations, Section C.2.6. The basic operations for removing a section of rectangular steel surface H feet high by W feet wide are listed below, together with the estimated clock times required to accomplish each operation.

- Install scaffolding at surface location — 15 min.
- Install contamination control system — 15 min.

• Install track-mounted torch system	(a)	10 min.
• Attach lifting devices to surface section		10 min.
• Make major cut in metal surface		A min.
• Remove track-mounted torch system		10 min.
• Place the tank section in the disposal container		10 min.[(b)]
• Remove contamination control system		15 min.
• Remove scaffolding and move to next location		15 min.

(a) These operations are repeated for each major cut.
(b) This activity is conducted in parallel with torch track removal and reinstallation for next cut.

Total Crew-hours for segmenting a rectangular section (actual duration): [60 + N(30 + A)]/60,
where N is the number of major cuts per section, and A is the average time per major cut. A major cut is a vertical or horizontal cut extending across the complete height or width of the rectangular section. Thus a major cut is either H feet long or W feet long. The number of major cuts is given by:

$$N = Nhoriz + Nvert,$$

where Nhoriz, the number of horizontal cuts, is given by

$$Nhoriz = TRUNC[H/7.5],$$

and Nvert, the number of vertical cuts, is given by

$$Nvert = TRUNC[W/18]$$

The average time for each major cut is

$$A = (Nhoriz \times W + Nvert \times H)/N/Rate,$$

where Rate is the cutting rate, 4 feet/minute.

Example Calculation: Sectioning a steel surface 40 feet high by 80 feet wide.
H = 40, W = 80.
The number of horizontal cuts, Nhoriz, is given by
Nhoriz = TRUNC(40/7.5) = 5,
and the number of vertical cuts, Nvert, is
Nvert = TRUNC(80/18) = 4.
Thus, the total number of cuts is given by
N = Nhoriz + Nvert = 9.
Putting this together gives for the average length of time per cut:
A = (Nhoriz x W + Nvert x H)/N/Rate = (5 x 80 + 4 x 40)/9/4 = 15.6 minutes/major cut.
Total crew hours = 1.3 x 1.574 x [60 + N(30 + A)]/60 = 1.3 x 1.574 x [60 + 9(30 + 15.6)]/60 = 16.0 hours.
The factors 1.3 and 1.574 are the work difficulty and non-productive time adjustments, developed in Section C.2.6.

C.2.17 Removal and Packaging of Contaminated Ducts 6 x 8 in. to 42 x 80 in.

All contaminated ducts are assumed to be galvanized steel, 20 to 16 gauge. The ducts are assumed to be separated into about 8-ft sections. The time bases are drawn from R.S. Means 1991(1) for duct removal. The average rate of removal in linear feet per 8-hour day for the inventory of ductwork in the reference BWR is calculated to be about 62 linear feet, by interpolation of the Means data. Thus, the average time per section of duct removed is about 60 minutes, including scaffolding. Subtracting 4 minutes per hour for work breaks leaves 56 minutes of direct labor per 8-ft section. The time duration factors that need to be considered are respiratory protection, protective clothing changes, work breaks and ALARA. The postulated crew size, cost, and associated radiation dose are given below.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Doses rate (mrem/crew-hr)
2.0	Laborer	26.37	52.74	2
0.5	H. P. Tech	36.82	--[b]	0
0.5	Crew Leader	54.84	27.42	0
3.0			80.16	2
Average labor cost, 2 shift operation			$84.17[c]	

(a) Includes a 10% shift differential for the second shift.
(b) Part of DOC overhead staff. Labor costs appear in undistributed cost.
(c) 10% shift differential for second shift

The removal operations and associated time durations are listed below.

• Install scaffolding at cut location	--
• Remove duct section	56 min.
• Bag ends of duct section	5 min.
• Flatten section	5 min.
• Transfer the flattened section to a maritime container	5 min.
• Remove scaffolding and move to next location	--

Crew-minutes for removing one section (actual duration) — 71 min.

Work Difficulty Adjustments:

Respiratory protection adjustment — 20% of actual duration

Adjusted Work Duration — 1.2 x actual duration = 85 min.

Non-productive time adjustments:
Radiation/ALARA adjustment — 8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing — 39.4% of adjusted duration
Break time — 9.8% of adjusted duration

Total Work Duration per section 1.574 x adjusted duration = 134 min.

Crew-Hours per ft = 134 min/8 ft = 16.75 min/ft = 0.279 hours/ft

Total Labor Cost per ft = 0.279 x $84.17/crew-hr = $23.50

Operations: 2 crews per shift, 2 shifts per day

Crew Exposure Hours per ft, assuming exposure to 2 laborers = 2 x 0.279/1.574
= 0.355 hrs/ft.

Assumed radiation dose rate = 1.0 mrem/hr
Radiation Dose per ft removed = 0.355 mrem/ft

C.2.18 Removal of Steel Floor Grating

It is assumed that contaminated steel floor grating (on stairs, platforms, and walkways) will be removed during decommissioning in essentially the same manner in which it was installed; therefore, installation labor factors were used, based on "Building Construction Cost Data 1991" by R. S. Means,[2] p. 130, and modified for a radiation zone environment. Steel floor grating is assumed to weigh 10.4 lb/ft^2. In an uncontaminated environment, the performance rate is 550 ft^2 of steel floor grating installed (removed) per 8 hours (about 68.75 ft^2/hr), by interpolation of the Means values. Based on the non-productive work time factor (1.574) given in Section C.2.1, the available time per 8-hr shift used in this re-evaluation analysis is found by:

$$8 \text{ hrs}/1.574 = 5.083 \text{ hrs}$$

The worker efficiency in respiratory equipment (1.2) for a radzone environment reduces the total removal efficiency per shift as follows:

$$5.083 \text{ hrs} \times (68.75 \text{ ft}^2/\text{hr} / 1.2) = 291.2 \text{ ft}^2/\text{shift}$$

or to an hourly rate of 291.2 / 8 hrs = 36.4 ft^2/hr

The postulated crew size, cost, and associated radiation dose are given below.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Doses rate (mrem/crew-hr)
3.0	Laborer	26.37	79.11	3
0.5	H. P. Tech	36.82	--[b]	0
0.5	Crew Leader	54.84	27.42	0
4.0			106.53	3
Average labor cost, 2 shift operation			$111.86[c]	

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

Crew-Hours per ft^2	0.0275
Total Labor Cost per ft^2	0.0275 x \$111.86/crew-hr = \$3.08
Crew Exposure Hours per ft^2	0.0275 hrs.
Exposure Pers-hours per ft^2	@ 4.0 pers-hours/crew-hour = 0.11 hrs.
Radiation Dose-rate (mrem/hr)	1.0

Principal material costs are gases for torches at \$7.76/hr, including 15% DOC profit (see Section C.2.2).

C.2.19 Decontamination of Handrails

All contaminated handrails are assumed to be 2-inch-diameter carbon steel. One lineal foot (LF) of handrail equals about 1/2 ft^2 of surface area. The assumed decontamination rate is 15 ft^2/hour or about 30 LF/hr. Decontamination will be done manually using industrial wipes and Radiacwash™ (diluted 5:1). The waste will be bagged for disposal. This work is not anticipated to require either respiratory protection or scaffolding. The postulated crew size, cost, and associated radiation dose are given below.

Pers-hrs/crew-hr	Category	Labor Rate (\$/pers-hr)	Cost[(a)] (\$/crew-hr)	Doses rate (mrem/crew-hr)
2.0	Laborer	26.37	52.74	2
0.5	H. P. Tech	36.82	--[(b)]	0
0.5	Crew Leader	54.84	27.42	0
3.0			80.16	2
Average labor cost, 2 shift operation			\$84.17[(c)]	

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

The decontamination operations and associated time durations are listed below.

- Manually decontaminate 1 LF of handrail — 2 min.[1]
- Radiation survey — 1 min.
- Move to next location — 1 min.[2]

Crew-minutes for decontamination of 1 LF (actual duration)	= 3.0 min.
Work Difficulty Adjustments: None required.	
Adjusted Work Duration: 1.0 x actual duration	= 3.0 min.

[1]Assumed to be washed twice, rinsed once, and dried.
[2]The move is made in parallel with the survey.

Non-productive time adjustments:	
Radiation/ALARA adjustment	3.1% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	37.5% of adjusted duration
Work breaks (2 per shift)	9.4% of adjusted duration
Total Work Duration per LF 1.500 x adjusted duration	= 4.50 min.
Crew-Hours per LF	= 0.075 hrs.
Total Labor Cost per 1 LF 0.05 x $84.17/crew-hr	= $6.31
Crew Exposure Hours per 1 LF (adjusted duration)	= 0.033 hrs.
Exposure Pers-hours per 1 LF @ 2.0 pers-hours/crew-hour	= 0.10 hrs.
Radiation Dose-rate (mrem/hr)	= 1.0

During an 8-hour (480 minute) shift, the actual cleansing time is estimated to be 5.33 hours (320 minutes), based on the following:

480 - 120 (suit-up) - 30 (breaks) - 10 (ALARA)

Assuming a cleansing rate of 30 LF/hour (15 ft^2/hour), about 160 LF (80 ft^2) can be cleansed in one crew-shift. Assuming two crews per shift, two shifts per day, the duration of the cleansing effort in the containment, fuel, and auxiliary buildings would be about 17.6 days, based on an estimated 11,226 LF of handrails to be cleansed.

The costs of materials used in the decontamination operations are

Industrial Wipes w/hand-held dispenser (McMaster-Carr, Edition 98, p. 1060.)
Wipes @ $14.76/275-ft roll (9-3/4 in. wide)
Dispenser @ $13.50/each
Radiacwash™ @ $15/gal (Air Products Corporation, Catalog 68)

Principal material costs are: 1) industrial wipes (at an estimated usage rate of 10 wipes/6-ft section) for an equivalent cost of about $0.09/LF and 2) cleansing solution, used at a rate of 430 LF/gal, for an equivalent cost of about $0.03/LF. In addition, it is estimated that eight hand-held dispensers are needed, for an equivalent cost of about $0.01/LF. A used wipe is estimated to occupy about 0.00324 ft^3. At 1.67 wipes per foot, this works out to 0.0054 ft^3 of waste per LF of railing. Similarly, the waste volume from the gallon cans of cleansing solution accumulates at a rate of

$$(1/430) \text{ gallon-containers/ft} \times 0.134 \text{ ft}^3\text{/gallon-container} = 0.0003 \text{ ft}^3\text{/LF}.$$

Thus the rate at which waste is generated is about 0.0057 ft^3/LF. A 55-gallon drum holds about 7.35 ft^3. So, at $26.95 per drum, the cost for this waste is about $0.02/LF. Thus, the total cleansing cost per lineal foot is estimated to be:

$6.31 (labor) + $0.09 (wipes) + $0.03 (Radiacwash™) + $0.02 (drums) + $0.01 (dispensers) = $6.46/LF

Summary

Unit cost factor = $6.46/LF
Waste volume generated = 0.0057 ft^3/LF

C.2.20 Removal of Contaminated Floor Drains

Discussions between the authors and senior staff of Pacific Nuclear Services (PNS)[3] were held concerning PNS's experiences to date with chemical decontamination of drain systems at nuclear power plants. PNS indicates that it is probably not cost-effective, nor practical to chemically decontaminate reactor drain systems prior to disassembly. Therefore, the piping in the drain systems at the reference BWR is not postulated to be chemically decontaminated before disassembly. Removal and packaging of contaminated piping associated with the drains is covered under Sections C.2.3 and C.2.4. This section discusses only the removal of the drains, which is postulated to occur after the drain piping has been removed.

It is estimated that there are 320 drains that could be radioactively contaminated. The volume of a "typical" drain is conservatively estimated to be about 2.80 ft^3, using a rough approximation to calculate the space occupied by the "plug" that is postulated to be removed by a core drill. Each plug is estimated to weigh about 550 pounds, based on a 16-in-diameter concrete plug (containing the drain) being cut from a nominal 2-ft-thick reinforced concrete floor.

The following procedure for the removal of contaminated floor drains is based upon discussions between the authors and senior staff of the Columbia Concrete Sawing Company.

It is assumed that 3-inch-wide steel strapping is bolted underneath the plug to prevent it from falling upon completion of the core drilling operation. In addition, the top of each drain is covered with plastic prior to the start of drilling. A water mist is used during core drilling operations for dust control, as required. The water is collected by means of a vacuum at the top end and by a plastic trough that empties into a bucket at the bottom of the plug, resulting in the collection of an estimated total of 5 gallons of potentially contaminated waste water per plug. Very limited, if any, respiratory equipment is anticipated to be needed for core drilling operations associated with removal of the floor drains.

Upon completion of drilling, the plug is rigged for lifting, raised, moved, and placed in a B-25 metal container. The basic operations are listed below, together with the estimated clock times required for each operation.

• Above Drain: drill anchor hole for drill stand, set anchor, and bolt drill stand to floor; cover drain with plastic; water & vacuum clean in place	10 min.[(a)]
• Below Drain: install scaffolding; drill bolt holes and affix steel strapping; rig plastic trough/bucket	35 min.
• Core drill the drain plug	206 min.[(b)]
• Collect and dispose of waste water	30 min.[(c)]
• Rig, lift, move, and place plug in disposal container	30 min.
• Secure prefabricated cover over hole	5 min.
• Remove scaffolding and equipment and move to next location	15 min.

[3]Pacific Nuclear Services specializes in chemical decontamination services and is currently under contract to Consolidated Edison of New York to perform the first full-system decontamination of a commercial PWR in the U.S.

Crew minutes for removing one drain (actual duration) 291 min.

(a) This operation is conducted in parallel with the Below Drain operations.
(b) Nominal time for core drilling rate of 7 in./hr., including diamond-core bit replacements.
(c) This operation is conducted in parallel with the core drilling operations.

Work Difficulty Adjustments:

Height/Access adjustment 7% of actual duration

Adjusted Work Duration 1.07 x actual duration = 311 min.

The total crew-minutes per drain removal activity =

estimated work duration of 291 min. x work difficulty adjustment of 7% x non-productive time adjustment given previously in Section C.2.1 of 1.574 = ~ 490 minutes (roughly, one drain removed per 8-hr shift)

Radiation Exposure time =

estimated work duration of 291 min. x 1.07 = ~311 min. (or, ~ 5.2 hrs)

A crew consisting of 1 laborer, 1 crafts, 0.5 crew leader, and 0.5 health physics technician is required for the removal operation. Normally, there will be four crews working per shift, with two-shift operations. The crew labor costs and exposure levels are:

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Doses rate (mrem/crew-hr)
1.0	Laborer	26.37	26.37	0.5
1.0	Crafts	49.70	49.70	0.5
0.5	H.P. Tech.	36.82	--[b]	0
0.5	Crew Leader	54.84	27.42	0
3.0			103.49	1
Average labor cost, 2 shift operation			$108.66[c]	

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

Crew-Hours per drain = 8.0 hrs
Total Labor Cost per drain (8.0 x $108.66/crew-hr) = $869.28
Crew Exposure Hours per drain (adjusted duration) = 5.2 hrs.

Exposure Pers-hours per drain @ 2.0 pers-hours/crew-hour = 10.4 hrs.
Radiation Dose-rate (mrem/hr) = 0.5

Principal material costs (including 15% DOC profit) are:

- diamond-core bit replacements at $4.60/inch depth
  - $4.60/inch depth x 24-in. thick floor = $110.40/drain
- absorbent materials and plastic are estimated at $5.80/drain
- equipment rentals
  - (4 power units at $1,035/wk + 4 drain plug pullers at $138/wk) / 5 days/wk = $938.40/day
  - ($938.40/day) / 8 drains/day = $117.30/drain

On a weight-basis, it is estimated that a B-25 container will hold 17 drain plugs, situated in two layers. Thus the container cost per drain is ($618.50/container) / (17 drains/container) = $36.38.

Thus, the total removal cost per drain is $869.28 (labor) + $110.40 (core bits) + $5.80 (materials) + $117.30 (equipment rentals) + $36.38 (containers) = $1,139.16/drain.

Summary[4]

Unit cost factor = $1,139.16/drain
Waste volume generated, water = 5 gal/drain
Waste volume generated, solids = 2.80 ft^3/drain
Radiation exposure = 5.2 mrem/drain

C.2.21 Removal of Pipe Hangers

It is estimated that 12,500 potentially contaminated pipe hangers will need to be removed. These hangers range from simple U-bolts for the 1-inch and smaller lines, to massive engineered structures designed to accommodate the 30-inch main steam lines. A typical 1-inch pipe hanger weighs about 60 pounds; a 30-inch hanger weighs about 1,000 pounds. Based on data from a sample of 4-, 6-, 10-, 12-, 14-, 18-, and 26-inch hangers, it was found that the hanger weight can be roughly approximated by

$$Wgt = 21.7*D + 50,$$

where D is the diameter of the pipe in inches, and Wgt is the hanger weight in pounds.

The most cost-effective disposal container for the hangers is one that will hold the greatest weight in the smallest volume without exceeding the legal weight truck of 40,000 pounds. To determine the volume of this container, an estimate must be made of average hanger density. Hanger material consists of essentially flat pieces: wide-flange beams, angle irons, channels, and plates. It is reasonable to assume that the large hangers (pipe diameter greater than 4 inches) can be cut into two or three large pieces and laid flat inside the container. Smaller hangers will not need to be cut up and can be used to fill in voids left by the larger hangers. The wide-flange beams (usually strengthened with metal plate stiffeners) have the lowest effective density (largest void space) of all the common hanger materials, so a lower weight limit can be estimated by assuming that hangers consist of nothing but these beams. This assumption leads to an effective density of about 100 lbs/ft^3. A modified Sea-Van 2 feet high, 8 feet wide, and 20 feet long, weighing 2,500 pounds, filled with material of

[4]Specific specialized equipment purchases for this drain removal task are included separately in Appendix B, Table B.6.

this average density contains about 32,000 pounds of payload. This weight is a lower bound. An actual load should weigh somewhat more than this. Thus, the 2-foot-high Sea-Van appears to be appropriate for hanger disposal and was used in this study.

For this analysis, two unit cost factors were developed, one for hangers for 4-inch pipe and smaller, and one for hangers for pipe larger than 4 inches. The pipe removal crew (Section C.2.2) is used for hanger removal.

Removal of Pipe Hangers 4 Inches and Less

It is assumed that the hangers can be removed in small enough sections so that no rigging will be required. The basic removal operations are listed below.

• Cut 4 concrete fasteners or bolts	10 min
• Cut support welds	10 min
Crew minutes for one hanger (actual duration)	20 min
Work difficulty adjustments:	
Respiratory protection adjustment	20% of actual duration
Adjusted work duration per hanger	1.2 x actual duration = 24 min
Adjusted work duration for torch operation	1.2 x 10 min = 12 min
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/unsuit in anticontamination clothing	39.4% of adjusted duration
Work breaks (two per shift)	9.8% of adjusted duration
Total work duration per hanger	1.574 x adjusted duration = 38 min
Crew-hours per hanger	= 0.63 hrs
Total labor cost per hanger (0.63 hrs x $190.13/crew-hr)	= $119.78
Material costs (Gases) @$6.75/hr x 12 min/(60 min/hr)	= 1.35
Total Cost, small hanger	= $121.13
Crew exposure-hours per hanger (adjusted duration)	= 0.4 hrs
Exposure person-hrs per hanger (@ 4 pers-hour/crew-hour)	= 1.6 hrs

Removal of Pipe Hangers Greater than 4 Inches

Rigging will be required for the larger hangers, and additional time will be needed to cut hangers into smaller sections. The basic removal operations are listed below.

• Rig portable crane	10 min
• Cut concrete fasteners/and or bolts	15 min
• Cut support welds	15 min
• Cut hanger (w/torch) into smaller sections	20 min

Crew minutes for one hanger (actual duration)	60 min
Work difficulty adjustments:	
Respiratory protection adjustment	20% of actual duration
Adjusted work duration per hanger	1.2 x actual duration = 72 min
Adjusted work duration for torch operation	1.2 x 35 min = 42 min
Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/unsuit in anticontamination clothing	39.4% of adjusted duration
Work breaks (two per shift)	9.8% of adjusted duration
Total work duration per hanger	1.574 x adjusted duration = 113 min
Crew-hours per hanger	= 1.89 hrs
Total labor cost per hanger (0.63 hrs x $190.13/crew-hr)	= $359.35
Material costs (Gases) @$6.75/hr x 12 min/(60 min/hr)	= 4.72
Total Cost, small hanger	= $364.07
Crew exposure-hrs per hanger (adjusted duration)	= 1.2 hrs
Exposure person-hrs per hanger (@ 4 pers-hour/crew-hour) = 4.8 hrs	

C.3 Transportation Costs

The CECP data base contains distances from all commercial reactor sites to the postulated geologic repository at Yucca Mountain and to the low-level disposal sites at Hanford and Barnwell. The distances provided are suggested distances only and may be changed as desired by the user. If the user does not find the desired site in the site listing, the desired site name and distances to disposal facilities can be added to the site listing. In addition to site name and distances, the user specifies the name of the desired low level waste disposal site. This site information, along with the plant inventory and reactor pressure vessel characteristics, enables the CECP to calculate transportation costs.

To calculate transportation costs, the CECP employs a different cost formula for each cask (CNS 8-120B, NuPac 14-210H, NAC-LWT, and TN-8) that will be used in decommissioning. These formulas are provided in Appendix B.

C.4 References

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

2. "Building Construction Cost Data 1991," Robert Snow Means Company, Inc., Kingston, Massachusetts 1991.

Appendix D

Effects of the Spent Nuclear Fuel Inventory on Decommissioning Alternatives

Appendix D

Effects of the Spent Nuclear Fuel Inventory on Decommissioning Alternatives

Current U.S. Nuclear Regulatory Commission (NRC) policy requires removal of all spent nuclear fuel (SNF) from a facility licensed under Title 10 CFR Part 50[1] before DECON can be accomplished. A number of removal alternatives exist, including transfer to another storage pool or transfer to either a wet or dry independent spent fuel storage installation (ISFSI), licensed under Title 10 CFR Part 72.[2] Transfer to another storage pool is constrained by the availability of space in another pool. Transfer to a dry ISFSI is constrained by limits on allowable fuel cladding temperatures. These temperature limits necessitate storage in water pools for extended periods of time following discharge from the reactor prior to dry storage, with the length of the storage period dependent upon the fission product heat generation in the fuel, which is a function of the initial enrichment and irradiation history of the fuel. The use of a dry ISFSI may also be constrained by the availability of equipment to transfer SNF from dry storage casks to transportation casks prior to shipment to a repository.

The analyses presented in this appendix reflect the expected situation at the reference boiling water reactor (BWR), the WNP-2 plant near Richland, Washington, if the plant operated until expiration of its operating license, and therefore are representative of other large BWRs that do operate until their licenses expire. These analyses do not necessarily reflect the actual situation at the WNP-2 reactor.

Under the contractual agreements between the U.S. Department of Energy (DOE) and the nuclear utilities for disposal of SNF, SNF owned by utilities is placed in an acceptance queue, ranked by date of discharge on an oldest-fuel-first (OFF) basis. Subsequently, the amount of SNF accepted from a given utility in a given year is determined by its place in the queue and the amount of SNF to be accepted by DOE during that year.

Based upon the current regulatory environment and upon the SNF cooling time analyses presented in this appendix, the minimum period for spent fuel pool operation and plant safe storage prior to dismantlement at the reference BWR is estimated to be 4.6 years, provided that the owner constructs and licenses an onsite ISFSI under Part 72. Without an onsite ISFSI, the minimum period for pool operation and plant safe storage prior to decommissioning is estimated to be 9 years. This 9-year estimate presumes the utility maintains its fuel pool under a Part 50 possession-only license after shutdown, together with reliance on the DOE's acceptance of the SNF under the 10 CFR Part 961 contractual agreement to empty the fuel pool.

The regulatory considerations, background information, and the details of the analyses leading to the above conclusions are presented in subsequent sections of this appendix in the following order:

- regulatory considerations governing SNF disposal
- postulated allocation of the waste management system's annual acceptance capacity for the reference BWR
- background information related to post-shutdown storage of SNF

- generic considerations related to post-shutdown storage of SNF, including the range of storage/disposition alternatives and a methodology for evaluating the present value of the total storage system life-cycle costs for two basic options of SNF storage

- required SNF cooling time following discharge before dry storage

- rationale for the spent fuel storage option postulated for the reference BWR.

D.1 Regulatory Considerations Governing SNF Disposal

The Nuclear Waste Policy Act of 1982 (NWPA)[(3)] assigns to the federal government responsibility to provide for the permanent disposal of SNF[1] and high-level radioactive waste (HLW).[2] The Director of the Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) is responsible for carrying out the functions of the Secretary of Energy (Secretary) under the NWPA. Section 302(a) of the NWPA authorizes the Secretary to enter into contracts[3] with owners or generators[4] of commercial SNF or HLW. The Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste[(4)] represents the sole contractual mechanism for DOE acceptance and disposal of SNF and HLW. It establishes the requirements and operational responsibilities of the parties to the Contract in the areas of administrative matters, fees, terms of payment for disposal services, waste acceptance criteria, and waste acceptance procedures. The Standard Disposal Contract provides for the acquisition of title to the SNF or HLW by DOE, its transportation to DOE facilities, and its subsequent disposal.

Concerning the issue of priority being afforded to permanently shutdown reactors, DOE has responded thusly[(5)]:

> "Article VI.B of the Standard Disposal Contract allows that priority *may* [emphasis added] be afforded to shutdown reactors. DOE has not determined whether or not priority will be accorded to shutdown reactors or, if priority is granted, under what circumstances. DOE recognizes that granting priority to shutdown reactors invites questions of equity among all owners and generators of SNF."

With regard to DOE's beginning operations in 1998, DOE's intention, consistent with the NWPA and the Contract, is to initiate acceptance of spent fuel from Purchasers as soon as a DOE facility commences operations. DOE has stated that waste acceptance at a monitored retrievable storage (MRS) facility could begin in 1998 if the initiatives detailed in the November 1989 "Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program"[(6)] are fully implemented. While SNF acceptance by DOE appears unlikely, for the purpose of this study the acceptance schedule developed by DOE which assumes starting acceptance in 1998 are used. Until waste acceptance begins, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel.

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[1]As delineated in Title 10 CFR Part 961, Appendix E,[(4)] 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. One of the General Specifications for standard fuel is a minimum cooling time of five years.

[2]HLW means the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

[3]Individual contracts are based upon the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (10 CFR Part 961), which will be referred to as the "Standard Disposal Contract" or "Contract" for subsequent discussion in this report.

[4]Owners or generators of SNF and HLW who have entered into agreements with DOE or have paid fees for purchase of disposal services are referred to as "Purchasers."

D.1.1 Standard Disposal Contract Requirement for an Annual Capacity Report

Under the terms of the Standard Disposal Contract (Article IV), the DOE issues an Annual Capacity Report (ACR)[7] wherein DOE's annual SNF/HLW receiving capacity is projected and the annual acceptance ranking allocations to the Purchasers are presented for 10 years following the projected commencement of DOE facility operations. As specified in the Contract, the ACR is for planning purposes only and thus is not contractually binding on either DOE or the Purchasers. The Standard Disposal Contract states that beginning April 1991, DOE shall issue the first annual Acceptance Priority Ranking for receipt of SNF/HLW. The Contract further specifies that, beginning in January 1992, and based on the Acceptance Priority Ranking, the Purchasers shall submit Delivery Commitment Schedules (DCSs) to DOE identifying the SNF/HLW that the Purchasers propose to deliver to the Federal Waste Management System (FWMS). The Contract provides that the approved DCSs will become the bases for Final Delivery Schedules, which are to be submitted by the Purchasers not less than 12 months before the designated year of DOE's anticipated acceptance of title to the SNF/HLW and subsequent transport to a DOE facility.

D.1.2 Waste Acceptance Projections

The waste acceptance projections used in the ACR are representative of a FWMS configuration authorized by the Nuclear Waste Policy Amendments Act of 1987 (Amendments Act),[8] which includes an MRS facility. Article II of the Standard Contract specifies that "The services to be provided by DOE under this contract shall begin, after the commencement of facility operations, not later than January 31, 1998...." DOE recognizes that, under current conditions, waste acceptance at a DOE facility can begin in 1998 only if the federal government is able to consummate a timely agreement, which is enacted into federal law, with a host State or Indian Tribe for the siting of an MRS facility. No such agreement has yet been developed.

DOE's projected acceptance rates for the first 10 years of FWMS operation, extracted from the ACR,[7] are given in Table D.1. These rates do not reflect the MRS facility schedule linkages with the repository development that were imposed by the Amendments Act, but are consistent with the 10,000-MTU storage capacity limit contained in the Amendments Act for an MRS facility before a repository starts operation. These acceptance rates assume commencement of facility operations in 1998. If the current linkages between MRS facility construction and repository construction authorization are maintained, it is estimated that commencement of MRS facility operations could not start until at least 2007.[7]

Operation of the FWMS with the waste acceptance rates presented in Table D.1 would result in the receipt of 8,200 MTU of SNF at the MRS facility during the first 10 years of operations. This table provides only the current estimate of the system throughput rates and is subject to change depending upon the system design and configuration and Congressional action regarding the conditions for the siting of an MRS facility. DOE will further define and specify the system operating and waste acceptance parameters as the program progresses and inform the Purchasers accordingly at the earliest feasible time. Until the SNF is accepted by DOE, Section 111(a)(5) of the NWPA assigns the waste owners and generators the primary responsibility to provide for, and pay the costs of, interim storage.[7]

D.2 Postulated Allocation of the Waste Management System's Annual Acceptance Capacity for the Reference BWR

As previously mentioned, DOE is required to accept all commercial SNF/HLW for permanent disposal from owners or generators who executed and have complied with the Contract as prescribed in the NWPA. However, since acceptance capacity will be limited in any given year, a ranking or sequencing process is necessary to allocate the available acceptance capacity. The ranking is based on the date-of-final-discharge data supplied by the Purchasers and the OFF criterion established by the Contract.

Table D.1 Projected waste acceptance rates for spent nuclear fuel[a]

Year	SNF (MTU)
1998	400
1999	600
2000	900
2001	900
2002	900
2003	900
2004	900
2005	900
2006	900
2007	900
Total	8,200

(a) According to Information contained in Reference 7, the reference BWR's first fuel acceptance allocation does not appear until CY 2011.

No quantities of SNF from the reference BWR are currently eligible for acceptance during the first 10 years of projected FWMS operation. Projections done for this study of the transfers of SNF necessary to deplete the SNF inventory at the reference BWR are presented in Table D.2. The data shown in the table are based upon the projected acceptance rates, shown previously in Table D.1, but continued until approximately 10,000 MTU (the legal limit) are stored at the MRS in 2010, at which time the repository is scheduled to begin operation. Beyond 2010, the FWMS is projected to operate at an annual receipt rate of 3,000 MTU. The final shipments of SNF from the reference BWR are projected to occur in the year 2033.

Based upon a pool capacity of 2,658 spent fuel assemblies, it can also be seen from Table D.2 that the reference BWR will not have adequate pool capacity to accommodate its remaining inventory without the need for additional storage capability for 2 years, assuming DOE receives SNF beginning in 1998 and at the rates given in Table D.1. For the purpose of this study, it is assumed that some form of onsite SNF storage is provided during this 2-year period by the utility. Because this SNF storage requirement occurs during the operating years of the reference plant, it is considered an operations cost.

It should be noted that WNP-2's current operating license expires in CY-2013, based upon a 40-year license period, beginning with the start of construction. The NRC now permits the operating license periods of commercial nuclear reactor power stations to begin at the start of commercial operation of those reactors. The Energy Information Administration's (EIA) projected year of final shutdown for the WNP-2 plant is CY-2024 (the date shown in Table D.2).[10] 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. The EIA's shutdown date of CY-2024 is used throughout this study for the purpose of developing decommissioning schedules.

Table D.2 Postulated SNF disposition schedule for the reference BWR[a]

Calendar year of fuel pick up	Year/month of discharge	SNF inventory (assemblies)	SNF assemblies accepted each year
2011	1986/04	2840	96
2011	1987/04	2835	124
2012	1988/04	2684	151
2012	1989/04	2669	137
2013	1990/04	2584	208
2014	1991/04	2580	120
2015	1992/04	2504	76
2015	1993/04	2364	140
2016	1994/06	2344	132
2017	1995/09	2212	132
2017	1996/09	2234	91
2018	1996/09	2197	37
2018	1997/10	2181	130
2018	1999/01	2165	130
2020	2000/02	2150	130
2021	2001/03	2024	126
2021	2002/04	1899	125
2022	2003/08	1891	123
2023	2004/09	1769	122
2023	2005/10	1760	124
2024[b]	2006/11	2485	124
2025	2008/02	2365	120
2026	2009/03	2246	119
2026	2010/04	2127	119
2027	2011/06	2008	119
2028	2012/09	1886	122
2028	2013/09	1763	123
2029	2014/11	1658	105
2030	2014/11	1647	11
2030	2016/02	1535	112
2031	2017/03	1422	113
2031	2018/05	1308	114
2031	2019/09	1194	114
2032	2020/10	1079	115
2032	2022/01	964	115
2033	2023/03	849	115
2033	2024/02	764	85
2033[c]	2024/04	0	764

(a) Based on Reference 9 and on the postulated acceptance projections done for this study (see text for details). Does not represent the actual situation at the WNP-2 reactor, but is reasonably representative of large BWRs that operate for their licensed lifetime.
(b) CY 2024 is the EIA projected year of final shutdown for the reference BWR (see text for details).
(c) CY 2033 is the year in which the reference BWR's SNF inventory is reduced to zero on the OFF allocation basis.

D.3 Background Information Related to Post-Shutdown Storage of Spent Nuclear Fuel

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) submitted the "Final Version Dry Cask Storage Study" to NRC in January 1989 for final review. Information copies of the document were also provided to Congress. After receiving final NRC comments on the study, OCRWM formally submitted the "Final Version Dry Cask Storage Study,"[11] to Congress in March 1989 accompanied by NRC's comments. The study presents two major conclusions: 1) existing technologies are technically feasible, safe and environmentally acceptable options for storing spent fuel at civilian reactor sites until such time as a federal facility is available to accept the spent fuel, and 2) OCRWM is not authorized to provide direct financial support for at-reactor storage. The latter conclusion is based on the NWPA, which established the Nuclear Waste Fund. As stated in Section 111(a)(5), "the generators and owners of high-level radioactive waste and spent nuclear fuel have the primary responsibility to provide for, and the responsibility to pay the costs of, the interim storage of such waste and spent fuel until such waste and spent fuel is accepted by the Secretary of Energy in accordance with the provisions of this Act." Thus, it is the DOE's position that the utilities are responsible for storing spent fuel at reactor sites until an operating federal facility is available to accept the fuel.[12]

In a generic environmental impact statement on spent fuel storage,[13] the NRC expressed confidence that the regulations now in place will ensure adequate protection of the public health and safety and the environment during the period when the SNF is in storage. The reactor operating license may be amended at the end of the plant operating life. Thus, spent fuel may be stored in the reactor pool under an amended reactor operating license pursuant to 10 CFR Part 50.[1] The reactor license, however, cannot be terminated until the reactor is decommissioned. To fully decommission the reactor, all spent fuel must be removed from the fuel pool.

Currently, there are nine shutdown licensed nuclear power plants in the U.S. with fuel onsite. They are: Rancho Seco Nuclear Generating Station of Sacramento Municipal Utility District; Humboldt Bay Unit 3 of Pacific Gas & Electric; the Dresden 1 plant of Commonwealth Edison Company; the LaCrosse unit of Dairyland Electric Co-op, Inc.; the Shoreham station of The Long Island Power Authority; the Fort St. Vrain plant of Public Service Co. of Colorado; the Yankee Rowe plant of Yankee Atomic Electric Co. of Massachusetts; the San Onofre Unit 1 of Southern California Edison Co. and San Diego Gas and Electric Co.; and the Trojan plant of Portland General Electric Co. All shutdown plants have utilized light-water-cooled reactors with the exception of the Fort St. Vrain plant, which employs a high-temperature gas-cooled reactor. Fort St. Vrain fuel is highly enriched and for that reason, may require special treatment before disposal at the presently contemplated federal geologic repository.

Several storage system designs are presently licensed or about to be licensed for storage of SNF in the U.S. These include water pools for wet storage, and metal casks, concrete casks, horizontal concrete modules, and air-cooled vaults for dry storage. A natural-circulation-cooled vault ISFSI is in service at Ft. St. Vrain. Transportable metal storage casks, for at-reactor dry storage, are not currently certified in the U.S. To use metal casks designed for dual-purpose service, a utility would have to obtain an NRC license for storage under 10 CFR Part 72[2] and specify a cask certified for storage by the NRC and for transportation in accordance with regulations in 10 CFR Part 71.[14] In addition, the licensing and certification of these casks would have to address concerns about using the casks for transportation after extended use for storage. Concrete casks and horizontal storage modules cannot be transported intact. However, the metal canisters containing the fuel may be able to fit inside a transportable cask. Nonetheless, some form of storage unit-to-transport cask transfer capability would be required on the reference site, to provide for recovery from a cask seal failure or some abnormal condition occurring with the storage units.

On the other hand, the safety of storage in spent fuel pools has been widely demonstrated. In the review of its Waste Confidence Decision,[15] the NRC concluded that spent fuel can be stored safely and without significant environmental impacts for at least 30 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor at its spent fuel storage basin or at either an onsite or an offsite ISFSI. This finding was supported by the NRC's experience in conducting more than 80 individual safety evaluations of spent fuel storage. In particular, the NRC noted that the cladding of the spent fuel is highly resistant to failure under the conditions of pool storage, and the NRC cited up to 18 years of continuous-storage experience for Zircaloy-clad fuel.

Thus, SNF can be stored either in a pool or in dry storage facilities. Though both types of storage may be used at the same reactor site, they are subject to different NRC regulations. This is because the spent fuel pool is normally considered to be an integral part of the nuclear power plant and subject to regulation under 10 CFR Part 50. Dry storage facilities are considered independent of the plant, and are subject to regulation under 10 CFR Part 72. A general license under 10 CFR Part 72, Subpart K, can be granted to Part 50 licensees, if approved storage devices are used.

D.4 Generic Considerations Related to Post-Shutdown Storage of SNF

An important consideration when selecting the decommissioning mode to employ on a retired power reactor facility is what to do with the SNF stored onsite. The range of storage/disposition alternatives of SNF is discussed in Section D.4.1. A methodology for evaluating the present value of the total storage system life-cycle costs is presented in Section D.4.2, together with an evaluation for two basic alternatives for SNF storage.

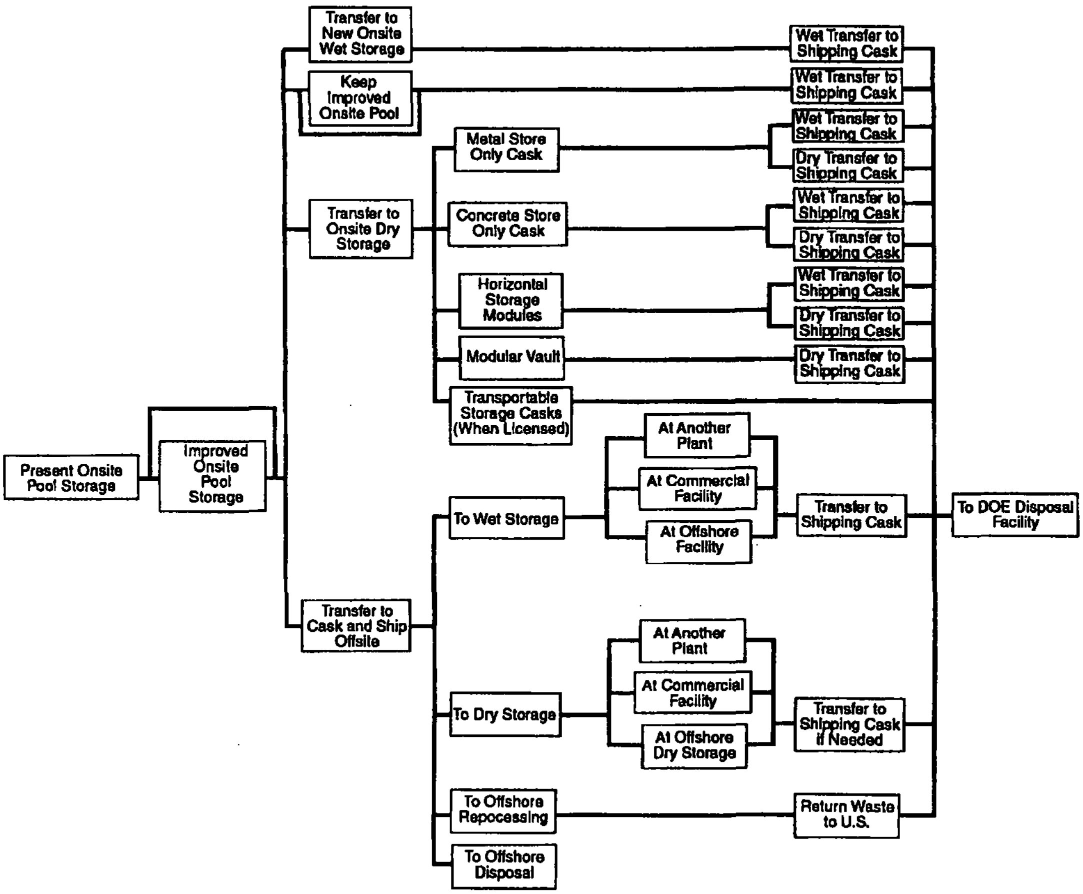
D.4.1 Storage/Disposition Alternatives for SNF

The following discussion on the disposition alternatives for SNF is based upon information extracted from a study on such alternatives for Rancho Seco Nuclear Generating Station(16) and other sources. Based upon those sources, an overview of post-shutdown spent fuel storage alternatives is presented in Figure D.1. The disposition alternatives for SNF shown in the figure appear to illustrate the range of alternatives currently available upon final shutdown. It can be seen from the figure that two major groups of alternatives are available, onsite and offsite storage.

The onsite storage alternatives can be subdivided into wet and dry storage. Wet storage could be accomplished by utilizing the existing spent fuel pool (SFP) or by transferring the SNF to a wet ISFSI. Both alternatives are included as possibilities in Figure D.1. It should be noted that a bypass is provided around the improvements associated with modifying the existing pool (i.e., a reduction in support systems necessary to maintain SNF in wet storage) in the event the time of storage in the SFP can be limited, thereby reducing the incentive for incurring the costs of the changes.

Five alternatives for dry storage are shown in Figure D.1: metal storage casks, concrete casks, vault storage, horizontal storage modules, and transportable or dual-purpose casks. These methods of dry storage have been previously studied and evaluated by DOE.(11) Depending upon the type of dry storage selected, a transfer to a shipping cask may be necessary before transport to the DOE repository. That mode of transfer can be wet or dry, as illustrated in Figure D.1. However, it should be recognized that the NRC may require the licensee to maintain fuel transfer capability in case of emergencies as long as fuel is onsite.[5] Off-site storage alternatives include both wet and dry storage possibilities for storing SNF at another plant, a commercial storage facility, and off-shore. The possibilities of foreign reprocessing and disposal are included

[5]For an at-reactor-site ISFSI that is to become its own separate site, it is necessary, as part of decommissioning design requirements, that the ISFSI be capable of direct spent fuel shipments to the MRS or geologic repository. Currently, the issue of compatibility of dry storage designs with offsite transportation system designs for shipment to an MRS or geologic repository remains unresolved. Achievement of compatibility in design means that spent fuel in dry storage would not need to be returned to the reactor pool for unloading and the loading into a shipping cask. Vendors are exploring various means to meet NRC policy on this matter. Presently, the approaches include dual-purpose casks, shipment of sealed canistered spent fuel,(17) and dry transfer facilities.



(a) Based on information contained in References 11 and 16.

Figure D.1 Storage/disposition alternatives for spent nuclear fuel[a]

in Figure D.1, even though no serious opportunity for foreign disposal currently exists. In the case of reprocessing, all wastes arising from that process that are returned to the U.S. should be in a form acceptable to the DOE for final disposal, as shown in Figure D.1.

In the Rancho Seco study[16] the possibility of carrying out a demonstration program with transportable dry storage casks, and shipping 56 low-burnup Rancho Seco fuel assemblies for reinsertion in another nuclear plant was considered. The demonstration program was selected by Rancho Seco because a dual-purpose cask demonstration program with long-term storage prior to shipment has not yet been carried out.

It was concluded in the Rancho Seco study that none of the alternatives with economic viability evaluated for their spent fuel storage and disposition were precluded specifically because of lack of an applicable structure of federal safety regulations. However, differences did emerge among the attractiveness of alternatives due to cost of compliance with applicable regulations. The study also concluded that many of the alternative paths for Rancho Seco spent fuel disposition are not viable because of a combination of technical, economic and recipient acceptance barriers. Included in this category are:

- early shipment to storage at another plant, commercial, or government site
- disposal offshore
- offshore storage or reprocessing.

The Rancho Seco study showed that offshore storage/reprocessing had the highest cost relative to other options evaluated for Rancho Seco as well as the greatest number of regulatory and non-regulatory impediments.

Other conclusions drawn from the Rancho Seco study[16] are:

- storage in concrete storage-only casks or storage in the modified SFP are the lowest cost options, *if* Congressional or DOE policies and programs delay initiation of delivery services of the spent fuel well beyond 1998
- the lower the fuel pool security, monitoring and maintenance cost actually achieved, the more attractive is the fuel pool option
- the longer the predicted storage time (after the initial years that the fuel must remain in the pool to remove decay heat), the more economically attractive is dry storage in concrete casks relative to storage in the modified pool
- the crucial problem with *all* the storage-only options is the uncertainty in predicting delivery time plus the necessity of managing a one- to two-year backend loading-to-shipping-cask campaign, cask disposal, and a cask facility dismantling program in the indefinite future.

Overall, the study concluded that for several reasons the Rancho Seco situation with regard to spent fuel storage and final disposition was unique and that the higher capital cost transportable cask alternative should be pursued. However, it should be recognized that a similar conclusion may be unlikely at other light water reactor power stations, because of differences in their fuel storage and disposition situations.

D.4.2 Consideration of Two Basic Alternatives for SNF Storage

Because of delays in the implementation of the FWMS, many reactors will have large inventories of SNF, and in some situations may have already been forced to install external dry storage facilities on their sites to contain SNF that exceeded their pool capacities. An additional complication arises because the FWMS will only be able to accept SNF at a finite rate, and, under the terms of the contract between DOE and the U.S. nuclear utilities, allocation of acceptance rights to the utilities is to be based on an OFF basis, and the SNF must be cooled at the reactor site for at least five years before acceptance. Because of the large backlog of SNF in the utilities' pools, periods ranging from 5 to 26 years after reactor shutdown will pass before an individual reactor's pool could be emptied and the pool decommissioned (see Table D.3).

Faced with the need to store the SNF for an extended period of time, a utility has to evaluate its storage options to determine which decommissioning mode best suits its particular situation. If, for example, the utility had strong reasons for pursuing DECON, it would be necessary to transfer the SNF from the pool to an onsite dry ISFSI as soon after shutdown as

Table D.3 Distribution of sites storing SNF for given number of years following shutdown[a]

Years after shutdown until spent nuclear fuel inventory reaches zero	Number of sites
5	7
6	3
7	10
8	5
9[b]	12
10	7
11	5
12	4
13	2
14	11
15	28
16	12
17	7
18	1
19	1
20	1
24	2
25	2
26	3

(a) Derived from information contained in Reference 9.
(b) The reference BWR's (WNP-2's) inventory is reduced to zero in the year 2033, or 9 years after final shutdown, assuming the plant operates until 2024.

possible, to make it possible to proceed with decontamination and disassembly of the reactor facility in a timely manner. If, on the other hand, the utility preferred to place the reactor facility in SAFSTOR for an extended period (< 60 years), the utility could choose to maintain the pool under a Part 50 possession-only license (POL) until the FWMS had accepted all of the site

SNF inventory, or to place all of the SNF in an ISFSI (wet or dry) initially, even though the facility was placed in SAFSTOR, depending upon the amount of SNF in the inventory and the length of the storage period until the inventory was removed. Two basic alternatives are evaluated further in subsequent subsections:

- continue operation of the spent fuel pool at the reactor (under a Part 50 POL)
- transfer all SNF to an onsite ISFSI (wet or dry), and maintain fuel transfer capability.

In some circumstances, a given reactor site may have already installed a dry ISFSI onsite to handle the overflow from its reactor pool. In that case, the options involve continuing to operate both storage facilities or to transfer the pool SNF inventory to the onsite ISFSI. In all of these situations, a major factor in the decision-making process is the total life-cycle cost of the planned operations. To assist in making these decisions, a methodology has been developed which evaluates the present value of the life-cycle cost of each of the utility's options. A number of factors influence these evaluations, including such things as:

- What is the total onsite SNF inventory at reactor shutdown?
- When does the reactor terminate power operations?
- When does the FWMS begin accepting SNF from the site?
- At what rate does the FWMS accept SNF from the site?
- What would be the minimum time required for DOE to accept all of the utility's SNF?

  Note: In accordance with 10 CFR Part 961 (the Contract), the minimum time to deliver the last discharge of SNF would be 5 years following shutdown.

- If no ISFSI exists at shutdown, what are the costs of building and licensing, under 10 CFR Part 72, an onsite ISFSI (wet or dry)?
- What are the costs of continuing wet storage in the existing reactor pool(s)?
- What are the costs per unit quantity of SNF for dry storage devices?
- What are the annual operating costs associated with the existing wet storage mode and/or an ISFSI (wet or dry)? What are the decommissioning costs for the existing wet storage mode and/or an ISFSI (wet or dry)?

  Note: Regarding the potential impacts on the selection of decommissioning alternatives, the following statement is made in 10 CFR Part 50.54(bb) concerning how reasonable assurance will be provided that funds will be available to manage and provide funding for the spent fuel upon expiration of the reactor operating license. "For nuclear power reactors licensed by the NRC, the licensee shall, within 2 years following permanent cessation of operation of their reactor or 5 years before expiration of the reactor operating license, whichever comes first, submit written notification to the Commission for its review and preliminary approval of the program by which the licensee intends to manage and provide funding for the management of all irradiated fuel at the reactor following permanent cessation of operation of their reactor until title to the irradiated fuel and possession of the fuel is transferred to the Secretary of Energy for its ultimate disposal in a repository. Licensees of nuclear power reactors that permanently ceased operation by April 4, 1994, are requested to submit such written notification by April 4, 1996. Final Commission review will be undertaken as part of any proceeding for continued licensing under Part 50 or Part 72 of this chapter. The licensee must demonstrate to NRC that the elected actions will be consistent with NRC requirements for licensed possession of irradiated nuclear fuel and that the actions will be implemented on a timely basis. Where implementation of such actions requires NRC authorizations, the licensee shall verify in the notification that submittals for such actions have been or will be made to NRC and shall identify them. A copy of the notification shall be retained by the licensee as a record until expiration of the reactor operating license. The licensee shall notify the NRC of any significant changes in the proposed waste management program as described in the initial notification."

D.4.3 Present Value Life-Cycle Costs of Two Alternatives for SNF Storage

The present value (PV) of the total storage system life-cycle cost can be estimated for each system, for purposes of comparison. The following expression yields the PV of the life-cycle cost for the case of utilizing the spent fuel pool until the total inventory of SNF has been transferred to DOE.

$$PV = D_{p0} + \sum_{i=1}^{N} D_{pi}/(1+k)^i + DD_p/(1+k)^N$$

where D_{p0} is the cost of isolating the spent fuel pool from the retired plant systems; D_{pi} is the annual operating costs of the wet storage facility in constant dollars of Year 0 (year of reactor shutdown); k is the net discount rate (interest minus inflation) which is assumed constant over the storage period; i is the number of years since reactor shutdown for which the operations costs are being calculated; and N is the number of years after reactor shutdown required for the onsite inventory to reach zero. Once the inventory is zero, the existing storage facility is decommissioned, at a cost of DD_p, in constant Year 0 dollars.

A similar expression can be used to calculate the present value of the life-cycle cost of utilizing the spent fuel pool until the hottest fuel assemblies can be safely placed into dry storage, then using dry storage until the total inventory of SNF has been transferred to DOE.

$$PV = D_{p0} + \sum_{i=1}^{n} D_{pi}/(1+k)^i + D_{d0}/(1+k)^n + DD_p/(1+k)^{n+1} + \sum_{i+n}^{N} D_{di}/(1+k)^1 + DD_d/(1+k)^N$$

where n is the number of years after reactor shutdown that the hottest SNF must cool before being placed into dry storage; D_{d0} is the cost of creating and loading the dry ISFSI in Year n; D_{di} is the annual cost of operating and maintaining the dry ISFSI; and DD_d is the cost of decommissioning the dry ISFSI, all values in Year 0 dollars. Other terms are as defined above. Because the costs of deactivating and decommissioning the pool are included in the normal plant decommissioning costs, they are not costed in these life-cycle cost analyses.

The estimated annual costs of operating the SNF storage pool or the ISFSI storage facility are given in Table D.4. The cost of separating the spent fuel pool systems from the balance of plant systems is estimated to be about \$0.5 million, and operating and maintaining the spent fuel storage pool during safe storage of the rest of the plant is estimated to be \$5.5 million per year, as given in Table D.4.

The net discount rate is assumed to be 3% per year, and the duration of pool operations is assumed to be 9 years, based upon information in Table D.2. With these assumptions, the present value of the SNF pool operations until the inventory has reached zero is evaluated to be about \$43.3 million.

Similarly, the initial cost of establishing a dry ISFSI (D_{d0}) includes the capital costs of casks, transporters, and other handling equipment, plus the labor costs of loading the SNF into the casks and transporting the casks to the ISFSI location for storage. Assuming a pool inventory of 1886 assemblies, storage capacity for about 359 metric tonnes of uranium (MTU) is required. Based upon data from Reference 11, the estimated cost of storage capacity is about \$65,000/MTU (about 37 concrete casks), for a total cost of about \$23.4 million, expended during Year 4. Because the plant must install an ISFSI for operational reasons about 2 years prior to shutdown, equipment and storage pads/ fences/etc., which would otherwise cost about an additional \$5 million during Year 4, are already in place and not charged to decommissioning. The labor costs for removing the SNF from the pool and placing it in the ISFSI during Year 4 are estimated to be about \$0.25 million. Thus, the total cost for additional casks and for loading the ISFSI (D_{d0}) would be about \$23.7 million. Labor and non-personnel costs associated with ISFSI operation (D_{di}) are estimated to be about \$2.1 million per year. Decommissioning costs for the ISFSI (DD_d) are estimated to be about 10% of the capital cost, or about \$2.9 million during Year 10.

Table D.4 Estimated SNF storage operational costs at the reference BWR[a,b]

Cost category	Estimated annual cost (1993$)[c]		
	Pool	Safe storage	ISFSI[d]
Non-Personnel Costs			
Instr. & Elect. Maint. (matl. & supplies)	113,958	--	10,000
Mech. Maint. (materials & supplies)	146,960	--	5,000
Chemistry (materials & supplies)	283,800	--	--
Radwaste Onsite Processing (supplies)	59,980	--	10,000
Radwaste Contract Removal & Disposal	84,800	--	15,000
Environmental Monitoring (matl. & supplies)	43,743	4,860	43,743
Protective Clothing Laundry	83,539	9,282	27,300
Electric Power (@ $0.027/kWh)[e]	48,600	5,400	23,824
State Regulatory Costs[f]	220,000	24,000	220,000
Licensing & Inspection[g]	13,666	1,518	13,666
Nuclear Liability & Property Ins.[h]	507,600	600,000	507,600
Subtotal, Non-Personnel Costs	1,606,646	645,060	876,133
Personnel Costs			
Utility Staff Labor[i]	3,902,809	433,646	1,241,530
Total Annual Operating Cost	5,509,455	1,078,706	2,117,663

(a) Based on information found in Reference 18, and adjusted for use in this reevaluation study.
(b) The values given in the table do *not* contain a contingency allowance.
(c) The costs of operating the pool and providing safe storage for the plant are allocated 90% to pool operations and 10% to safe storage operations.
(d) ISFSI costs, with concurrent safe storage operations.
(e) Based on estimated plant load of 0.23 MW during Period 3.
(f) Derived from Table B.16.
(g) Study estimate: based on NRC billings to two utilities with SNF stored in pools at retired reactors.
(h) Based on $1,107,600/yr for both pool and safe storage operations, and subsequent $600,000/yr for safe storage only (see Table B.8).
(i) Derived from Table 3.2.

The first 4.6 years of pool storage results in an initial cumulative expenditure of $23.5 million (present value). Added to those pool operating costs are the capital cost of sufficient casks to store the remaining fuel in the ISFSI ($20.77 million, present value), and the cumulative costs of 5 years of ISFSI operation ($8.64 million, present value) and of the ISFSI decommissioning costs ($2.19 million, present value). The resulting cost of SNF storage operations utilizing 4.6 years of pool storage and 5 years of dry cask storage is about $55.11 million, in present value.

Simply continuing to operate the spent fuel pool for the additional 5 years would result in a total cost for storing the SNF remaining in the pool of about $47.4 million, present value. Thus, for the relatively short storage time considered in this analysis, it would be more cost-effective to store the SNF in the fuel storage pool than to add sufficient casks to store all of the fuel in the dry ISFSI. However, if the storage period were to be extended to 13 years or greater, the present value cost of ISFSI storage would become less than that of spent fuel pool storage, as shown in Figure D.2, where the present value of the cumulative costs for pool operation and for pool plus dry ISFSI operation and decommissioning are shown for 15 years following reactor shutdown.

D.5 Required SNF Cooling Time Following Discharge Before Dry Storage

To determine the cooling time required before fuel from WNP-2 could be placed in dry storage at the site, the assumption was made that the fuel would be stored in metal storage casks (which may or may not be transportable). The required time delay following discharge before spent fuel can be placed into the dry cask storage is primarily a function of the fuel burnup and reactor operating history (with a small sensitivity to initial enrichment). The first step in the approach taken to estimate the required delay time was to develop a curve of maximum cladding temperature for fuel stored in metal casks as a function of the decay heat output rate (watts/MTU). Data from an experimental program at GE-Morris were examined, wherein maximum fuel rod cladding temperatures were inferred from measurements made on the REA cask containing 52 BWR assemblies from the Cooper Nuclear Station.[20] The measurement made with an ambient temperature of 22 degrees centigrade and nitrogen coolant was selected for this analysis, to permit comparison with the later measurements made on PWR fuel in three cask test programs[21,22,23] at the Idaho National Engineering Laboratory, as discussed in NUREG/CR-5884, the reevaluation of decommissioning the reference PWR.[24] For the BWR fuel, the data included:

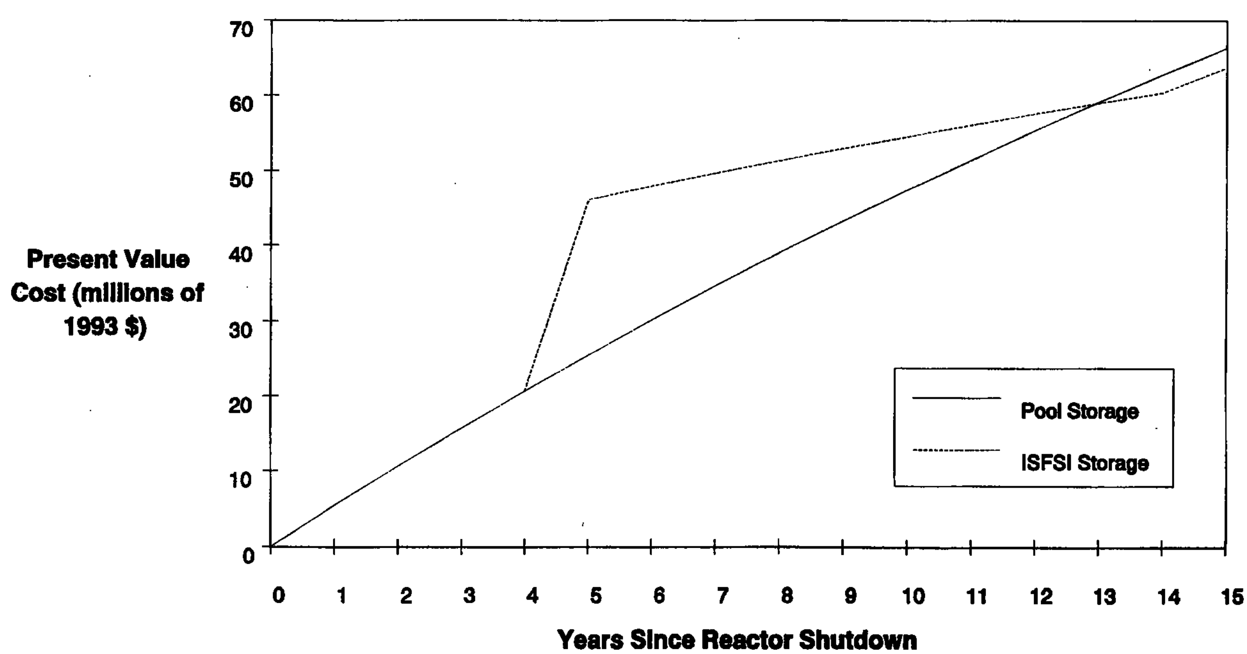


Figure D.2 Present value costs for SNF storage operations

- An average value of 0.1904 MTU/assembly, derived from data contained in PNL-5777, *BWR SPENT FUEL STORAGE CASK PERFORMANCE TEST: Volume 1, Cask Handling Experience and Decay Heat, Heat Transfer, and Shielding Data*[20] for the fuel used in the cask test. The decay heat load on the REA cask was 14,400 watts at the time of the measurement, with 52 assemblies, 9.9012 MTU/cask load, for a heat loading of 1454 watts/MTU, and a maximum cladding temperature of 209°C with a nitrogen atmosphere in the cask, and an ambient temperature of 22°C. The average fuel burnup was 26,544 MWD/MTU, the cooling time was 2.81 years at the time of the measurement, and the initial enrichment was 2.5 wt% ^{235}U.

For the PWR fuel, the data included:

- An average value of 0.4582 MTU/assembly, derived from data contained in DOE/RL-90-44, *Spent Fuel Storage Requirements 1990-2040*[19] for the fuel used in the PWR cask tests. The average fuel burnup ranged from 24,200 to 35,400 MWD/MTU, and the initial enrichments ranged from 1.86 to 3.20 wt% ^{235}U.

- Castor-V/21 cask: 28 kW heat load, 21 assemblies, 9.622 MTU/cask load, for a heat loading of 2910 watts/MTU and a maximum cladding temperature of 368°C in a cask atmosphere of nitrogen, and an ambient temperature of 24°C, extracted from EPRI NP-4887, *THE CASTOR-V/21 PWR SPENT-FUEL STORAGE CASK: Testing and Analyses.*[21]

- MC-10 12.6 kW heat load, 24 assemblies, 10.9972 MTU/cask load, for a heat loading of 1146 watts/MTU and a maximum cladding temperature of 181°C in a cask atmosphere of nitrogen, and an ambient temperature of 24°C, extracted from EPRI NP-5268, *THE MC-10 PWR SPENT-FUEL STORAGE CASK: Testing and Analysis.*[22]

- TN-24P 20.5 kW heat load, 24 assemblies, 10.9972 MTU/cask load, for a heat loading of 1862 watts/MTU and a maximum cladding temperature of 241°C in a cask atmosphere of nitrogen, and an ambient temperature of 20°C, extracted from EPRI NP-5128, *THE TN-24P PWR SPENT-FUEL STORAGE CASK: Testing and Analyses.*[23]

These average heat loadings were plotted versus the maximum cladding temperature inferred from the measurements on each loaded cask, to obtain a curve of maximum cladding temperature versus fuel decay heat emission rate, as shown in Figure D.3.

The second step was to calculate the allowable maximum temperatures for two levels of internal fuel rod pressurization, for cooling times of 1 to 5 years. Assuming the use of standard 8x8 BWR fuel assemblies, cladding hoop stresses during storage in the range from about 6 to 9 MPa were calculated. The maximum allowable cladding temperature during dry storage was calculated using the methodology given in PNL-6639, *DATING - A Computer Code for Determining Allowable Temperatures for Dry Storage of Spent Fuel in Inert and Nitrogen Gases.*[25] Postulating a storage period of 300 years to avoid any sensitivity to storage duration, the allowable cladding temperatures were calculated for fuel with cooling times ranging from 1 to 5 years, for assumed cladding hoop stresses ranging from 6 to 9 MPa. The results of these calculations are shown in Table D.5.

Because the difference between the measured and calculated cladding temperatures in the cask tests discussed earlier tended to be in the vicinity of 30°C, a safety factor of 30°C was subtracted from the above values, resulting in allowable values ranging from 546 to 442°C.

Nominal values of 540 and 445°C were selected as a reasonable range of cladding temperatures to consider for limits, taking into account the safety factor. Maximum allowable decay heat rates for cladding temperatures of 540 and 445°C were read from the curve of Decay Heat versus Cladding Temperature (Figure D.3) to be about 4000 and 3280 watts/MTU, respectively.

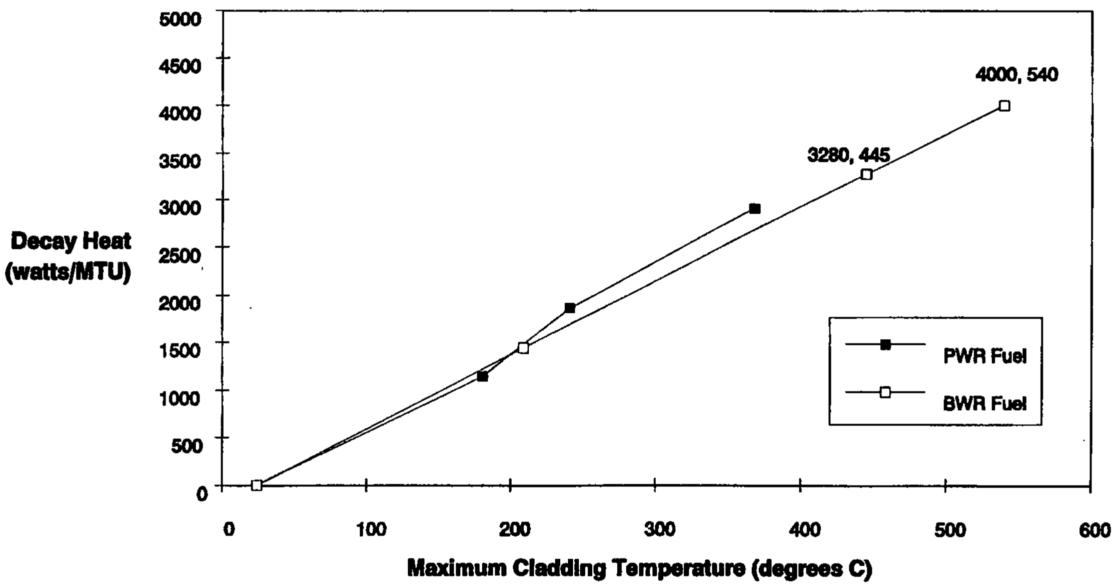


Figure D.3 Decay heat emission rate as a function of maximum cladding temperature for BWR and PWR fuel stored in metal casks

Table D.5 Calculated allowable BWR cladding temperatures in dry storage

Cooling time (years)	1	2	3	4	5
Max. Temp. (°C @ 6 MPa)	576	547	529	512	485
Max. Temp. (°C @ 7 MPa)	571	542	524	507	480
Max. Temp. (°C @ 8 MPa)	567	538	520	503	476
Max. Temp. (°C @ 9 MPa)	563	534	516	500	472

To determine the required cooling times for spent fuel having differing levels of burnup and initial enrichment, calculated data on decay heat emission were read from tables contained in Regulatory Guide 3.54, *Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation*,[26] for cooling times of 1, 2, and 5 years, at burnups of 27, 40, and 46 GWD/MTU, and for initial enrichments of 2.5, and 4.0 wt% ^{235}U in the fuel. Those data were adjusted according to the procedures given in the Guide, including an adjusted set for the fuel projected for the end-of-life discharge from WNP-2[27] (42,486 MWD/MTU @ 3.072 wt% ^{235}U). The data were plotted on a log scale and smooth curves were drawn through the points, as shown in Figure D.4. The cooling times required for decay heat emission rates of 4000 and 3280 watts/MTU, as

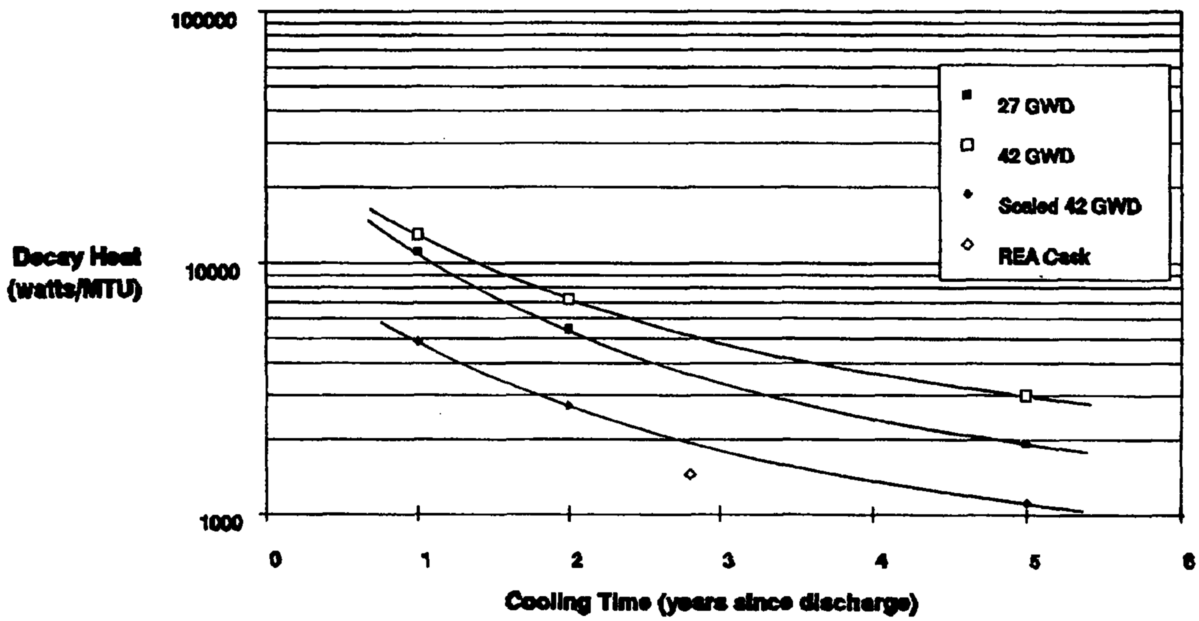


Figure D.4 Spent fuel decay heat as a function of cooling time for BWR fuel

read from the curve for the projected end-of-life level of burnup and initial enrichment at WNP-2, are 3.82 and 4.59 years, respectively. Based on this analysis, the fuel pool could not be finally emptied until nearly 5 years following reactor shutdown, if the SNF is destined for dry storage onsite. However, examination of Figure D.4 illustrates the very large conservatism that is inherent in the data and procedures delineated in Regulatory Guide 3.54. Comparison of the decay heat rate measured in the REA cask tests (1454 W/MTU after 2.8 years cooling) with the calculated value (3890 W/MTU) at the same cooling time for approximately the same burnup (26,554 MWD/MTU for the experiment vs. 27,000 MWD/MTU for the calculation) shows that the calculation appears to overestimate the decay heat rate by a factor of about 2.67. If the calculated curve for the end-of-life fuel were adjusted downward to compensate for the apparent bias in the calculated values, the cooling times required for that fuel would be more like 1.25 and 1.60 years, respectively. For conservatism, and for consistency with the analysis in the previous PWR reevaluation study,[24] a minimum cooling time of 4.6 years has been selected for this reevaluation of the reference BWR study.

D.6 Rationale for the Spent Fuel Storage Option Postulated for the Reference BWR

When the reference BWR is operating and space is available in its fuel pool, the incremental cost of storing spent fuel is relatively low because security services, fuel handlers, pool maintenance and monitoring personnel are already available at the site. When the plant is shut down, the facility operating license issued by the NRC needs to be modified to one permitting possession of the fuel and radioactive materials but not operation of the facility. This modification enables a significant reduction in the costs of maintaining the facility. A substantial portion of the costs required to maintain the shutdown facility becomes those associated with safe storage of the spent fuel. Even when the aforementioned license modifications are accomplished, it is anticipated that the reference BWR will sustain significant costs, unrelated to decommissioning, for spent fuel security, cooling, and monitoring. Such expenses will stop only when the fuel is removed from fuel pool storage. If the ultimate disposal of the fuel is in the contemplated federal repository, the costs may extend over a long period of time, especially if construction of the federal repository is delayed.

The following general information concerning spent fuel storage is extracted from Klepfer and Bowser,[16] and adapted, where appropriate, to this study in support of the rationale for the spent fuel storage option postulated for the reference BWR.

The costs of spent fuel storage at a shutdown nuclear plant vary depending upon the characteristics of the storage site, the owner's future plans for it, and whether the utility has other nuclear plants. Typical considerations are as follows:

- If the shutdown plant is at a multi-unit nuclear site, such as in the case of Dresden-1, the costs of storing spent fuel will be relatively low and roughly equivalent to those for an operating plant. [The reference BWR, WNP-2, is not a multi-- unit nuclear site.]

- If the utility owns other nuclear plants, it can consider transshipment of the spent fuel from the shutdown plant to its remaining operating nuclear plants. Such a transfer could reduce costs, especially if the federal repository gets further and further delayed. [For the purpose of this study, it is assumed that the reference BWR's owners cannot consider transshipment of the reactor's fuel to another of its nuclear plants because the reactor is the only nuclear plant owned by the utility.]

- If the shutdown plant is at a site where other power generation units are located, such as in the case of Humboldt Bay and LaCrosse, the costs of storing spent nuclear fuel are reduced because security and maintenance services are available already. [At present, the reference BWR is exclusively a nuclear generating site.]

- When the shutdown plant is large in size, as is the case of the reference BWR, there could be incentives to repower the plant with other types of fuel. Such repowering is even more attractive if the nuclear plant can be decontaminated and decommissioned. The NRC regulations provide for two principal alternatives after a reactor has been shut down and defueled:

  - DECON - This option requires that the fuel be shipped offsite.[6] The equipment, structures, and portions of the facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations.[28] [This means that the reference plant (WNP-2) cannot be decontaminated and released from regulatory controls until its fuel is shipped. In the OFF option, this cannot occur until at least 2033,[10] some 9 years after final reactor shutdown, unless another option for offsite spent fuel storage besides the permanent DOE repository can be developed. In this study, the OFF option is assumed to be the most *realistic* case. On the other hand, due to the exchange process contained in the Contract, the most *optimistic* case would allow SNF delivery to DOE at shutdown plus 5 years (presumed in this study to be a highly unlikely event).

  - SAFSTOR - This option permits placing the facility in a safe storage condition for up to 60 years. Fuel may be stored in the fuel pool. According to information contained in Reference 29, WNP-2's licensed/ maximum fuel pool capacity of 2,658 assemblies (including full core reserve) will occur in 1999, with a total additional capacity needed

[6]"Offsite" could be a wet or dry "independent spent fuel storage facility (ISFSI)," but it may be that this separate facility could be adjacent to the plant facility. Two "redefined" sites, a DECON reactor site and an ISFSI site, would result. Use permits and licenses for the resulting sites could conceivably be complicated by the interaction of the two sites.[16]

for 2,211 assemblies through 2021. The end of plant life is projected by EIA to be 2024.[10] However, as previously shown in Table D.2, the reference BWR will not have adequate pool capacity to accommodate its remaining inventory without the need for additional storage capability for 2 years, assuming DOE receives SNF beginning in 1998 and at the rates given in Table D.1. For the purpose of this study, it is assumed that some form of onsite SNF storage is provided during this 2-year period by the utility. Because this SNF storage occurs during the operating years of the reference plant, it is considered an operations cost.

To determine the minimum SAFSTOR period for the reference BWR, it is assumed that the SNF remains stored in the reference BWR's fuel pool, under the 10 CFR Part 50 possession-only license, after final reactor shutdown in CY 2024.[7] Then, the minimum SAFSTOR period for the reference BWR, without use of the DCS exchange process, can be defined as the time between the year of reactor shutdown, in CY 2024, and the year in which the last shipments occur in CY 2033, or 9 years.

It is further concluded that immediate dismantlement (DECON) in the exact same manner as defined in the original BWR study[30] does not appear to be viable because decommissioning cannot start immediately after final reactor shutdown without removal of the stored SNF. Based upon the estimated SNF cooling-time analysis presented in Section D.5, the fuel pool could not be finally emptied until at least 4.6 years following reactor shutdown because of cladding temperature limitations for dry storage. The transfer of the fuel from the pool into dry storage could proceed beginning at shutdown, and continue throughout the intervening years until the final assemblies were removed; or, the transfer of the fuel could be done in a single campaign, beginning about 4 years after shutdown.

For this study, it is assumed that the spent fuel pool is maintained under the POL and is *not* converted into an NRC-licensed ISFSI under 10 CFR Part 72, which might allow immediate dismantlement of the remainder of the facility. The reasons provided by the NRC for not assuming conversion of the existing fuel pool into a licensed wet-storage ISFSI in this study are:

- Interpretation of the NRC definition of decommissioning does not allow conversion to a Part 72 license. The license must remain a Part 50 license until the reactor is decontaminated and the site restored for unrestricted use.

- Conversion to a Part 72 license is a costly and difficult undertaking and separating the reactor components from those needed to support a wet ISFSI usually cannot be done in a satisfactory way to ensure the health and safety during the reactor dismantlement process because areas and equipment that support spent fuel pools have commonality with the existing reactor; dismantlement of the reactor could compromise the integrity of the wet ISFSI.

- Costs for maintaining a Part 50 possession-only license (POL) can be reduced by amendments or exemptions as requested by licensees with shutdown reactors. Amendments or exemptions have been made for reduction of onsite property damage insurance and the staff is also considering similar requests for liability insurance.

The modified DECON alternative developed for this study entails transferring the SNF, after an adequate cooling period, to an at-reactor-site ISFSI (dry-cask storage), which is licensed under Part 72, followed by decommissioning of the reference reactor facility. It is further assumed that the at-reactor-site ISFSI has fuel transfer capability in case of emergencies as long as fuel is onsite; however, it should be recognized that no licensed dry-storage technology currently provides such capability.

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[7]CY 2024 is the Energy Information Administration's projected year of final shutdown for the WNP-2 plant, as defined in References 10 and 19.

It is important to note here that there is a definite interaction between decommissioning decisions and any final selection for post-shutdown storage of a specific reactor's spent fuel, if required. Such decisions must include consideration of the final disposition schedule of the fuel within the context of the overall federal waste management system.

The results of the analyses presented in this appendix realistically reflect the available decommissioning alternatives for the reference BWR. It should be recognized, however, that the situation described in this appendix, with regard to spent fuel storage and its eventual delivery to DOE, is predicated on the current regulatory environment and on site-specific information associated with the reference BWR. Therefore, the conclusions reached herein concerning decommissioning alternatives for the reference BWR may not be the same for other BWR power stations.

D.7 References

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File N6883.PRJ.RW859.Y92.GENERIC.FILE.SEPT1

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Appendix E

Dismantlement and Disposal Activities, Manpower, and Costs for the Reactor Pressure Vessel and Internals, and Sacrificial Shield

Appendix E

Dismantlement and Disposal Activities, Manpower, and Costs for the Reactor Pressure Vessel and Internals, and Sacrificial Shield

The levels of neutron-activation in the metallic reactor pressure vessel (RPV) and its internals vary greatly with proximity to the fueled region of the vessel. Those components located close to the fueled region are very highly activated, with some segments being classified as Greater-Than-Class C (GTCC) radioactive waste (10 CFR 61.55).[1] The GTCC material must be packaged for transport to and disposal in a geologic repository or other such disposal facility as the Nuclear Regulatory Commission (NRC) may approve. The canisters postulated for this study are 9 in. square outside dimension, and can contain material as long as 175 in. Transport of the GTCC material to the repository is postulated to be accomplished using spent fuel casks (NAC-LWT and TN-8, containing 1 and 2 canisters per shipment, respectively, because of weight limitations on the cask payload). Other components, located some distance from the fueled region, are still strongly activated but are classified as Class B or C waste and require packaging for shielded transport to and disposal in a licensed low-level waste (LLW) burial site. Still other portions of these components are only slightly activated and are classified as Class A waste, acceptable for unshielded transport to an LLW burial site. In this analysis, the activation analyses for the reference BWR, originally presented in NUREG/CR-0672,[2] are used to define the classification of the various components and segments of those components, as described in Addendum 2 to NUREG/CR-0672,[3] and the various segments are segregated for packaging according to their activity levels.

E.1 Basic Disassembly Plan

To facilitate the disassembly and packaging operations for the RPV internals, two plasma-arc cutting systems are postulated to be installed inside the Reactor Building. One is mounted on the refueling bridge, principally for major disassembly of the core barrel and other internals. The second cutting system is mounted on a separate bridge/manipulator assembly at the far end of the dryer/separator storage pool, together with a cutting table and appropriate jigs for holding the various pieces during cutting operations, to facilitate packaging in appropriate containers. All cutting of the stainless steel internals with the plasma-arc systems is performed under water, with the exception of the reactor coolant system (RCS) piping connections to the RPV.

The RPV head and the steam separator and dryer assemblies are removed and placed in their normal storage locations prior to defueling. Following defueling, the steam separator and dryer assemblies are segmented and packaged for disposal. The core spray and feed water ring headers are removed and segmented for packaging and disposal. The lower core support assembly and core shroud are removed from the RPV and placed into the dryer/separator storage pool for disassembly. The control rod guide tubes are removed and packaged. The jet pumps are removed and segmented for packaging and disposal. Disassembly, sectioning, and packaging of the RPV internal structures are carried out in the dryer/separator storage pool. That pool is maintained filled with deionized water until removal, sectioning, and packaging of the stainless steel RPV internals have been completed, after which it is drained and decontaminated. Following the sectioning and packaging of the RPV internals, the RPV head is reinstalled and the RCS is drained for the safe storage period.

Sectioning and packaging of the RPV is delayed until the deferred dismantlement period. The RPV is refilled with deionized water to provide shielding during the subsequent sectioning of the RPV. The seals between the RPV and the reactor containment enclosure and the Reactor Building structure are removed to provide access for removing the insulation surrounding the vessel prior to beginning sectioning of the RPV. Following insulation removal, the oxyacetylene cutting of the RPV gets under way, with the water level being maintained just below the level of the cutting operations. Cutting of the RCS piping/RPV connections is performed as the connections are uncovered during the lowering of the water level in the RPV. Cutting of the RPV is performed in air within the concrete/steel sacrificial shield, using an oxyacetylene cutting system. The oxyacetylene torch is applied to the outside of the RPV, thereby avoiding any problems in penetrating the stainless steel lining of the vessel. The viability of this approach was demonstrated by Lundgren(4) for cutting thick (9 in.) sections of carbon steel clad with thin stainless steel on one side.

The postulated procedures for these activities are presented in this appendix, together with estimates of the time and cost of these activities. The dimensions of the RPV and its internal structures used in these analyses are derived from information given in the reference BWR report(2) and from backup information supporting that report. The density postulated for stainless steel in these analyses is 0.29 lb/in.^{3}, or 8044 kg/m^3.

E.2 Core Shroud Assembly Components

The core shroud in the reference BWR consists of three cylindrical shells, attached together to form a tall cylinder, as illustrated in Figure E.1. The upper cylinder is about 43 in. tall and about 220 in. outside diameter. The central cylinder, which surrounds the fueled region of the core, is about 168 in. tall and approximately 207 in. outside diameter. The lower cylinder is about 56 in. tall and about 201 in. outside diameter. The cylinders have wall thicknesses of 2 in., and are joined using 2 coupling rings at the intersection of the cylinders. The upper and lower coupling rings are 2 in. and 3.7 in. thick, respectively, and have outer and inner diameters of 220 in. and 203 in., and 207 in. and 186 in., respectively. The shroud is supported on the shroud support cylinder which is about 205 in. O.D., 195 in. I.D., and about 69 in. high. The jet pump support ring is attached to the RPV wall and the shroud support cylinder which is attached to the RPV lower head, and the jet pump assemblies are attached to the support ring and to the recirculation inlet nozzles in the RPV wall.

E.2.1 Shroud Components Expected to Exceed Class C Activation Levels

The upper and central core shroud cylinders and their coupling ring, which surrounds the fueled region of the core, are expected to have a significant fraction of their material activated to greater-than-class C (GTCC) levels. Thus, the upper and central core shroud cylinders and coupling ring are segmented and packaged as GTCC material. The full-density volumes of these shroud assembly components are calculated below.

Upper Cylinder: $(\pi/4)[(220)^2 - (216)^2]$ in.^{2} x 43 in. = 58,899 in.^{3}, or 0.965 m^3.
Upper Ring: $(\pi/4)[(220)^2 - (203)^2]$ in.^{2} x 2 in. = 11,296 in.^{3}, or 0.185 m^3.
Central Cylinder: $(\pi/4)[(207)^2 - (203)^2]$ in.^{2} x 168 in. = 216,393 in.^{3}, or 3.546 m^3.

The weight of the GTCC material is calculated to be:

$$286{,}588 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 83{,}111 \text{ lb, or } 37{,}778 \text{ kg.}$$

The upper and central shroud cylinders are separated from the upper and lower coupling rings (circumferential cuts of 691, 650, and 650 lineal inches @ 2 in. thick). The cylinders are cut into vertical strips, 8.5 in. wide, and 43 in. long for the upper cylinder, and 168 in. long for the middle cylinder:

$\pi(220/8.5)$ = 81.3 strips (82 cuts for 3,526 lineal inches @ 2 in. thick)
and $\pi(207/8.5)$ = 76.5 strips (77 cuts for 12,936 lineal inches @ 2 in. thick).

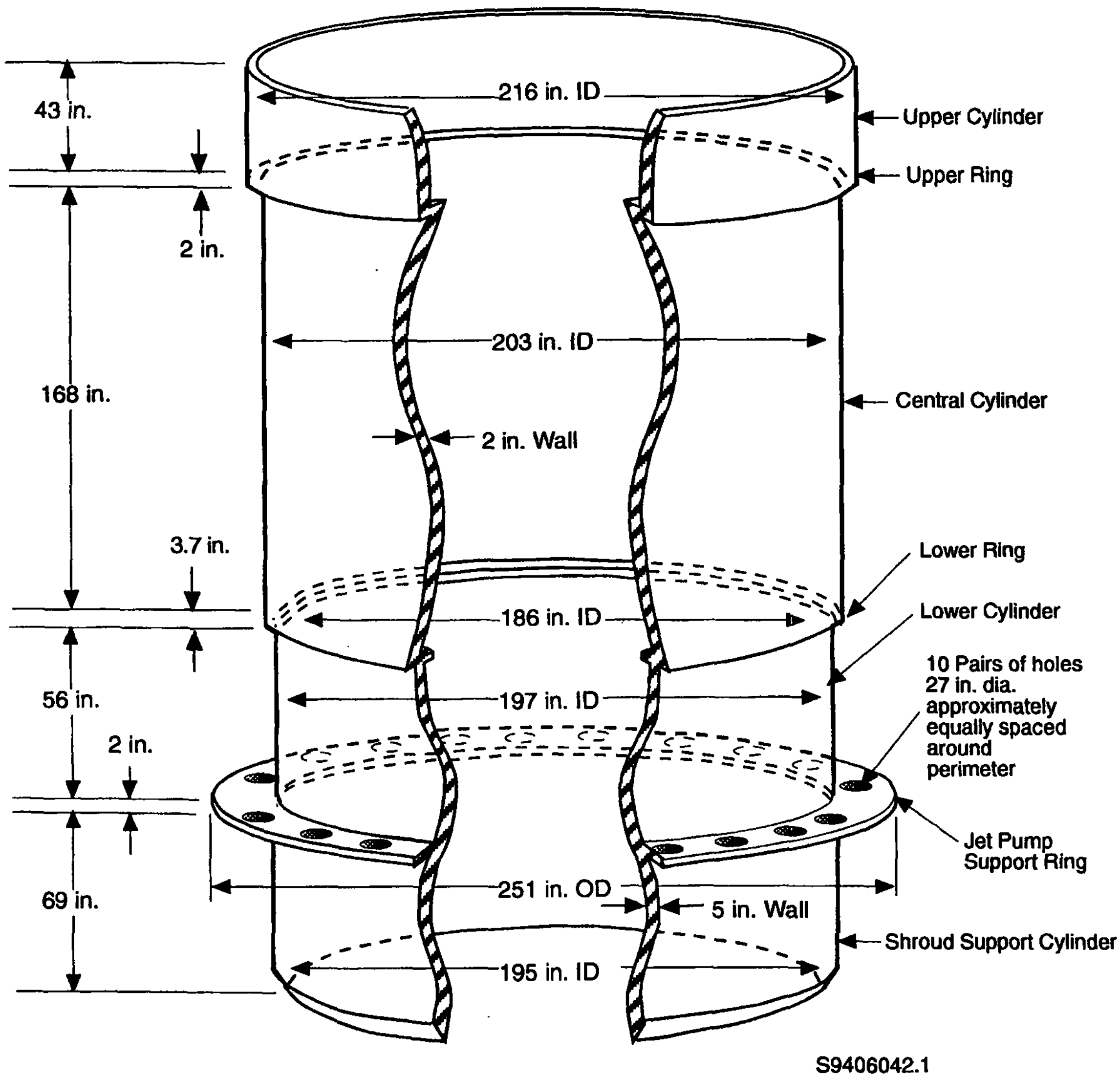

Figure E.1 Reference BWR core shroud assembly

The equivalent length of these strips is:

$$82 \times 43 \text{ in.} + 77 \times 168 \text{ in.} = 16{,}462 \text{ in.},$$

which, when arranged into pieces that are 175 in. long for canister loading, and 4 strips per canister, results in 23.5 canisters. The residual half-strips are inserted into the partially filled canister, yielding 24 canisters total. The upper coupling ring is cut into 16 pieces, 43 in. long, (136 lineal inches of cut @ 2 in. thick), an equivalent of 4 strips 2-in. thick, for one additional canister.

The packaged volume, weight per canister, and effective packaged density of the GTCC material within the canisters are:

25 canisters x 0.24 m^3/can = 6.000 m^3
37,778 kg/25 canisters = 1,511 kg/can, with an effective density of 6.296 kg/m^3, about 79% of theoretical density.

E.2.2 Core Shroud Components Activated to Less than GTCC Levels

The full-density volumes of the core shroud assembly components expected to be activated to Class C levels or less are calculated below.

Lower Ring: $(\pi/4)[(207)^2 - (186)^2]$ in.^{2} x 3.7 in. = 23,983 in.^{3}, or 0.393 m^3.
Lower Cylinder: $(\pi/4)[(201)^2 - (197)^2]$ in.^{2} x 56 in. = 70,020 in.^{3}, or 1.147 m^3.
Lower Support: $(\pi/4)[(205)^2 - (195)^2]$ in.^{2} x 69 in. = 216,770 in.^{3}, or 3.552 m^3.
Jet Pump Ring: $(\pi/4)\{[(251)^2 - (197)^2] - [10 \times (20)^2] - [2 \times (25)^2]\}$ in.^{2} x 2 in. = 29,754 in.^{3}, or 0.488 m^3.
Jet Pump Assm: $10\,\pi(10.75)(0.365)138 + 20\,\pi(8.625)(0.322)125 + 10\,\pi(6.625) \times (0.280)75 + 20\,\pi(11.5)(0.365)85$ = 65,612 in.^{3}, or 1.075 m^3.

The lower coupling ring is separated from the shroud lower support cylinder (1 cut, 631 lineal inches @ 2 in. thick), and is cut into 18 segments about 38 in. x 10.5 in. x 3.7 in. (18 cuts, 189 lineal inches @ 3.7 in. thick) for packaging in an 8-120B cask liner.

The lower cylinder is separated from jet pump ring (1 cut, 619 lineal inches @ 2 in. thick) and is cut into 18 segments about 46 in. x 56 in. x 2 in. (18 cuts, 1008 lineal inches @ 2 in. thick) for packaging in an 8-120B cask liner. The cylinder weight is about 20,300 lb.

The shroud support cylinder is separated from the jet pump ring (1 cut, 675 lineal inches @ 2 in. thick) and from the RPV lower head (1 cut, 675 lineal inches @ 4.75 in. thick), and is cut into 18 segments, about 46 in. x 69 in. x 4.75 in. (18 cuts, 1,242 lineal inches @ 4.75 in. thick), for packaging in 9 maritime containers. The cylinder weight is about 62,860 lb.

The jet pump assemblies are separated from the recirculation inlet nozzles, and are cut into segments to facilitate packaging the highly activated portions in 12 cask liners for the NAC-1 cask. The total weight of the components is about 12,500 lb. The less highly activated jet pump diffusers (weight about 6,500 lb) are cut and packaged into 1 liner for the 8-120B cask. The disassembly operations require 220 cuts, for a total of 16,100 lineal inches @ 0.36 in. thick.

The jet pump support ring is separated from the RPV wall (1 cut, 789 lineal inches @ 2 in. thick), and is cut into three 120-degree segments for packaging in a maritime container (3 cuts, 54 lineal inches @ 2 in. thick). The weight of the ring is about 8,630 lb.

E.2.3 Top Fuel Guide

Some portions of the top fuel guide are expected to be activated to GTCC levels. Thus, this assembly is also segmented and packaged for disposal as GTCC material.

The top fuel guide is an egg-crate type of structure, with a 12-in. pitch. The structural material is about 12 in. wide and about 0.4 in. thick. The egg-crate is attached to a circumferential ring, about 207 in. outer diameter, 2 in. thick, and 12 in. high. The full-density volume of this material is:

$$5{,}395 \text{ in. x } 0.4 \text{ in. x } 12 \text{ in.} = 25{,}896 \text{ in.}^3\text{, or } 0.425 \text{ m}^3,$$

for the eggcrate, plus the volume of the circumferential ring:

$$(\pi/4)[(207)^2 - (203)^2] \text{ in.}^2 \text{ x } 12 \text{ in.} = 15{,}457 \text{ in.}^3\text{, or } 0.253 \text{ m}^3,$$

for a total of 0.678 m^3.

The weight of this material is:

$$[25{,}896 \text{ in.}^3 + 15{,}457 \text{ in.}^3] \text{ x } 0.29 \text{ lb/in.}^3 = 11{,}992 \text{ lb, or } 5{,}440 \text{ kg.}$$

The plates making up the egg-crate are cut into approximately 12 in. x 8 in. segments (588 cuts, for 7,056 lineal inches @ 0.4 in. thick). The flat segments make up an equivalent strip length of 8,092 linear inches, which, when arranged in 175 in. lengths, yields 46 strips. The strips are loaded 20 per canister, or 2.30 canisters.

The surrounding support ring is segmented into vertical sections 8.5 in. wide by 12 in. high by 2 in. thick (77 cuts, for 924 lineal inches @ 2 in. thick), or the equivalent of 5.3 strips 175 in. long. The strips are loaded 4 per canister, yielding 1.3 canisters. Thus, the combined packaged volume for the top fuel guide is about 4 canisters of GTCC material.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

4 canisters x 0.24 m^3/can = 0.96 m^3.
5,440 kg /4 canisters = 1,360 kg/can, with an average density of 5,667 kg/m^3, about 70% of theoretical density.

E.3 Core Support Plate and Associated Substructures

The lower portion of the RPV internals is comprised of the core support plate, 185 4-lobe orificed fuel supports and 24 single-lobe orificed fuel supports, 185 control rod guide tubes, 185 control rod drive housings, and 55 instrumentation guide tubes. These components are assumed to be activated to Class C levels or less.

E.3.1 Core Support Plate

The core support plate assembly is comprised of the top plate, 7 stiffener beams, 14 stiffener rods, and a peripheral ring. The weight of the assembly is about 20,500 lb. The assembly is unbolted from the core shroud assembly, and removed from the RPV. The stiffener rods are cut free from the peripheral ring (14 cuts, 13 lineal inches @ 0.88 in. thick) and the bolts attaching the stiffener beams to the plate are removed, separating the plate from the remainder of the assembly. The rods are cut on both sides of the beams (184 cuts, 162 lineal inches @ 0.88 in. thick). The beams are cut twice for packaging (14 cuts, 357 lineal inches @ 0.88 in. thick). The peripheral ring is cut free from the plate (1 cut, 625 lineal inches @ 1.75 in. thick), and is cut into 18 sectors (18 cuts, 257 lineal inches @ 1.75 in. thick). The plate is cut into 8 strips approximately 24 in. wide, which are cut into 3 segments for packaging (98 cuts, 334 lineal inches @ 2 in. thick). The assembly pieces are packaged in liners for the 8-120B cask.

E.3.2 Orificed Fuel Supports

There are 185 4-lobe and 24 1-lobe orificed fuel supports. The units are about 11 in. in height, and weigh about 62 lb and 15 lb, respectively, for a total weight of about 11,830 lb. All of the units are packaged, without cutting, in an 8-120B cask liner for disposal.

E.3.3 Control Rod Guide Tubes and Drive Housings

There are 185 control rod guide tubes which are about 160 in. in length, are 10.75 in. O.D., and weigh about 18.70 lb/ft. The upper 70 in. of each guide is activated to varying levels and is separated from the rest of the tube for packaging in an 8-120B cask liner and weigh about 20,180 lb. The lower portions of the CR guide tubes (about 26,000 lb) and the CRD housings (about 41,860 lb) are separated from the RPV at the vessel penetrations, and cut as necessary to facilitate packaging in a modified maritime container. Total cutting is about 185 cuts, 6,248 lineal inches @ 0.165 in. thick, plus 185 cuts, 3,867 lineal inches @ 0.5 in. thick. There are also 185 CR velocity limiters, 9.9 in. dia. x 20 in. long, which weigh a total of about 14,222 lb. The limiters are nested within the lower portions of the CR guide tubes, and packaged in modified maritime containers.

E.3.4 Instrumentation Guide Tubes

There are 55 instrumentation guide tubes which penetrate the bottom of the RPV and extend up to the core support plate. These tubes are about 335 in. in length, 1.9 in. O.D., and weigh 2.718 lb/ft, for a total weight of about 4,173 lb. The upper 70 inches of the tubes are separated from the rest of the tubes (55 cuts, 328 lineal inches @ 0.15 in. thick) for packaging into 8-120B cask liners, together with the upper CR guides. The lower portions of the tubes are cut free from the RPV lower head at the feed-through sleeves (55 cuts, 435 lineal inches @ 0.5 in. thick), and as appropriate to facilitate packaging in maritime containers (about 55 cuts, 328 lineal inches @ 0.15 in. thick). The 872 lb of activated guide tube is packaged in an 8-120B cask liner, together with the activated CR guide tube segments, and the remaining 3,301 lb of tube is packaged in a modified maritime container.

E.4 Steam Separator and Dryer Assemblies

The steam separator consists of 226 tubes attached to the domed steam shroud plate positioned above the top fuel guide. The steam dryers are positioned above the steam separator tubes, with a skirt that surrounds and extends about half-way down the length of the separator tubes. The separator tubes are comprised of two tubes of different diameters, stacked one above the other, end to end. The domed steam shroud plate and the lower sections of the separator tubes are expected to be activated to some significant level of radioactivity, while the upper sections of the separator tubes and the dryer assemblies are expected to be contaminated on the surfaces, with little activation.

E.4.1 Steam Separator

The activated lower sections of the 226 separator tubes are separated from the domed steam shroud plate and cut to about 48 in. in length. The tube segments are 6.625 in. O.D., 6.357 in. I.D., and weigh about 9.29 lb/ft, for a total weight of about 8,398 lb. The remaining upper segments of the separator tubes range from about 115 in. to 150 in. in length, and consist of the remainder of the 6.625 in O.D. pipe, plus the 12.75 in. O.D., 12.39 in. I.D. pipe with its internal structure, which weighs about 50,000 lb. The domed steam shroud plate is attached at its periphery to an outer edge ring which is 3 in. thick, 10 in. high, 220 in. O.D., and weighs about 5,930 lb. The domed plate is about 2 in. thick, has a radius of curvature of about 210 in., and weighs about 19,700 lb.

The ring is cut from the domed plate (1 cut, 672 lineal inches @ 2 in. thick) and is cut into 15 segments (15 cuts, 150 lineal inches @ 3 in. thick. The lower tube segments are cut free of the domed plate and from the upper tubes (452 cuts, 9,408 lineal inches @ 0.134 in. thick), for packaging into 8-120B cask liners, together with the CR guide tubes and instrumentation guide tubes.

The domed plate is segmented into strips about 24 in. wide (116 cuts, 800 lineal inches @ 2 in. thickness), and the strips are packaged in 8-120B cask liners, with maximum payloads of about 12,500 lb per liner, resulting in about 2 cask liners.

The upper portions of the 6.625 in O.D. steam separator tubes are left attached to the 12.75 in. O.D upper separator tubes and are packaged into 4 modified maritime containers.

E.4.2 Steam Dryer Assembly

The steam dryer assembly is comprised of six steam dryer units mounted on a support plate, with a skirt attached to the support plate, located above the steam separator assembly. Each dryer consists of an enclosure containing a set of perforated plates, about 24 in. wide and 90 in. high. The length of the units vary from about 164 in. to 236 in. The dryer units are cut free from the support plate (6 cuts, 2,536 lineal inches @ 1 in. thick) and packaged as units into 3 modified maritime containers. The support plate is cut free from the dryer skirt (1 cut, 2,680 lineal in. @ 0.5 in. thick) and cut into a few segments and packaged into the same maritime containers (4 cuts, 100 lineal inches @ 1 in. thickness).

The dryer skirt is about 268 in. O.D., 72 in. high, and about 0.5 in. in thickness, and weighs about 8,774 lb. The skirt is cut into 18 segments about 47 in. x 72 in. (18 cuts, 2,138 lineal inches @ 0.5 in. thick), and packaged into maritime containers together with the steam dryers.

E.5 Reactor Pressure Vessel

The RPV, illustrated in Figure E.2, is a right circular cylinder with a diameter of 265 in., a 7 in. wall thickness, and hemispheric ends.

The seal between the RPV and the surrounding reactor containment vessel is removed to improve access to the RPV and facilitate separating the RPV from the RCS piping, and to facilitate removal and packaging of the insulation surrounding the RPV. With the insulation and the RCS piping removed, access to the outside of the RPV is available for sectioning the RPV using oxyacetylene torches. Disassembly and packaging of the RPV is described in the following subsections.

E.5.1 Insulation

The vessel insulation is comprised of packages of multiple layers of thin aluminum sheet contained within a stainless steel outer jacket. The insulation is built in segments which are latched together and which are contoured to surround the entire vessel, top and bottom heads and the cylindrical side wall. These packages are approximately 4 in. thick and are of various sizes to facilitate installation and removal. The packages are removed, flattened to reduce their volume, and packaged in 2 standard maritime containers.

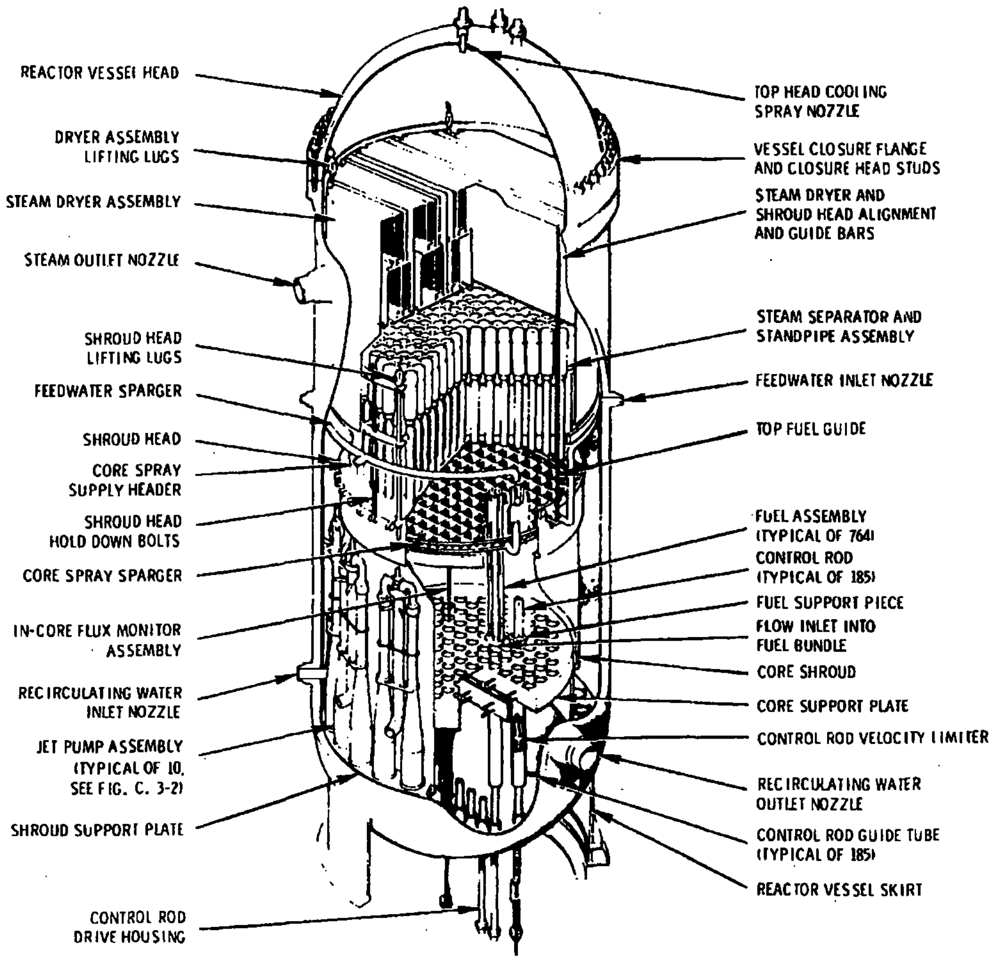

Figure E.2. Reference BWR Pressure Vessel and Internals

E.5.2 RPV Upper Head and Flanges

The penetrations through the RPV upper head are cut off flush with the hemispheric surface, and are packaged together with the head and flange segments in special steel boxes for unshielded shipment.

A circumferential cut is made just above the head upper flange 1 cut, 830 lineal inches @ 4.5 in. thick). The flange is cut into 20 segments (20 cuts, 600 lineal inches @ 17 in. thick) and packaged 2 segments/per box, for 10 boxes (48 in. x 48 in. x 36 in.) with a weight/box of about 12,174 lb. The remainder of the upper head is cut into 39 segments (12 cuts, 3,588 lineal inches @ 4.5 in. thick) approximating 46 in. x 46 in. in area and packaged 6 segments/box, for 7 boxes (48 in. x 48 in. x 30 in.) with a total weight of about 65,260 lb.

A circumferential cut is made just below the head lower flange (1 cut, 832 lineal inches @ 7 in. thick). The flange is cut into 20 segments (20 cuts, 720 lineal inches @ 14 in. thick) and packaged 2 segments/box, for 10 boxes with a weight/box about 12,168 lb.

The 3 nozzles on the upper head are cut out of the head (3 cuts, 124 lineal inches of cut @ 4.5 in. thick), and packaged with the head segments.

There are 108 studs and nuts for fastening the RPV upper head to the rest of the vessel. The studs are about 7 ft long and about 6 in. O.D., and the nuts are about 10 in. long and about 10 in. O.D., for a total weight of about 67,000 lb. The studs and nuts are packaged into special steel boxes which contain 18 ea. studs and nuts, for 6 boxes with a weight per box of about 11,167 lb.

E.5.3 RPV Side Wall

The RPV side wall consists of 3 sections, the upper 261 in. section of slightly activated material, the central 240 in. section of strongly activated material, and the lower 83 in. section of slightly activated material. These sections contain 40 nozzles of varying size, which are removed by cutting around the nozzle at the RPV side wall. The 40 nozzle cuts comprise about 3,080 lineal inches of cut @ 7 in. thick.

Circumferential cuts are made in the upper section at three 87 in. intervals (3 cuts, 2,498 lineal inches @ 7 in. thick). Each of the three rings is cut into 18 segments (54 cuts, 4,698 lineal inches @ 7 in. thick), yielding pieces about 46 in. x 87 in. x 7 in., and packaged 2 segments/box, for 26 boxes (48 in. x 96 in. x 18 in.) with a weight of about 15,900 lb/box.

The strongly activated portion of the RPV wall is cut into 8 rings, each about 30 in. high (8 cuts, 6,600 lineal inches @ 7 in. thick). Each ring is cut into 20 segments (160 cuts, 4,800 lineal inches @ 7 in. thick) ranging in width from 50 in. to 20 in., to facilitate packaging in 27 cask liners for the 8-120B cask, which are 62 in. dia. and 32 in. high, with weights of about 14,626 lb/liner.

The lower slightly activated section of the RPV wall is cut free from the lower head (1 cut, 832 lineal inches @ 7 in. thick) and segmented into 18 sections (18 cuts, 1,494 lineal inches @ 7 in. thick) about 46 in. x 83 in. x 7 in. and packaged in 9 steel boxes (48 in. x 96 in. x 18 in.), 2 segments/box, which weigh about 15,000 lb/box.

E.5.4 RPV Lower Head

The RPV lower head is cut free of the RPV support skirt (1 cut, 795 lineal inches @ 2 in. thick). The head is cut into 53 segments (15 cuts, 4,876 lineal inches @ 8 in. thick) about 46 in. x 46 in. x 8 in., and packaged into 14 steel boxes (48 in. x 48 in. x 36 in.), 2 segments/box, with a weight of about 17,467 lb/box. Separation of the various lower head penetrations from the lower head was described previously in Sections E.3.3, and E.3.4.

The RPV support skirt is cut free from the skirt base ring (1 cut, 795 lineal inches @ 2 in. thick), forming a cylinder about 253 in. O.D., 90 in. high, and 2 in. thick. The skirt is cut into 18 segments (18 cuts, 1,620 lineal inches @ 2 in. thick) about 49 in. x 90 in. x 2 in., and packaged in maritime containers. The total weight of the skirt is about 41,160 lb.

The skirt base ring is about 268 in. O.D., 234 in. I.D., and 5 in. thick. The ring is cut into three 120 degree segments (3 cuts, 51 lineal inches @ 5 in. thick) and packaged in a maritime container. The total weight is about 19,438 lb.

The inner collar beneath the lower RPV head is about 247 in. O.D., 72 in. high, and about 3 in. thick. The collar is cut into 18 segments (18 cuts, 1,620 lineal inches @ 3 in. thick) about 46 in. x 72 in. x 3 in., and packaged in maritime containers. The total weight is about 48,000 lb.

The bottom CRD housing and instrumentation guide plate is about 232 in. dia. and about 3 in. thick. It is penetrated by 185 CRD housings and 55 instrument guides. The plate is cut into three strips (2 cuts, 373 lineal inches @ 3 in. thick), each about 78 in. wide, for packaging in a maritime container. The total weight is about 7,670 lb.

E.6 Sacrificial Shield

The approach, duration, and cost of dismantling the sacrificial shield are discussed in this section. The sacrificial shield assembly consists of a bottom steel ring seated upon the reactor support pedestal, and 5 structural rings of varying heights, assembled to form a right cylindrical shell whose nominal dimensions are 360 in. O.D., 310 in. I.D., and 575 in. high. The structural rings are comprised of steel structural members and inner and outer skins, with the voids filled with concrete. Numerous openings pierce the shield to accommodate the RCS piping connections to the RPV.

The postulated disassembly process utilizes a specialty contractor employing diamond rope saws to segment the shield into 60 pieces, each approximately 93 in. x 114 in. x 25 in thick. To facilitate sawing, the outer skin and the top plate of the shield are cut along the planned saw lines to provide the diamond rope access to the contained concrete. Both axial cuts and circumferential cuts are made, to separate the shield into segments that can be transported by truck to the disposal site.

Seventeen major cuts with oxyacetylene torches are made to provide access to the concrete, with a total length of cut of about 1,100 ft. The holes for the diamond rope are bored through the shield at the corners of the planned segments, 60 holes, for total length of bore of about 125 ft. The total area to be sawn in segmenting the shield is estimated to be about 2,314 ft^2. Scaffolding is installed within the shield enclosure to support the diamond rope saw equipment, and is repositioned to permit repositioning the equipment to lower elevations as the sawing progresses. The total time required for segmenting the shield is estimated to be about 8 weeks for 2 crews of 5 persons each, assuming the use of two saw units simultaneously, on a 2-shift operation. The estimated specialty contractor cost for the effort is about $750,000.[1]

The segments, which weigh about 36,000 lb each, are packaged in form-fitting steel containers, which weigh about 1000 lb each, and are shipped unshielded, in 60 legal-weight truck shipments of about 37,000 lb each. The total disposal volume of the sacrificial shield is about 9,760 ft^3.

E.7 Summary of Cutting and Packaging Analyses

The results of the analyses for cutting and packaging the RPV internals and the RPV itself are presented in this section.

E.7.1 Cutting Team Compositions

Removal of the RPV internals and the RPV requires a sequence of operations, repeated many times, to cut and package these contaminated/activated materials. The equipment is set up to make the cut, the piece to be cut is grappled to support it during and after the cutting, the cut piece is removed from the cutting location to the packaging location, and the piece is

[1]Based on discussions with concrete sawing specialty contractors.

placed into the appropriate container preparatory to shipment for disposal. All of the GTCC material is packaged in canisters (9 in. x 9 in. x 178 in.) which can be stored in the spent fuel pool and which are compatible with spent fuel shipping cask baskets.

Removal and packaging of the RPV internals is postulated to require two manipulator systems with attached plasma arc cutting devices, one mounted on the refueling bridge crane for in-vessel cutting, and a second unit mounted over the location of the disassembly stand for the core shroud and other internals, in the dryer/separator storage pool. Taking into consideration the two cutting systems operated in parallel by a single crew, and the handling times associated with moving large sections from the RPV to the refueling cavity for further sectioning, the cumulative crew-hours for cutting are postulated to be about one-third less than the cumulative operating time, for both the plasma arc torch and the oxyacetylene cutting operations. During RPV sectioning, oxyacetylene cutting torches are attached to the manipulator systems.

One crew per shift operates the cutting systems. Each crew is postulated to consist of the staff listed in Table E.1.

In addition to the dedicated cutting crews, a non-dedicated crew for handling the packaged materials operates on the third shift, to deliver and remove the casks/containers to and from the work areas and to prepare the casks and containers for transport. This crew is comprised of a foreman, 2 equipment operators, 2 craftsmen, and 2 health physics technicians. During the cutting and packaging of the RPV internals, this crew is provided by the utility, at a daily cost of $1,546.40, and received an average radiation dose of about 35 mrem/crew-hr. During the cutting and packaging of the RPV, this crew is provided by the DOC, at a daily cost of $2,500.48, and received an average radiation dose of 35 mrem/crew-hr. These costs are included in the non-dedicated labor costs.

E.7.2 Cutting Operation Time Estimates

It is estimated that about 2 weeks will be required for initial installation and checkout of the cutting and manipulator systems. Subsequent cutting operations are estimated to require about 20 minutes to set up for each cut, including attaching grapples to the piece to be cut. The cutting time will depend upon the type of cutting, the material thickness, and the length of cutting required. Following a cut, about 20 minutes is estimated to be required to remove the cut piece from the cutting location and place it in the appropriate package. These efforts can continue in parallel with the next setup/ grappling operation, which begins about half-way through the moving/ packaging operation.

Table E.1 Staffing and labor rates postulated for cutting crews

Person-hrs per crew/hr	Category	Labor rate ($/hr)[a]	Labor cost ($/crew-hr)	Dose-rate (mrem/crew-hr)
3	Craftsman	49.70	149.10	30
4	Laborer	26.37	105.48	40
1	H.P. Tech.	36.82	--[b]	5
1	Foreman	54.84	54.84	5
9			309.42	80
Average cost per crew-hour (cutting)			324.89[c]	

(a) Labor rates are in 1993 dollars, and include 110% overhead, and 15% DOC profit.
(b) Part of utility/DOC overhead staff, included in undistributed costs.
(c) Includes a 10% shift differential for second shift work.

Underwater plasma arc cutting rates are postulated to range from about 14 in./min. for 0.5-in. thick stainless steel to about 5 in./min. for 5-in.-thick stainless steel, based on information developed at TMI-2 [5] and European experience described in ECFOCUS.[6] Rates for oxyacetylene cutting of carbon steel are postulated to range from about 13 in./min. for 1.5-in. thick carbon steel to about 3 in./min. for 14-in.-thick carbon steel, based on information presented in the Decommissioning Handbook.[7] For many of the cutting operations, the actual cutting time is a very small fraction of the total operating time for a cut.

The total operating time (in minutes) for cutting the j^{th} component can be expressed by:

$$T_j = 30\,N_j + \sum (L_{ij}/R_{ij})$$

where N_j is the number of cuts, L_{ij} is the length of the i^{th} cut, and R_{ij} is the cutting rate for the i^{th} cut in the j^{th} component.

The effective time required to segment a component is greater than the total operating time described above. The effective time also includes the amount of time the crew spends in radiation protection/ALARA activities, in dressing and undressing with anti-contamination clothing, and on work breaks. The cutting equipment is basically automated and controlled remotely underwater. The gases evolved during cutting are filtered through the pool water and are captured and removed using ventilation hoods placed just above the pool surface over the cutting areas. As a result, respiratory protection should not be required for the crew during underwater cutting.

An additional factor associated with the plasma arc cutting is the time required to change the torch when it fails to function. Experience at TMI-2[5] suggests that a torch fails about every 7.5 cuts. Assuming the change-out time is 2 hours each occurrence, the torch change-out factor is about 46%. Thus, the work difficulty factors appropriate for the underwater cutting are:

Non-productive-Time Adjustments

• Protective Clothing	(8 x 15 min./shift)	39.4%
• Break Time	(2 x 15 min./shift)	9.8%
• ALARA Activities	(25 min./shift)	8.2%

Work Difficulty Adjustments

• Torch Change-out	(1 every 7.5 cuts)	46%

Thus, the effective time for underwater cutting is given by:

$$TE_j = T_j\,(1 + 0.394 + 0.098 + 0.082)(\,1.46) = 2.30\,T_j$$

For the in-air oxyacetylene cutting of the RPV, and the in-air plasma arc cutting of the insulation and RPV piping, respiratory protection is assumed to be required for the crew, with a work difficulty factor of 20%. The torch change-out problems anticipated with the underwater plasma arc torch should not occur with the in-air plasma arc torch or the oxyacetylene torch. For in-air cutting, the effective cutting time per component is given by:

$$TE_j = T_j\,(1.574)(1.20) = 1.88\,T_j$$

Because the single cutting crew is operating two cutting systems in parallel, and some of the cutting is accomplished simultaneously, it is assumed that the actual crew-time will be reduced from the operating time by about a factor of ⅔. Thus, the actual time for the purposes of calculating cost and schedule is given by $TB_j = \frac{2}{3} TE_j$. The exposure hours for the cutting crews are given by $TB_j/1.574$, since only actual contact hours in the radiation fields apply.

The cost of the cutting operation for the j^{th} component is calculated as the product of the actual crew-time for that component, TB_j, and the cost per crew-hour, as displayed in the next-to-last column of Table E.2.

E.7.3 RPV and Internals Cutting Analyses Details

The details of the analyses for cutting the RPV internals and the RPV into pieces suitable for packaging for disposal are presented in Table E.2, where each component is identified, and the number of cuts needed to section that component, the cutting thickness of the component, the total length of cut, the cutting rate for that material thickness, the cutting time and total elapsed time, and the labor costs for that component are listed.

E.7.4 GTCC Cutting and Packaging

The details of the cutting and packaging of material postulated to be activated to levels greater than Class C are presented in Table E.3. These materials are postulated to be packaged in 9-in. x 9-in. x 178-in.-square canisters whose envelopes approximate that of a PWR fuel assembly and are compatible with PWR spent fuel cask baskets. The components are listed in column 1, and the component weights calculated from the reference BWR report[2] (and from Reactor Safety Analysis Reports and other supporting information) are given in column 2. Dividing those values by the theoretical density of the metal yields the full-density volumes given in column 3. The volumes of the component material, when packaged using the high-density approach developed in this appendix, are given in column 4. The numbers of 9-in.-square canisters that would arise from the high-density packaging approach are given in column 5.

E.7.5 Packages for Disposal

The number, type, and weight of packages, volume per package, number of shipments, weight per shipment, and disposal volume per shipment resulting from the cutting and packaging of the RPV, its internals, and the sacrificial shield are summarized in Table E.4.

E.7.6 Estimated Costs

The costs of removing, cutting, packaging, transport, and disposal are summarized in Table E.5. The removal/cutting labor costs are derived from Table E.2. The cost of disposal containers, transport cost (including cask rental), and disposal costs are derived from Table E.4 and Appendix B.

E.7.7 Postulated Schedule for Cutting and Packaging the RPV, the RPV Internals, and the Sacrificial Shield

For this schedule analysis, it is assumed that the cutting and packaging activities occur on 2 shifts per day, with movement of casks and boxes into and out of the containment building occurring on the third shift. This latter activity is performed by the handling/shipping crew, not by the cutting crews.

The initial 2 weeks (20 shifts) of the RPV internals cutting operations are devoted to installing and testing the plasma arc torches and the manipulator systems in the RPV and dryer/separator pool areas.

Table E.2 Reactor pressure vessel and internals cutting details

Component	Thickness (in.)	No. of cuts	Total length (in.)	Cutting rate (in./min)	Cutting time (min)	Operating time (min)	Effective time (min)	Labor costs[a] (1993 $)	Dose[b] (person-rem)
Internals									
Equipment							6 crew-wks	77.974	2.16
Core Shroud (GTCC)	2.0	178	18,589	8	2,325	7,665	11,741	63,577	
Top Fuel Guide (GTCC)	0.4, 2	665	7,980	15, 8	586	20,536	31,457	170,336	
Shroud Support	2, 4.75	58	5,039	8, 5	739	2,459	3,797	20,562	
Jet Pumps & Support	0.3, 2	224	16,943	16, 8	1,112	7,832	11,997	64,962	
Core Support Plate	0.9, 2	329	1,747	11, 8	194	10,064	15,416	83,476	
CR Guides	0.165	185	6,248	23	272	5,822	8,918	48,290	
CR Drive Housings	0.5	185	3,867	14	276	5,826	8,924	48,344	
Inst. Guides	0.2, 0.5	165	1,091	23, 14	60	5,010	7,674	41,535	
Steam Separator	0.14, 2, 3	584	11,030	6, 24, 8, 6	601	18,121	27,758	150,304	
Steam Dryer	0.5, 1	29	7,454	14, 11	584	1,454	2,227	12,060	
		2,602			6,749	84,809	129,911 (2,166 hr)	703,446	110.06
Reactor Pressure Vessel									
Equipment Setup/Testing and Post-Use Removal							4 crew-wks	51,983	1.44[b]
Upper Head									
	4.5	16	4,542	7.5	606	1,086	1,367	7,404	
Upper Flange	17	20	600	2	300	900	1,133	6,136	
Lower Flange	14	20	720	3	240	840	1,058	5,727	
Activated Wall Sections									
	7	168	11,400	5.5	2,073	7,113	8,955	48,492	
Non-Act. Wall Sections	7	77	10,354	5.5	1,883	4,193	5,280	28,585	
Nozzles	7	40	3,080	5.5	560	1,760	2,216	11,999	
Lower Head	8	16	5,671	8, 4.5	1,183	1,663	2,094	11,337	
Skirt	2	19	2,415	12	201	771	971	5,256	
Skirt Ring	5	3	51	7	8	98	123	663	
Collar	3	18	1,620	9.5	171	711	895	4,855	
Base Ring	3	2	373	9.5	40	100	126	679	
Subtotal		399			7,265	19,234	24,217	131,132	33.61[b]
							404 hr		147.27

(a) Does *not* include a 25% contingency.
(b) Includes radioactive decay from reactor shutdown to time of cutting.

Table E.3 Calculated weights, full-density volumes, packaged volumes, and numbers of canisters of GTCC LLW generated during the decommissioning of the reference BWR

Reactor core components	Component weight (lbs)	Full-density volume (ft^3)	Packaged volumes (ft^3)[(a)]	No. of canisters
Core Shroud	83,111	165.8	208.6	25
Top Fuel Guide	11,992	23.9	33.4	4
Totals	95,103	189.7	242.0	29

(a) 9-in.-sq. by 178-in.high canisters, disposal volume of 8,344 ft^3 (0.24 m^3) each.

The estimated schedule for cutting and packaging of the RPV internals is shown in Figure E.3. Upon completion of the cutting and packaging operations for the internals, a final week is devoted to removal of the plasma-arc cutting systems and to final packaging and shipping from the dryer/separator pool. The elapsed calendar time for the cutting and packaging of the RPV internals is estimated to be about 37 weeks.

The initial week (10 shifts) of the RPV sectioning is devoted to installing and testing the oxyacetylene torches and the manipulator system in the reactor vessel. The estimated schedule for cutting and packaging of the RPV and the sacrificial shield is shown in Figure E.4. Upon completion of the cutting and packaging operations, a final week is devoted to removal of the cutting systems and to final packaging, shipping, and cleanup. Thus, the elapsed calendar time for the cutting and packaging of the RPV and the sacrificial shield is estimated to be about 15 weeks.

E.7.8 Impacts on Transport and Disposal Costs of Disposal at Barnwell

The transport and disposal costs for low-level radioactive wastes are sensitive to the distance between the reactor site and the disposal facility, and to the charge schedule at the disposal site. The costs of transport and disposal of LLW from the WNP-2 site to and disposal at the Chem-Nuclear facility at Barnwell, South Carolina and the U.S. Ecology facility at Richland, Washington, are presented in Table E.6. The estimated transport cost to Barnwell is about a factor of 6 larger than the transport cost to Richland, reflecting the much greater distance traveled. Similarly, the disposal cost at Barnwell is about a factor of 4 larger than the disposal cost at Hanford, reflecting the much higher disposal rate structure at Barnwell.

Table E.4 Summary of information on RPV, internals, and sacrificial shield packaging for disposal

		Containers						
Component	Number	Ci/ea.	Liner dose rate (R/hr)	Weight[a] (lb)	Volume (ft^3)	Weight/ ship- ment[b]	Number of shipments	Disposal volume (ft^3)
Steam Dryer	3[c]	<15	<0.1	33,333	640	33,333	3	1,920
Steam Separator	4[c]	<15	<0.1	21,700	640	43,400	4	2,560
	3[d]	3,200	735	13,343	126	72,663	3	378
GTCC Material								
Core Shroud (GTCC)	25[e]	NA	NA	3,624	8.4	54,824	25	210
Top Fuel Guide	4[e]	NA	NA	3,292	8.4	54,492	4	34
Other Act. Internals								
Jet Pumps	12[f]	3,330	1,900	1,744	13.7	52,944	12	164
Support Ring	1[d]	700	50	7,200	126	66,520	1	126
Core Support Plate	3[d]	217	16	8,833	126	68,153	3	378
Orif. Fuel Supports	1[d]	700	50	13,830	126	73,150	1	126
CR Guides	2[d]	5,500	100	12,526	126	71,846	2	252
Limiters, Housings, Inst. Guides	3[c]	<2	<0.01	35,310	640	35,310	3	1,920
Shroud Support	9[g]	<15	<0.1	11,400	48	34,200	3	432
RPV Segments								
Upper Flange	10[i]	<2	<0.01	12,574	48	37,722	3.3	480
Upper Head	7[i]	<2	<0.01	9,673	40	38,692	1.75	280
Insulation	2[j]	<2	<0.01	4,130	1,360	8,260	1	2,720
Lower Flange	10[i]	<2	<0.01	12,368	40	37,104	3.3	400
Non-Act. RPV Wall	35[g]	<2	<0.01	16,469	48	32,938	17.5	1,680
Act. RPV Wall	27[k]	72	<1	14,663	56	73,983	27	1,512
Lower Head	14[h]	<2	<0.01	17,867	48	35,734	7	672
Nozzles	4[c]	<2	<0.1	35,594	640	35,594	4	2,560
Studs & Nuts	6[g]	<2	<0.01	11,967	48	35,901	2	288
Skirt, Base Ring & Collar	4[c]	<2	<0.01	36,813	640	36,813	4	2,560
Sac. Shield	60	<7	<0.01	37,000[l]	163	37,000	60	9,760

(a) Includes weight of container and contents.
(b) Includes weight of cask, where applicable.
(c) Mod. maritime container, 8 ft x 4 ft x 20 ft, 640 ft^3 disposal volume, 3,000 lb empty weight, $4,965
(d) 8-120B cask liner, 62 in. OD x 72 in. high, 126 ft^3 disposal volume, 2,000 lb empty weight, $4,695
(e) GTCC canister, 9 in. x 9 in. x 178 in., 8.4 ft^3 disposal volume, 300 lb empty weight, $520
(f) NAC-LWT liner, 13 in. OD x 178 in., 3.7 ft^3 disposal volume, 700 lb empty weight, $1,000
(g) Special steel box, 4 ft x 8 ft x 1.5 ft, 48 ft^3 disposal volume, 400 lb empty weight, $730
(h) Special steel box, 4 ft x 4 ft x 3 ft, 48 ft^3 disposal volume, 400 lb empty weight, $430
(i) Special steel box, 4 ft x 4 ft x 2.5 ft, 40 ft^3 disposal volume, 350 lb empty weight, $400
(j) Std. maritime container, 8 ft x 8½ ft x 20 ft, 1,360 ft^3 disposal volume, 4,180 lb empty weight, $3,650
(k) 8-120B cask liner, 62 in. OD x 32 in. high, 56 ft^3 disposal volume, 1,500 lb empty weight, $3,200
(l) Averaged over all segments.

Table E.5 Summary of costs for cutting, packaging, transport, and disposal of the RPV, its internal structures, and the sacrificial shield[a]

Components	Costs in 1993 dollars				
	Cutting[b]	Containers[c]	Transport[d]	Disposal[e]	Total
GTCC Material					
Core Shroud	63,577	13,000	418,233	1,365,000	1,859,811
Top Fuel Guide	170,336	2,080	87,669	218,400	478,484
Other Activated Internals					
Shroud Support	20,562	6,570	544	30,535	58,210
Jet Pumps & Support Ring	64,962	16,695	145,651	663,367	890,676
Core Support Plate	83,476	14,085	36,757	36,804	171,122
Orif. Fuel Supports	--	4,695	29,347	14,783	48,825
CRD Guides	48,290	9,390	32,436	36,921	127,037
Limiters, Housings, Inst. Guides	89,879	14,895	544	125,060	230,378
Steam Separator	150,309	33,945	37,142	241,798	463,189
Steam Dryer	12,060	14,895	544	125,060	152,559
RPV Segments					
Insulation	--	7,300	181	131,906	139,387
Upper Flange	6,136	4,300	604	33,928	44,967
Upper Head	7,404	2,800	317	17,306	27,827
Lower Flange	5,727	4,000	604	22,289	40,379
Low-Act. RPV Wall	28,585	25,550	3,171	174,659	231,965
Hi-Act. RPV Wall	48,492	86,400	111,040	138,411	384,343
Lower Head	11,337	6,020	1,268	69,864	88,489
Nozzles	11,999	19,860	725	166,747	199,330
Studs & Nuts	--	4,380	362	20,357	25,099
Skirt, Base Ring, & Collar	11,453	19,860	725	166,747	198,785
Sac. Shield	750,000	63,000	10,872	1,112,261	1,936,133
Totals	1,584,579	373,720	918,737	4,919,959	7,796,994

(a) Costs do *not* include a 25% contingency.
(b) Data from Table E.2, rearranged to correspond to the packaging arrangements in Table E.4.
(c) Calculated using data from Table E.4.
(d) Calculated by Cost Estimating Computer Program, using data from Table E.4.
(e) Calculated by Cost Estimating Computer Program, using data from Table E.4.

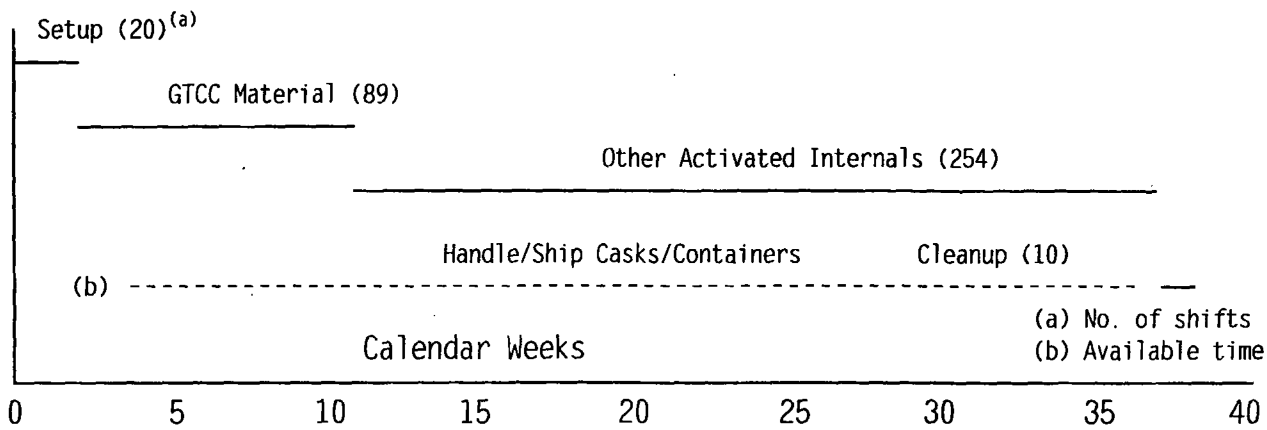

Figure E.3 Postulated schedule for cutting/packaging the RPV internals

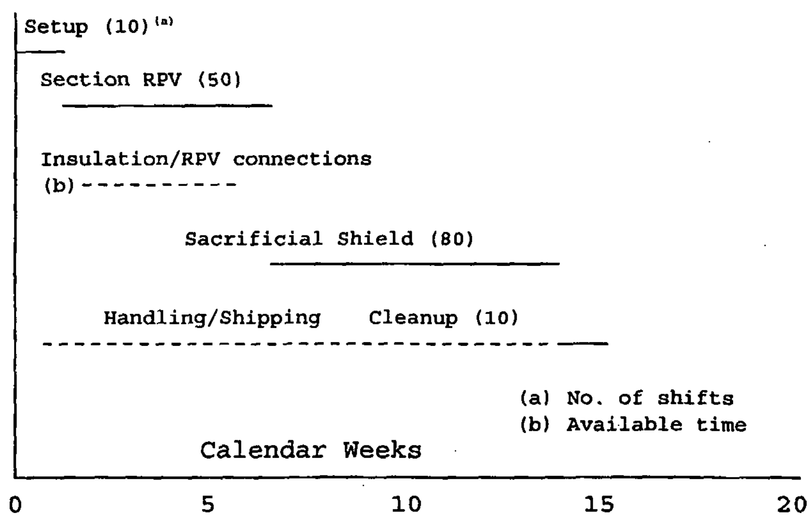

Figure E.4 Postulated schedule for cutting/packaging the RPV and Sacrificial Shield

Table E.6 Sensitivity of transport and disposal costs for LLW to disposal facility location and rates[a]

Location	Transport costs (1993 $)	Disposal costs (1993 $)
Richland LLW	1,111,726	36,604,983
Barnwell LLW	6,783,175	154,745,915

(a) Costs do *not* include a 25% contingency.

E.8 References

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6. *ECFOCUS*, No. 11, Commission of the European Communities, DG XII - Science, Research and Development - Joint Research Centre, December 1989.

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

Appendix F

Activities, Manpower, and Costs for Dismantlement and Disposal of the Turbine, Turbine Condenser, Moisture Separator Reheaters, Feedwater Heaters, Feed Pump and Turbine Assembly, and Drywell Structural Members

Appendix F

Activities, Manpower, and Costs for Dismantlement and Disposal of the Turbine, Turbine Condenser, Moisture Separator Reheaters, Feedwater Heaters, Feed Pump and Turbine Assembly, and Drywell Structural Members

Because the reference boiling water reactor (BWR) utilizes a direct-cycle steam turbine system, with the steam generated within the reactor vessel using reactor coolant water, the turbine and turbine condenser are contaminated internally. As a result, it is postulated for this study that all of the turbine and turbine condenser must be removed and packaged for disposal as low-level radioactive waste (LLW). In practice, it may be possible to decontaminate a significant fraction of the material in these units to unrestricted release levels. However, for conservatism, no release of turbine or condenser materials is assumed.

F.1 Disassembly and Packaging

The approach assumed in this analysis is to section the various elements of the turbine, condenser, moisture separator reheater, feedwater pump and turbine drive, feedwater heaters, and the drywell structural members, into segments sized to fit within standard or modified maritime containers, or to be capped and sealed for shipment as its own container. In many cases, the packaged segments weigh more than is allowed for a legal-weight truck shipment, and must be transported as over-weight truck shipments. The segmentation, packaging, and transport parameters utilized in these analyses were selected on the basis of simplicity and achievability, without any significant effort to trade off segmentation costs against packaging and transport costs.

While the thickness of the material being cut varies from one location to another, a conservative cutting rate of 0.4 ft per min. has been postulated for all materials. The results are not very sensitive to the cutting rate because the actual cutting time is a small fraction of the crew-time devoted to a cut. The cutting crews and the unit cost factor defined in Appendix C for cutting large, thick-walled pipe, greater than 30 in. dia. are used, unless otherwise specified. It is assumed that there are 2 crews per shift, 2 shifts per day, for a total of 32 crew-hours per day. For tube bundle cutting, specialty contractor crews are brought in to operate the diamond rope saws, with an assumed cutting rate of 5 ft^2/hr, at a cost of \$325/ft^2 of cross-sectional area cut. The radiation dose rate to workers is postulated to be in the range of about 1 mrem/hr for direct-contact work.

F.2 Segmentation and Packaging of the Turbine

A moveable ventilation enclosure, about 30 ft long x 20 ft high and 30 ft wide, is placed over the section of the turbine being segmented, to collect and filter the smoke and fumes arising from the cutting operations. Each repositioning is postulated to require about 2 hr. The enclosure will have to be repositioned frequently to facilitate handling and packaging of the large segments, perhaps 20 times during the turbine segmentation. The results of the cutting and packaging analyses for the turbine are presented in Table F.1.

For the 170 cuts identified in Table F.1, the duration of the turbine segmentation would be about 1,105 crew-hrs, plus the 40 crew-hrs devoted to moving the ventilation enclosure, plus about 135 crew-hrs devoted to constructing the ventilation

Table F.1 Segmentation and packaging of turbine components

Component	Number of containers(a)	Container shipping weight (lb)[b]	Disposal volume (ft^3)	Length of cut (ft)	Number of cuts
H. P. Turbine Cover	3	46,242	1,920	33	2
Base	3	50,567	1,920	46	2
Rotor	1	79,506	640	12	2
Blades & Bolts	1	49,746	640	--	--
L. P. Turbine Cover & Ends	15	44,027	9,600	651	45
Outer Base Cover	21	47,906	13,440	630	36
Outer Base Ends	15	44,912	9,600	156	18
# 1 Inner Cover & Base	6	58,590	3,840	112	12
# 2 Inner Cover & Base	12	48,495	7,680	230	18
Outer Blades, Rings	3	42,433	1,920	10	9
Rotor Shaft	3	58,739	1,920	38	6
Rotor Blades	9	41,200	5,760	10	18
Steam Chest (2 ea.)	4	64,122	2,560	44	2
Totals	96		61,440	1.972	170

(a) Containers: 4 ft x 8 ft x 20 ft; empty weight: 3,000 lb; cost: $4,965; disposal volume: 640 ft^3.
(b) Each container comprises 1 shipment, LWT (<40,000 lb payload) or OWT (>40,000 lb payload).

enclosure and installing the associated fans and filters, for a total of about 1,280 crew-hrs, with a labor cost of about $243,372. At 32 crew-hrs per day, the turbine segmentation and packaging would require about 40 days, or about 8 weeks. The radiation dose to workers is estimated to be about 2.37 person-rem.

F.3 Segmentation and Packaging of the Turbine Condenser

The turbine condenser is a massive steel shell structure, about 105 ft long x 33 ft wide x 49 ft high, with a nominal wall thickness of 1 in., located directly beneath the turbine. The condenser contains 6 tube bundles, each about 50 ft long x 9 ft wide x 24 ft high. The segmentation and packaging of the condenser is summarized in Table F.2.

The approach postulated for disassembly and packaging of the condenser is as follows: The interior of the shell and the exterior of the tube bundles (about 42,000 ft^2 of surface) are washed using very high pressure water jets, to remove the

Table F.2 Segmentation and packaging of turbine condenser components

Component	Number of containers(a)	Container shipping weight (lb)[b]	Disposal volume (ft^3)	Length of cut (ft)	Number of cuts
Steam inlet shell	4	37,706	640	360	48
Shell upper housing	4	42,247	640	440	32
Shell side walls	8	41,284	1,280	1,740	64
Shell end and interior vertical plates	3	40,124	480	1,422	48
Tube bundle sections	30[c]	67,782	75,000	375[d]	36
Shell interior floor	2	41,688	320	546	23
Shell bottom floor	4	38,176	640	600	27
Water boxes and miscellaneous piping	5[e]	40,000	6,800	200	30
Totals	60		85,800	5,308 ft	272

(a) Unless otherwise noted, all containers are modified maritime containers, 1 ft x 8 ft x 20 ft; empty weight, 2,000 lb; cost, $4,000; disposal volume, 160 ft^3.
(b) Each container comprises 1 shipment, LWT (<40,000 lb payload) or OWT (>40,000 lb payload).
(c) Special containers: 10 ft x 10 ft x 25 ft; empty weight, 6,500 lb; cost, $6,000; disposal volume, 2,500 ft^3.
(d) Total cross-sectional area of tubes cut using diamond rope saw.
(e) Container: 8 ft x 8½ ft x 20 ft; empty weight, 4180 lb; cost, $3,650; disposal volume 1,360 ft^3.

readily removable surface contamination. One lower side wall is removed, sectioned and packaged, to provide ready access to the tube bundles and the intermediate water boxes for cutting into sections using a diamond rope saw. The tube bundles are cut free from the tube sheets at the water boxes and at every third tube support plate, resulting in 30 tube bundle segments that are approximately 9½ ft x 9½ ft x 24 ft high, and are packaged in special oversized boxes, nominally 10 ft x 10 ft x 25 ft. The assorted piping in the steam inlet areas is cut and removed, providing vertical access into the condenser shell. The intermediate water boxes and tube bundle segments are lifted vertically to the turbine building floor for packaging. The remaining sections of the condenser shell are sectioned and packaged. Because much of the condenser is comprised of large sheets of 1-in.-thick steel, a special modified maritime container, 1 ft high x 8 ft wide x 20 ft long, is used for most of the segments.

The internal washing operations are estimated to require about 210 crew-hrs to wash the internal surfaces of the condenser shell and the outside surfaces of the tube bundles. Because the condenser is divided into three compartments, three washing crews can operate simultaneously. Thus, the duration of the washing operation would be about 4½ days. The total washing cost would be about $28,927. The radiation dose to the workers is estimated to be about 0.292 person-rem.

For the 272 plate cuts identified in Table F.2, the duration of the turbine condenser segmentation would be about 1,768 crew-hrs, plus about 40 crew-hrs devoted to moving the ventilation enclosure, for a total of about 1,808 crew-hrs, at a cost of about $343,762, and an estimated radiation dose of 3.451 person-rem. At 32 crew-hrs per day, the turbine condenser segmentation and packaging would require about 56 days, or about 11 weeks. The cutting of the tube bundles by the specialty contractor staff would require about 75 hours of cutting time, plus about 2 hours for each new setup of the equipment, for about 145 actual hours. Including the work difficulty factor of 1.3 and the non-productive time factor of 1.574, the duration of the effort is about 297 crew-hrs. An on-site crew of 6 persons per shift is assumed for the diamond sawing team. Using two cutting systems, this effort could be accomplished in about 10 days on a two-shift basis, in parallel with the on-going shell separation operations. Assuming an average cost of $325/ft^2 of material sawed, the tube cutting operations would cost about $121,875, with an estimated radiation dose of 0.618 person-rem.

In summary, the duration of the condenser segmentation and packaging operations is estimated to be about 12 weeks, at a total labor cost of $465,637, and a cumulative radiation dose of about 4.36 person-rem.

F.4 Segmentation and Packaging of Moisture Separator Reheaters

The two moisture separator reheaters associated with the main steam system are nearly 13 ft dia. and 93 ft long, and weigh about 460,000 lb each. Each reheater contains four U-tube bundles of 1617 tubes each, which are about 36 ft long and 4½ ft dia., fastened to a tube sheet with a hemispheric channel head at the outboard end, two steam distribution manifolds, and 12 sets of mist extractor chevrons. The segmentation and packaging of the moisture separator reheaters is summarized in Table F.3.

The approach postulated for disassembly and packaging of these units is the following: The tube bundles are cut free from the shell by cutting around the channel heads, and the bundles are withdrawn from the shell and placed into special containers, 5 ft x 5 ft x 38 ft. With the tube bundles removed, the interior of the shell together with the steam manifolds and mist extractor chevrons (about 4,500 ft^2 of surface) are washed using high-pressure water jets to reduce the level of contamination. The remaining internal components of the shell are removed and cut as necessary to facilitate packaging with the tube bundles. The shell can now be treated as a large tank, and be cut into segments for reduced-volume packaging.

Table F.3 Segmentation and packaging of moisture separator reheaters

Component	Number of containers	Container shipping weight (lb)(a)	Disposal volume (ft^3)	Length of cut (ft)	Number of cuts
Tube bundles	4(b)	34,000	3,800	126	8
Shell	5(c)	39,865	1,600	691	30
Shell ends, baffles, supports, etc.	4(d)	41,608	2,560	140	50
Totals	13		7,960	7,960	88

(a) Each container comprises 1 shipment, LWT (<40,000 lb payload) or OWT (>40,000 lb payload).
(b) Special containers: 5 ft x 5 ft x 38 ft; empty weight, 4,300 lb; cost, $4,500; disposal volume, 950 ft^3.
(c) Modified maritime container: 2 ft x 8 ft x 20 ft; empty weight, 2,500 lb; cost, $4,600; disposal volume, 320 ft^3.
(d) Modified maritime container: 4 ft x 8 ft x 20 ft; empty weight, 3,000 lb; cost, $4,965; disposal volume 640 ft^3.

The washing of the interior of the shell and associated components is estimated to require about 22½ hrs. Because the shell interior consists of essentially a single compartment, only one crew at a time can work therein. Thus, the duration of the washing operation would be less than 2 days. The cost of the washing operation is estimated to be $3,099, and the radiation dose received by the workers is estimated to be about 0.033 person-rem.

For the 88 plate cuts identified in Table F.4.1, the duration of the moisture separator reheater segmentation would be about 572 crew-hrs, plus about 40 crew-hrs devoted to moving the ventilation enclosure, for a total of about 612 crew-hrs, at a cost of about $116,362. At 32 crew-hrs per day, the moisture separator reheaters segmentation and packaging would require about 19 days, or about 4 weeks. The radiation dose to workers is estimated to be about 1.167 person-rem.

In summary, the duration of the segmentation and packaging of the moisture separator reheaters is estimated to be about 21 days, at a labor cost of about $119,461, and a radiation dose to workers of about 1.200 person-rem.

F.5 Segmentation of the Feedwater Pump and Feedwater Pump Turbine Assemblies

There are two feedwater pump and turbine drive assemblies associated with the feed and condensate system. Each unit is skid-mounted, occupies a space of about 5045 ft^3, and weighs about 132,700 lb. For disposal, the assemblies are postulated to be disassembled and packaged as described below. The segmentation and packaging of the feedwater pump/turbine drive units is summarized in Table F.4.

Disassembly of the feedwater pump/turbine drive units for packaging is accomplished as follows: The pump is mechanically decoupled from the turbine, the inlet and outlet pump nozzles are capped, the pump, pump cradle, and the portion of the skid supporting the pump are separated from the rest of the skid, and the exterior of this smaller unit is washed with high-pressure waterjets. Assuming the exterior is successfully cleaned, the pump/cradle unit is shipped as its own container. The envelope enclosing the pump unit has a volume of about 480 ft^3, and the unit weighs about 14,360 lb.

Table F.4 Segmentation and packaging of the feedwater pumps and turbine drives

Component	Number of containers	Container shipping weight (lb)	Disposal volume (ft^3)	Length of cut (ft)	Number of Cuts
Feed pump	2[(a)]	14,360	960	8	6
Drive turbine	2[(a)]	96,788	2,098	8	6
Lubrication system	2[(a)]	16,800	1,376	0	0
Valves, servo motors,	1[(b)]	12,900	640	0	0
Totals	7	140,848	5,074	16	12

(a) Shipped as own container. Volume based on imaginary enclosure containing entire unit.
(b) Modified maritime container: 4 ft x 8 ft x 20 ft; empty weight, 3,000 lb; cost, $4,965; disposal volume, 640 ft^3.

The turbine drive unit and its supporting frame is separated from the lubrication system section of the frame, and all interconnecting piping is removed and openings capped or plugged. The appendages attached to the turbine unit, such as the control valves, servo motor, and connecting piping, are removed and packaged in steel boxes. The sealed turbine exterior is washed with high-pressure water jets. Assuming the exterior is successfully cleaned, the turbine drive unit is shipped as its own container. The envelope enclosing the turbine unit has a volume of about 1049 ft^3, and the unit weighs about 96,788 lb.

The lubrication system portion of the frame is drained of oil, and all interconnecting lines are removed and capped or plugged. The envelope enclosing the lubrication system has a volume of about 688 ft^3, and the unit weighs about 16,800 lb. The residual components removed previously are packaged in a single modified maritime container (4 ft x 8 ft x 20 ft) whose contents weigh about 9,900 lb.

It is estimated that preparing the feed pumps and their drive turbines for disposal would require about two crew-shifts for each assembly to remove the external piping and appendages, two crew-shifts for each assembly to wash and survey the external surfaces, and one crew-shift to section each of the support frames into three segments. The estimated labor cost per assembly is about $6,745, plus about $500 for closure materials and welding supplies, for a total labor and material cost of $13,489, and the duration of the effort would be about 8 days. The estimated radiation dose to workers is about 0.140 person-rem.

F.6 Feedwater Heaters

There are 16 large feedwater heaters associated with the feed and condensate system. These units are of a size (40 to 50 ft long x 6 to 8 ft dia., with weights between 78,000 and 162,000 lb) that would permit intact removal and shipment by capping all of the shell openings and decontaminating the exterior surfaces. All of the shipments would be by over-weight truck.

It is estimated that capping operations would require about two cutting crew-shifts per unit to weld the closure caps, about one surface washing crew-shift to decontaminate the exterior surface using high pressure water jets, at a materials cost of about $500 per unit and a labor cost of about $4,132 per unit, and an elapsed time of about 2 days per unit. The total labor and materials cost for all 16 units is estimated to be about $74,127. Assuming two units can be worked on simultaneously without interference, the removal duration is estimated to be about 16-18 days, or about 3½ weeks. The radiation dose to workers is estimated to be about 0.670 person-rem.

F.7 Segmentation of Beams, Plates, Gratings, and Cable Trays from the Containment Drywell

The interior of the reactor containment vessel (the drywell) contains a large assortment of steel beams, plates, and gratings, which are assumed to be surface-contaminated, and are removed and packaged for disposal as LLW. Some 118 individual items have been identified. In addition, the drywell contains a large number of cable trays filled with cables, which must also be removed and packaged for disposal. Estimates of the costs, waste volumes and radiation doses associated with these removal and disposal operations are developed in this section.

With the RPV and the sacrificial shield removed, the interior of the drywell is accessible from the refueling floor using the reactor building bridge crane. Thus, the removal of the structural members and major equipment is carried out simultaneously, starting at the upper level of the drywell. Gratings are lifted out and placed into modified maritime containers for transport and disposal. Beams are cut free from attachments and lifted out and packaged. Plates are segmented as necessary and lifted out and packaged. The many structural steel beams are assumed to be cut into lengths compatible with the maritime containers (<20 ft), and loaded into the 2-ft-high containers up to a payload of about 36,000 lb.

The total number of cuts required is estimated to be 611, with a total cutting length of 2,200 linear ft. These amounts are increased by 10% to account for additional items not identified uniquely, resulting in 672 cuts. The cutting time for these operations is postulated to be similar to cutting of medium-sized pipe, or about 3 hrs/cut, for a total operations time of 2,016 crew-hrs. At 32 crew-hr/day, the duration of these removal operations will be nearly 63 days, or about 12½ weeks. The removal labor cost will be about $383,302. The radiation dose to workers is estimated to be about 3.848 person-rem. The volume of waste for disposal is based on the payload weight limit of the maritime containers, about 37,500 lb. The total estimated weight of these materials is 1,189,312 lb, which, when divided by 37,500 lb/container, results in about 31.7 of the 2 ft x 8 ft x 20 ft modified containers, with a burial volume of 10,240 ft^3.

The weight and volume of the cables and cable trays are estimated based upon the maximum hanging weights for which the various elevations in the drywell are rated. The sum of these rated loads is 51,885 lb. To estimate the volume of this material, a specific gravity of 2 is assumed, with a resulting volume of 416 ft^3. Based on the 37,500 lb payload weight limit for the maritime containers, about 1.4 of the 2-ft-high containers would be required. The number of linear feet of tray w/cables is not known. An allowance of 100 cuts is made for cutting the cable trays into segments for packaging, for a duration of 300 crew-hours, at a cost of about $57,039, and an estimated radiation dose of about 0.572 person-rem.

In summary, the operations to remove beams, supports, gratings, and cable trays from the drywell will require about 2,316 crew-hrs, at a labor cost of about $440,350, and a radiation dose to workers of about 4.420 person-rem. and will fill about 33 modified maritime containers (10,560 ft^3 disposal volume).

Appendix G

Decommissioning Methods

Appendix G

Decommissioning Methods

The information presented in this appendix is essentially identical with the information presented in NUREG/CR-5884,[1] Appendix G, and is included here for completeness. Methods, equipment, and disassembly procedures postulated to be used to accomplish various decommissioning activities at nuclear facilities, such as the reference boiling water reactor (BWR), were discussed in considerable detail in NUREG/CR-0672.[2] Some of those methods are no longer state-of-the-art, other methods/techniques have seen improvements, some have never matured for subsequent decommissioning applications as anticipated (e.g., the arc saw),[1] and some new decommissioning-related techniques, methods, and equipment have come on the scene. Information associated with this latter group is presented in Appendix K of Reference 2 and is not repeated here. The information given in this appendix is presented in the following order: system decontamination surface decontamination removal techniques and equipment water treatment and disposal.

G.1 System Decontamination

The current state of knowledge regarding full-system chemical decontamination of PWRs and BWRs is not sufficient to make any significant distinctions between the two reactor types at this time. Thus, the information in this section is essentially identical with the information presented previously in Section G.1 of NUREG/CR-5884.[1] For this reevaluation study, a full-system chemical decontamination approach is postulated (recirculatory method) wherein dilute chemical decontamination solutions are recirculated through the reactor coolant and attached associated systems until the desired degree of decontamination is obtained. The dissolved radioactivity and chemicals are removed on ion exchange resin and the water is either reused for an additional decontamination step or treated further for discharge. This technique was identified to reduce the dose rates (and therefore exposures) incurred during the subsequent removal and disposition of the primary coolant system piping and associated equipment.The information presented herein is based to a large extent on discussions between the authors and senior staff of Pacific Nuclear Services (PNS), located in Richland, Washington, who specialize in chemical decontamination services.The major contributors to the estimated total cost and occupational radiation exposure for full-system chemical decontamination at the reference BWR are summarized in Table G.1. The total cost for these activities is estimated at about $14 million, not including contingency. The total occupational radiation dose is estimated to be about 46 person-rem.

The assumptions used in this study are described below, followed by a general discussion of the estimated cost, dose, volumes of radwastes, and schedule associated with the full-system chemical decontamination of the reference BWR.

G.1.1 Assumptions

In developing the chemical decontamination scenario and the subsequent analysis, the following assumptions were used:

- The BWR primary system components description and radioactive inventory were taken from NUREG/CR-0672.[2]

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[1]To date there is insufficient operating data to accurately compare arc saw cutting to other more conventional means.

Table G.1 Summary of estimated costs and radiation dose for full-system chemical decontamination of the reference BWR

Cost item	Estimated cost (1993$) [a]	Estimated dose (person-rem)[b]
Chemical Decontamination:	12,500,000	12
Fixed-cost Contract (Specialty Contractor)[c]	usc[d]	28
Utility Support		
Disposal of Radioactive Wastes from Chem. Decon 18 High-Integrity Containers (HIC)	404,498[e]	-
Electricity[f]	238,000[g]	-
Water treatment/release	750,000	~2
Fixed-cost Contract Specialty Contractor [c]		
Utility Support	usc	-
Radioactive Waste Disposal from Water Treatment:[c] 5 High-Integrity Containers	61,803	<0.1
Protective clothing & equipment services (vendor only)	22,176[i]	-
Totals (w/o contingency)	13,976,477	~45.7

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) A dash means not applicable, unless indicated otherwise.
(c) See text for details.
(d) "usc" indicates that costs are included in the utility staff costs during this period.
(e) Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B). The total estimated burial cost for the 18 HICs is $‘,731,780.
(f) Assumes the use of various pumps, including the recirculation pumps, for about 2 weeks consumes approximately 2,100 MWh of electricity as described in NUREG/CR-0672.[2]
(g) Undistributed cost.
(h) Based upon disposal cost information proved by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B). The total estimated burial cost for the 5 HICs is $373, 800.
(i) Based upon discussions with industry personnel, these services are estimated to be approximately $21/day/person for rad-zone workers only.

- Full-system chemical decontamination of BWRs by a specialty contractor (vendor) is postulated to be routine work by the time this operation commences at the reference BWR (i.e., it is assumed that at least three such campaigns have been successfully completed prior to the reference BWR campaign).

- The full-system chemical decontamination will be completed during the first year following final shutdown, after defueling of the reactor.

- No water rinses are needed following chemical decontamination; the solutions will be drained, treated, and released according to applicable release standards; the systems will be left dry.

- Decontamination does not permit release of the components for unrestricted use because of tightly adherent residual contamination; controlled removal and final disposition (either burial or shipment to a commercial decontamination/volume reduction facility) will be required.Removal of components after decontamination requires the same labor as without decontamination because the components are still contaminated. The same precautions and preparations, contamination controls and packaging would be required. However, significantly less occupational radiation dose would be incurred and fewer personnel would be needed to accomplish the work. The postulated decontamination factor (DF) for the full-system chemical decontamination of the reference BWR is a DF of 10.

- Decontamination dose reductions are accounted for in subsequent removal of components after chemical decontamination for each of the three decommissioning alternatives, as applicable.

- The waste disposal costs presented in this appendix were specifically developed for the reference BWR, which is located within the Northwest Compact, assuming disposal at the U.S. Ecology site in Richland, Washington. To provide additional information, the costs also were estimated for disposal of the reference BWR wastes at the Barnwell site in Barnwell, South Carolina.

G.1.2 Discussion

Just as in NUREG/CR-0672,[2] the principal systems considered for chemical decontamination in this reevaluation study are the reactor coolant system (RCS) and inter-tied systems, i.e., those systems that contain deposited contamination representing a radiation dose rate hazard for further decommissioning effort once they are drained and dried. In the opinion of the authors, chemical decontamination of these systems is a necessary step even if the current decommissioning plan calls for placing the facility in safe storage for an extended period of time, since completing the decontamination step removes most of the internal radioactive contamination and leaves all options open for changing the decommissioning plan at a later date. It is unlikely that a chemical decontamination could be carried out without major equipment renovation after the facility has been in safe storage for a few years, due to equipment deterioration. If a decision were made to dismantle after 5 to 10 years of safe storage, the radiation exposures encountered would be about a factor of 10 greater if the plant had not been previously decontaminated. It should be noted that even without chemical decontamination, the amount given for water cleanup prior to release (shown in Table G.1 would still be incurred.

The chemical decontamination project is postulated to be done by an experienced specialty contractor (vendor) well established in systems decontamination and associated integrated outage activities, under contract to the utility. During the planning and preparation stage, procedures and results from previous decontamination efforts will be reviewed to obtain maximum benefit from previous experience. Then, with the reactor completely defueled and the pressure vessel head reinstalled, the RCS and associated systems will be isolated from the spent fuel pool system. All possible branches of the systems will be operated during the decontamination period, with heated solution circulating through pumps, heat exchangers, piping, and tanks, and returning to the RCS loop for reheat and cleanup.

Current information on chemical decontamination of light-water reactors was obtained from a comprehensive review of the literature and from discussions with senior staff of PNS. The PNS staff emphasized that it should be recognized that: 1) full-system chemical decontaminations of light-water reactors are very plant-specific; 2) the amount of radwastes depends on the solvent used for the job; and 3) a first-of-a-kind full-system chemical decontamination of a BWR could cost in the range of $20 to $25 million. However, when such decontaminations of BWRs become "routine" (defined here as after at least three such campaigns have been successfully completed), a cost in the range of $10 to $15 million could be anticipated for a full-system chemical decontamination. This latter cost includes mobilization/demobilization costs, all contractor staff costs, the costs of chemicals, mobile equipment, hoses, etc., onsite radwaste processing, high-integrity containers (HICs) for the resultant waste, and transportation costs, but not final burial costs of the HICs.

Based upon the information obtained from PNS staff, the following schedule, dose and cost values, and volumes of radwastes associated with a specialty contractor's effort are postulated to be reasonable estimates for use in this reevaluation study:

- About 4 months is estimated for the completion of the full-system chemical decontamination project at the reference BWR. About 2 months is estimated for mobilization, including reactor-specific indoctrination training, equipment installation, tie-ins, etc.; 1 week around-the-clock for decontamination process application; 1 month to process the waste onsite (outside the reactor building such that these latter activities do not interfere with other decommissioning tasks) and for concurrent treatment and release of the water from the reactor systems; and 3 weeks for demobilization and shipment of the resultant wastes.

- A 3- to 5-step process will be required to obtain the desired results from the decontamination process.

- An occupational radiation exposure in the range of 30 to 50 person-rem could be expected for the decontamination effort. For purposes of this study, a mid-range value of 46 person-rem has been assigned to this work.[2]

- In consideration of the uncertainties associated with a full-system chemical decontamination to be done in the future, including the proprietary constraints and the highly competitive business climate for this type of work, and based upon an anticipated cost in the range of $10 to $15 million, a mid-range cost of about $12.5 million has been assigned to the work.

- Somewhere between about 2,400 and 3,500 ft^3 of dewatered resin, Class A waste, containing about 5,000 curies of activity, could be expected to result from the full-system chemical decontamination job. A mid-range volume of about 3,000 ft^3 is used in this study.

The polyethylene HICs postulated to be used for the radioactive resins resulting from the chemical decontamination operations must be dewatered before burial. The HICs also are assumed to contain a nominal 15% void. For the HICs postulated for use in this study (burial volume of 5.72 m^3 or about 200 ft^3/HIC), about 170 ft^3 of waste resin/HIC (assuming a 15% void) results in about 18 HICs requiring disposal at the low-level waste burial ground at Hanford. Nine of 18 HICs are postulated to require engineered concrete barriers for disposal, since they are assumed to contain 2% to 6% chelates. The remaining 9 HICs are assumed to contain <0.1% chelates. It is further assumed that the contact readings on the HICs are about 80 R/hr. Based upon these assumptions, it is calculated that each HIC contains approximately 278 curies.

Under the postulated conditions just described, the estimated burial cost for the 18 HICs given in Table G.1 is $404,498, for disposal at the U.S. Ecology facility at Hanford, and is $1,731,780 for disposal at the Chem-Nuclear facility at Barnwell (see Appendix B).

Upon completion of the chemical decontamination process, the solution remaining in the systems cannot be released without some form of additional treatment since the water is expected to still contain measurable radioactivity. Therefore, the water will be treated by batch process by a specialty contractor (sampled, analyzed and treated again, as necessary until release criteria are met) and released according to applicable release standards. The decontaminated systems will be left dry. As shown in Table G.1, the cost for final water treatment is estimated to be $750,000. It is further estimated to take 30 days, working 21 shifts per week. Since the waste activity concentration is not well known at this point, it is difficult to predict with confidence either the occupational radiation dose or the volume of waste that will result from these activities. However, for the purpose of this study, 1) an occupational radiation exposure of approximately 2 person-rem is anticipated for these activities; and 2) it is roughly estimated that an additional five 5.72-m^3 HICs of spent ion exchange resin could be

[2]It is postulated that the vendor's staff receive about 30% of the dose and the utility staff about 70%, based upon information contained in Reference 3.

required. Assuming disposal at the U.S. Ecology facility at Hanford (see Appendix B), the cost of subsequent disposal of the HICs (Table G.1), estimated to be $61,803,[3] is assumed to be the responsibility of the utility. For disposal at the Chem-Nuclear site at Barnwell (see Appendix B), the total estimated burial cost for the 5 HICs given in Table G.1 is $373,800.

The utility is responsible for the costs of indoctrination training for all non-utility staff coming onsite; energy; protective clothing and equipment services; routine radwaste collection, processing, and disposition; and final disposal of the decontamination wastes. Also, security measures required during the chemical decontamination project are assumed to be the responsibility of the utility.

In addition to the specialty contractor's (vendor's) staff, which is assumed to be 18 people, the utility must provide technical support. A description of the optimum project staff is provided in Reference 4, based upon recent chemical decontaminations at boiling water reactors. This study's approach is similar. Typical support staff for the reference BWR are listed in Table G.2.

The above-listed persons are part of the existing Period 2 utility staff.In addition, PNS staff related that their experiences to date with chemical decontamination of drain systems indicates that it is probably not cost-effective, nor practical, to chemically decontaminate reactor drain systems prior to disassembly. Therefore, the piping in the drain systems at the reference BWR is **not** postulated to be chemically decontaminated before disassembly.

Table G.2 Station staff support for chemical decontamination

Position	Estimated number required
Station Project Manager (days) or Responsible Engineers (one/shift)	3
Plant technical support (one per shift)	3
Head liaison engineer (one per shift)	3
Consultant (one per shift)	3
Dedicated health physics support (2 per shift)	6
One chemist plus one chemical technician per shift	6
Pipe fitters (two per shift on standby)	6
Instrument tech. and electrician (1 each/shift on standby)	
Laborers (two per shift on standby)	

[3]Based upon disposal cost information for HICs provided by U.S. Ecology (see Appendix B); assumes < 0.1 % chelates, < 50 curies, and < 5 R/hr contact readings.

G.1.3 Estimated Task Schedule and Sequence

The overall task schedule and sequence of events for performing the chemical decontamination is given in Figure G.1. It can be seen from the figure that the contractor's total time onsite, including mobilization and demobilization, is estimated at 4 months. It is further estimated to require a 12-month lead time to scope and schedule the work, develop the plans, procedures, training requirements, and calculations associated with the chemical decontamination project.

G.2 Surface Decontamination

In this study, all contaminated horizontal surfaces are assumed to be washed using a manually operated cleaning system which washes the surface using high-pressure (250 psig) jets and collects the water and removed material simultaneously using a vacuum collection system. This system permits excellent cleaning while avoiding recontamination due to dispersion of the water. The same system, employing modified cleaning heads, is used to wash vertical or overhead surfaces. An additional 20% of labor time is postulated to be required for the vertical and overhead surfaces cleaning.

In general, the water-jet/vacuum decontamination activity can proceed independently of the recirculatory method. The specifics of the water-jet/vacuum decontamination activity are described in detail in Appendix C, together with the costs per square foot of surface cleaned.

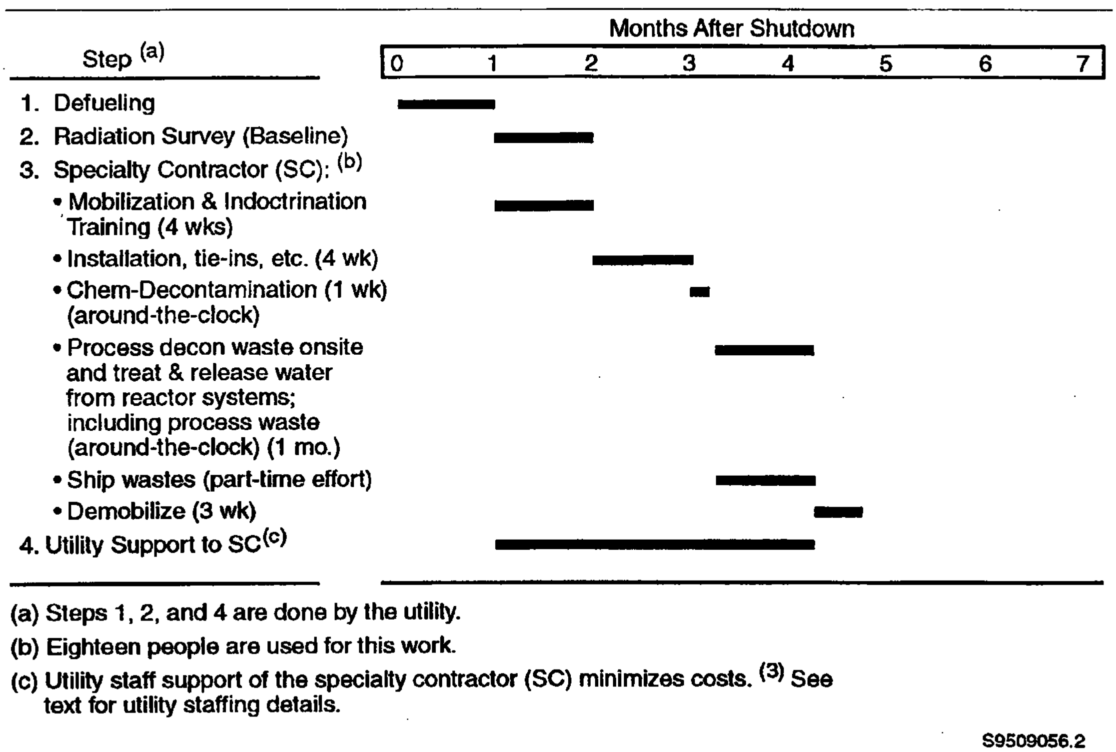

Figure G.1 Estimated task schedule and sequence for chemical decontamination

G.3 Removal Techniques and Equipment

The various removal techniques and equipment assumed for the removal of contaminated and uncontaminated structural materials are discussed in subsequent sections.

G.3.1 Removal of Contaminated Concrete Surfaces

Those contaminated horizontal surfaces which are not sufficiently decontaminated using the high-pressure washing system (see Section G.2) are removed using a commercially available pneumatically operated surface chipper removal system. Commercial systems which use very-high-pressure water jets for surface removal are also available. For this analysis, a specific commercial system manufactured by Pentex, Inc. is assumed (the Moose™ and associated smaller units), which chips off the surface and collects the dust and chips into a waste drum, and filters the air to prevent recontamination of the cleaned surfaces.

It is postulated that the depth of concrete to be removed will vary from location to location, but that on the average, removal of about 1.0 in. will be sufficient to remove the residual radioactive contamination. Because the removal system selected removes about 0.125 in. of material per pass, an average of 8 passes will be required over the contaminated areas. Because the Moose™ cannot get closer to walls than about 6 inches, smaller units of the same type are used to clean the perimeter areas of rooms. For this analysis, it is postulated that the perimeter areas comprise about 13% of the total surface area to be cleaned. For 1-pass removal operations, the Moose™ is assumed to clean at the rate of about 115 ft^2 per hour. Smaller units clean at the rate of about 30 ft^2 per hour. Combining these rates by weighting with the fractions of surface removed by each unit, the nominal removal rate becomes about 130 ft^2/hr. Assuming an average of 8 passes are required, the effective average cleaning rate becomes about 16.25 ft^2/hr.

The smaller units (Squirrel III™ and Corner Cutter™) could also be utilized on vertical surfaces. The cost per square foot for vertical surfaces would be approximately four times the cost for horizontal surfaces, due to the lower removal rates of the smaller units. Staffing of the crews and unit cost factors are developed in Appendix C and are not repeated here.

G.3.2 Cutting Uncontaminated Concrete Walls and Floors

All concrete walls and floors are assumed to be uncontaminated or to have been decontaminated before sawing operations begin. Thus, the costs of cutting uncontaminated concrete to provide access to other components are considered to be cascading costs.

Material and labor costs for cutting uncontaminated concrete walls and floors are based on the length of cut, measured in inch-feet (e.g., a cut 1-inch-deep, 1-foot-long, equals 1 inch-foot). Based up discussions with an industry source, 60 inch-feet per hour is used in this study as a reasonable cutting rate.

Cutting of concrete walls is accomplished using a wall-saw on a mechanically driven track system. Cutting of concrete floors is done with a slab-saw. Scaffolding will be used as needed for installing and removing the track system when sawing openings in walls. The concrete pieces are cut into various shapes and sizes, depending upon the size of the openings desired. No packaging is contemplated, since the removed material is postulated to be uncontaminated. The removed pieces of concrete are transferred to nearby storage areas. The basic operations for cutting concrete walls and concrete floors, together with the estimated clock times required to accomplish each operation, the staffing, and the unit costs, are developed in Appendix C.

G.4 Water Treatment and Disposal

Selected water treatment and solidification operations associated with decommissioning the reference BWR are described in this section.

G.4.1 Spent Fuel Pool Water Treatment and Disposal

Once the spent nuclear fuel inventory has reached zero, approximately 5 years after final shutdown, the spent fuel pool (SFP) water cannot be released without some form of additional treatment since the water will contain measurable radioactivity. Therefore, the water will be treated by a specialty contractor using a batch process (sampled, analyzed and treated again, as necessary until release criteria are met) and released according to applicable release standards. The SFP and associated systems will be left dry.

Discussions with a qualified vendor have suggested that the estimated vendor's cost for this task would be about $450,000. Subsequent transportation costs for the resultant radioactive wastes are included in this cost estimate, but radwaste burial costs are the responsibility of the utility. The effort is estimated to take 18 consecutive days, working 21 shifts per week (6 people per shift). Protective clothing and equipment for vendor's staff are expected to cost the utility about $ 6,804.

Since the SFP water quality and extent of deposit accumulation from the fuel assemblies are 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 these activities. However, for the purpose of this study, it is assumed that 1) an accumulated occupational radiation dose of approximately 2 person-rem will result from these activities; and 2) that about three 5.72 m^3 HICs would be required.

Based upon information contained in Appendix B, the cost of three HICs is estimated at $23,475. The transportation cost for the HICs from the manufacturer's facility to the plant site is estimated at $4,210, based upon a direct quote from the Tri-State Motor Transport Company. Twelve days of cask rental charges comes to an estimated $15,000. Burial costs at U.S. Ecology are estimated at $40,544. Burial costs at Barnwell are estimated to be $224,280, based upon the assumptions that individual HICs contain less than 50 curies of activity each and have surface contact readings of less than 20 R/hr.

A summary of the total estimated costs and occupational radiation dose for this activity is presented in Table G.3.

G.4.2 Temporary Waste Solidification System

The specifics associated with the decontamination of surfaces using high-pressure water wash/vacuuming are described in detail in Appendix C and are not repeated here. However, the water usage and associated liquid radwaste generation, treatment, transport and disposal are addressed here. At the calculated generation rate of 1 gallon per minute of system operation (see Appendix C for details), it is estimated that approximately 12,156 gallons of high solids, low activity waste solutions will result from the surface cleaning tasks at the reference BWR. It is postulated that a transportable evaporator-solidification system, together with specialty contractor operating personnel, will be used to provide this additional liquid radioactive waste handling capability and final cleanup capability at the reference BWR.

Based upon discussions with senior staff at PNS, the waste solutions are estimated to be processed for disposal (i.e., evaporated/solidified in four 5.72 m^3 HICs) at a unit cost of about $10/gallon. Mobilization/demobilization costs add another $20,000, resulting in a total cost of $141,560 for this fixed-price contract. Overall, about 26 days are required to complete the task, including mobilization/demobilization. Occupational radiation exposure is anticipated to be about 0.3 person-rem.

Table G.3 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 Contract[b]	450,000	~1.2
Transport of HICs to Plant Site from Mfgr.[c]	4,211	--[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 & Equipment & Services (vendor only)	6,804[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.
(f) Based on Table B.2.
(g) Included in $450,000 Fixed-Cost Contract.
(h) For disposal at the U.S. Ecology facility at Hanford. For disposal at the Barnwell site (see Appendix B), the total estimated burial cost for the three HICs is $224,280.
(i) Included in Period undistributed costs.

The cost of the HICs, cask rental, transportation and final disposal of the HICs are the responsibility of the licensee. Based on information contained in Appendix B, the HICs are estimated to cost $31,300; 14 days of cask rental come to $17,500; total transportation costs are estimated at about $28,589; and disposal costs at U.S. Ecology are estimated at $49,442. Burial costs at Barnwell are estimated at $293,300. The burial cost estimates are based upon the assumptions that individual HICs contain less than 5 curies of activity each and have surface contact readings of less than 5 R/hr. A summary of the total estimated costs and occupational radiation exposure for this activity is presented in Table G.4.

Table G.4 Summary of estimated costs and radiation dose for temporary waste solidification system operation and subsequent waste disposal

Cost item	Estimated cost (1993$)[a]	Estimated dose (person-rem)
Fixed-cost Contract	141,560	<0.3
Radwaste Disposal		
High-Integrity Container[c]	31,300	
Cask Rental[d]	17,500	
Transportation[e]	28,589	
Burial[f]	49,442	
Subtotal	126,831	<0.02
Totals	268,391	0.32

(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 Table B.3.
(d) Based on Table B.2.
(e) Based on direct quote from Tri-State Motor Transport Company. Includes transportation charges for the empty cask from Barnwell, SC to WNP-2, the loaded casks from WNP-2 to the U.S. Ecology site at Hanford, and the empty cask back to Barnwell, SC.
(f) For disposal at the U.S. Ecology site at Hanford. For disposal at the Barnwell site (see Appendix B), the total estimated burial cost for the four HICs is $293,300.

G.5 References

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Appendix H

Estimated Non-Radioactive Demolition and Site Restoration Costs for WNP-2

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Seattle, Washington

Appendix H

Estimated Non-Radioactive Demolition and Site Restoration Costs for WNP-2

The purpose of this study is to provide current bases in 1993 dollars for demolition cost estimates for non-radioactive demolition and site restoration for the reference boiling water reactor (BWR), WNP-2, and to upgrade NUREG/CR-0672. This study addresses changes in demolition costs, technology, and regulations to date and subsequent to the original decommissioning cost studies of the reference BWR in 1978.

Once all radioactive materials in a BWR are removed or decontaminated, the Nuclear Regulatory Commission (NRC) is requested to terminate the possession-only license and release the site for unrestricted use. Following license termination, the utility decides whether the remaining onsite structures are to be demolished or left standing. Although NRC does not exercise jurisdiction over removal of non-contaminated structures and restoration of the site, development of demolition and site restoration costs is presented in this appendix for completeness. The costs were calculated as if the demolition contractor were bidding on the job.

H.1 Summary

Technological improvements in demolition equipment and techniques over the past 15 years have improved safety and general efficiency, but have not overcome the persistent difficulties of demolishing the strongest nuclear structures.

Recycling of economically valuable resources was practiced in the demolition industry prior to its present emphasis, and remains a strong consideration. The recycling of concrete by onsite crushing is a relatively recent general practice.

In addition to general inflation, there has been a continuing extension of regulatory authority over general demolition and disposal. Costs of special handling of asbestos material and lead containing material have been greatly increased. Costs of disposal of demolition debris have far exceeded general inflation.

The total estimated cost of demolition for the reference BWR of $48,238,100 is summarized in Table H.1.

H.2 General Methodology for Demolition Cost Estimates

Basic structural characteristics which are relevant to demolition techniques were examined for the major plant structures, such as

- Physical Arrangement of the Plant
- Structure Seismic Classifications
- General Degree of Steel Reinforcing

Table H.1 Summary of estimated demolition and site restoration costs for WNP-2

Building name, description	Building #	Estimated demolition costs (1993 dollars)
Reactor Containment Building	2	$14,313,600
Turbine Generator Building	4	10,110,100
Radwaste and Control Building	3	4,964,700
Cooling Towers	n/a	2,911,100
Diesel Generator Building	7	670,600
Plant Support Structures	34	3,143,200
Service Building	27	388,000
Circulating Water Pumphouse	30	289,800
Rifle Range	n/a	61,500
Miscellaneous Light Structures	n/a	511,900
Site Restoration	n/a	1,426,000
Copper Salvage Allowance	n/a	-200,000
Sub Total		38,590,500
25% Contingency		9,647,600
Total		$48,238,100

- Height Above Grade of Various Structures
- Areas of Buildings and Footprint Areas
- Quantities of Reinforced Concrete, Steel, and Debris
- Disposal Sites for Concrete and Debris

Demolition quantity estimates in cubic meters (m^3), square meters (m^2), and megagrams (Mg) were taken from the demolition "quantities" described in NUREG/CR-0672, and generated from information furnished by WPPSS. Appropriate units costs were then applied to these quantities to develop cost estimates in 1993 dollars.

For certain "light" structures (such as warehouses, sheds and other miscellaneous "Butler Buildings") no material quantities, per se, were developed as an intermediate step in determining the demolition cost estimate. For these items, the contractor examined photographs and construction drawings, when available, together with a site visit to determine a unit cost per square meter for the individual buildings. These unit cost estimates are based on personal experience from demolishing similar structures. The building footprint (surface area of foundation) and number of stories were furnished by WPPSS or determined from plant drawings. The unit costs were then applied. Finally a 25% contingency factor was applied to the site's total cost to account for unforseeable changes of conditions and/or costs.

H.2.1 Assumptions for the Development of Cost Estimates

The analyses of the effort and costs involved in demolishing the reference BWR structures and restoring the site are based on the following assumptions:

- All above-ground structures on the plant site are demolished and removed.

- Building structures are to be demolished down to 1 m below grade; holes are broken in the sub-basement floors for drainage; the empty below-grade volumes are to be filled to within 1 m of the grade level with concrete rubble; and the last meter is backfilled with 0.85m earth and 0.15m topsoil.

- The demolition contractor has salvage rights, with these values reflected in the estimated costs of the respective structures. These values assume completely depreciated equipment after the useful life of the plant has expired.

- Excess rubble may be disposed below 1 meter below grade level onsite.

- Other debris is to be disposed of at the regional landfill at Roosevelt, Washington, some 100 km from the site.

- Costs associated with cement asbestos board (CAB) cooling fins and other CAB in the cooling towers are included in this estimate. Possible asbestos containing roofing materials on various buildings are included in these costs. Friable asbestos, such as found in pipe insulation and gaskets, is not included in this study.

- Costs associated with "normal" spillage of petroleum products and cleanup of the resultant contaminated earth are considered in this study as a contingency cost. Costs associated with compliance with the Lead Hazard regulations are considered in this study as a contingency cost.

H.2.2 Factors Affecting Estimation of Demolition Costs

Change in cost estimates for demolition of the reference BWR plant are influenced by regulatory requirements, available demolition technology, labor rates, equipment requirements, disposal costs for debris, salvage, the addition and upgrading of buildings and structures on the site, and problem areas in estimating demolition costs.

H.2.2.1 Regulatory Requirements

EPA and OSHA-initiated regulations and interpretations affect this study principally in the areas of asbestos, lead, and debris disposal requirements. There is a continuing addition of materials to the special handling categories. Non-friable Cement Asbestos Board (CAB) and roofing material are being regulated, where they were not 15 years ago. Fluorescent light bulbs and ballasts have been added. Lead paint has also been added. Fill sites that were considered safe 15 years ago are not acceptable today under current interpretations. Current regulatory costs are incorporated into this study; but the prediction of future regulatory requirements falls under the contingency allowance.

H.2.2.2 Demolition Technology

A new generation of hydraulic excavators with attachments such as hammers, grapples, shears, and crushers has developed. The diamond rope saw is a recent development that has potential application in heavy demolition, and it is cost effective in certain circumstances. Crane and explosives technologies have steadily improved.

The advance in demolition techniques and equipment most directly related to Seismic Class 1 structures has been the development of the hydraulic hammer. The hammer is taking over work previously only done by the crane and ball-and-chain and drilling and explosives. However, the crane continues to have greater reach than the hammer, while explosives continue to have far more breaking power than the largest hammers. Progress has been evolutionary, and the same ultimate limitations in dealing with reactor containment vessels that we faced in 1978, we still face in 1993.

H.2.2.3 Miscellaneous Factors

Changes in labor rates, equipment costs, and salvage have evolved along lines of general inflation. Disposal costs for demolition debris have increased nearly ten-fold in the past ten years. The addition and upgrading of buildings and structures is site-specific; while they add to decommissioning costs, they do not affect other costs.

H.2.3 Problem Areas in Estimation of Demolition Costs

No reliable precedent exists for estimating the costs of demolishing the heavily reinforced, massive Seismic Class 1 reinforced concrete structures of the reference BWR. The Shippingport reactor is the closest example, but its walls were only half the thickness and reinforcement of the BWR. Since difficulty increases geometrically with both strength and thickness, one to one comparisons would not be reliable. Shippingport demonstrated that the larger hydraulic hammers can break up substantial walls and floors that could previously only be broken by explosives. Limited experience at WNP-5 at Satsop, Washington, indicated that such hammers were ineffective. The estimates presented in the appendix result from comparisons of the reference BWR structures with industrial-type structures that have been demolished. In addition, judgment factors are applied, based on experience, for the massiveness, grade of concrete, extra-heavy reinforcing steel, and the height of the structures.

An area of concern in estimating demolition costs has been the cost assigned to hammering and separating the concrete from the rebar, both with and without weakening by explosives. Concrete in the reference BWR structures is high quality, extra thick, well aged, and well bonded to extra-heavy reinforcing steel. Most of the structures have confining and self-reinforcing cross walls that restrict access and make use of equipment difficult. Singly, these factors tend to increase demolition costs markedly, and their combination compounds the effect. In spite of the great improvements made in hydraulic attachments, a large "if" remains. In the case of the reactor containment vessel, the reinforcement is so massive that drilling for explosives is extremely difficult to the point of practical impossibility. The drills continually encounter steel and drills aren't designed to drill through massive steel. Diamond rope saw cutting has potential. Assigning dollar values to these factors relies heavily on subjective judgment.

H.3 Demolition Considerations

All above-ground structures on the plant site will be demolished and removed down to 1 meter below grade, and all site features restored, by grading and planting, to "Native" condition.

Major structures include the Reactor Building, Turbine Building, Radwaste Complex, Diesel Generator Building, Plant Support Facility, Plant Engineering Building, Service Building, Circulating Water Pumphouse, Makeup Water Pumphouse, Spray Pond Complex, Rifle Range, Records Management Building, Document Storage Building, and five warehouse buildings. The plant layout and major structures are illustrated in Figures B.1 through B.6 of Appendix B. Portable trailers are not included in these tables since they will either be removed prior to demolition or their resale value would offset the costs of removal.

H.3.1 Demolition Methods for Seismic Class 1 Structures

In the cases of the Reactor Building and the Turbine Generator Building, building demolition proceeds from the top down after machinery and equipment are removed. Where a bridge crane is in place, it is used for moving out the existing machinery and moving in the demolition equipment and supplies, using the existing lifting shaft. During floor-by-floor demolition, the lifting shaft is used to drop the rubble. Where floor openings are needed for rubble dumps, but do not already exist, they can be cut down to ground or basement level.

Typical demolition equipment required on the top working floor (for removing the roof, preparing the work floor for breaking by hydraulic hammer, drilling for placement of explosives, and removing rubble) consists of manlifts, a crane, hydraulic excavators with hydraulic hammers, shears and grapple attachments and drilling machines. (Hydraulic drilling machines are now being manufactured as attachments to hydraulic excavators.)

The top structure of a steel-capped building is conventionally removed by reversing the construction procedure. A hydraulic crane and man-lifts positioned on the floor below the roof, or on the ground, are used to remove the roofing, steel siding, and structural framework. Alternatively, the steel superstructure above the concrete work-deck may be removed by pullover.

Pullover can be accomplished by cutting loose and pulling out the end walls, then weakening and pulling the structure sideways. The walls are to be braced and rigged for pulling before weakening them. This procedure is in common use, but it should be overseen by an experienced superintendent. An appropriate engineering and safety plan is to be drawn up and reviewed and enforced for this and every other wrecking operation.

When the upper steel building has been removed down to the concrete work-deck, lift up drilling and hammering, grappling, and concrete crushing equipment to the work deck to proceed with the concrete removal. The drilling and explosive procedures are necessary for the reactor containment structure. In case of difficulty in locating the rebar patterns to find starting positions for down-drilling, the hydraulic hammers can be used to expose the rebar.

The general sequence for removal of the concrete would be to down-drill the shield and any other massive walls and floors for explosives. Blast half the floor, walls, and shield, then use hammers and shears and grapples to break through the broken floors to clear a working space, and, if possible, build a ramp down to the next lower level. Move equipment to a protected place on the lower floor or to the ground by crane, then blast the second half of the upper floor and walls and shield. From the lower floor working space, demolish the second half of the upper floor. Repeat the sequence floor by floor to the ground. Continually review the engineering and safety plan as the work progresses.

H.3.2 Transport of Demolition Debris

Loading and hauling demolition debris generally costs more than loading and hauling dirt or gravel. Demolition trucks are not loaded or dumped as fast as dirt and gravel trucks because of their longer, higher-sided trailers and the uneven sizes of the materials they haul. Hauling costs in the wrecking industry reflect these conditions.

Concrete rubble from the reference BWR may be buried on site. Demolition debris and asbestos are to be trucked to the Rabanco Regional Landfill at Roosevelt, Washington, some 100 kilometers distance.

H.3.3 Salvage and Recycling Considerations

In this study, structural steel has been given a nominal net value of $50 per ton ($55/ Mg) stockpiled on the ground. The costs of loading, hauling, and disposal (sale) are borne by the contractor from the point of stockpile. This appraisal is reflected in a lowered per unit price for steel buildings from what they otherwise would be. The recycle rate for structural steel approaches 100%.

Reinforcing bar is generally accounted for by moderating the unit demolition price rather that a separate itemization. The cost of removing unanticipated reinforcing bar greatly exceeds any salvage value of the rebar. Once in a stockpile, the costs of sorting, cutting, loading, shipping, and disposal costs are borne by the contractor, not as a job cost. When concrete is recycled, 100% of the related rebar is recycled.

Scrap tin (light sheet metal) generally does not pay for its preparation and hauling costs. It is not considered to be of any net scrap value or allowance; however, to avoid disposal costs, close to 100% of tin is recycled as scrap metal.

Equipment will be thoroughly depreciated and presumably obsolescent by the time the plants are to be dismantled. It is highly specialized and subject to technological change. Even when relatively new and unused, its sales value has been a disappointing 7% of cost (Satsop Plant WNP-5). Its principal value after use will be as scrap for its copper content. This copper content is included in the consideration for copper salvage. Close to 100% of equipment is recycled for its metal content.

Copper is a significant consideration in demolition of an electrical generation plant such as this. Estimation is made difficult by the fact that a portion of the copper will be radioactively contaminated and must be disposed of as such. A rough estimate is that there is a net value of copper of $200,000 which could be recovered by the contractor. All accessible copper is recycled.

It is recommended that the demolition bid invitation specify an allowance to the owner of $200,000 for copper salvage, which is to be deducted from the total bid price. This clear definition has several values to both parties. The owner (ratepayers) is assured of consideration for the copper salvage value. It clearly gives the contractor authority and responsibility for the security of the copper. (Copper is frequently "lost, strayed, or stolen".) It brings the contractor "on board" with the owner to prevent non-radioactive copper from going to the radioactive landfill along with externally contaminated conduit that it might be inside. It gives the contractor access to early cash flow when large expenditures are being made, but before payments have been received.

Concrete recycling generally costs some $5.00 per truck yard/ton beyond the costs of nearby free disposal. However when the waste material must be transported any distance or disposal fee paid, it is generally cheaper to crush and stock-pile the reusable material on site. Where there is a reuse for the material on site or a sale nearby, it costs less to recycle the concrete than to landfill it. On balance, the net cost of specifying the recycling of concrete and stockpiling it on site is negligible. It is recommended that recycling of concrete, not used to fill voids under structures, be specified. The cost estimates are unchanged because the economic opportunities equal the added costs.

H.4 Unit Costs

Where quantities of material were available for separate structures, cost estimates were based on volumes and tonnages. Where quantities were not readily available, square footages were used. Cross checks were calculated to relate known quantities and footages vs. footages only, to verify the correlation between the two. Primary structures were mainly estimated based on quantities. Most secondary structures were estimated on a square footage basis related to commercial experience.

It is to be noted that when concrete is broken, there is an expansion factor of approximately 2 to 1. In this study, the in-place solid measure has been used for consistency to describe the quantities in primary breaking, secondary breaking, and disposal. In commercial practice, the secondary breaking and disposal is commonly calculated in "truck measure". To convert the in-place measurements used here into truck measure, the quantities are to be doubled and the unit cost halved. The total cost remains unchanged.

Unit cost figures for removal of steel; drilling/blasting, secondary treatment and loading/hauling of reinforced concrete; and removing "light" structures were developed to cover labor, equipment, supplies, overhead, profit and taxes. Items included are base pay, FICA, unemployment insurance, bodily injury and property damage insurance, equipment rental and operating costs, fuel and supplies, and contractor overhead and profit. The unit costs do not include contractors' performance bonds. Washington State Sales Tax, which is applicable to the overall demolition contract price, is not included in the unit prices, but is itemized separately according to Washington State law.

H.5 Equipment Requirements for Demolition

A listing of the major equipment requirements is included as Table H.2. It is not intended to list every piece of equipment that could be used, but to give a basic capability to perform the essential tasks. Each contractor would vary these equipment requirements to suit their experience and personal preferences.

H.6 Demolition and Site Restoration Costs, WNP-2

The estimated costs for the non-radiological demolition and site restoration of the reference BWR after decommissioning by immediate dismantlement are developed in this section. Tables H.3 through H.7 show demolition cost estimates for specific major structures. Tables H.8 through H.12 summarize cost estimates for demolition of miscellaneous lighter structures and buildings, and Table H.13 details site restoration cost estimates. These costs include labor, supplies, insurance, overhead, and contractor profit, but exclude State Sales Tax and contractors' bonding costs. They show allowance for copper salvage as a separate line item. A 25% contingency is added to account for unknowns. Discussions of specific demolition methods and the derivation of cost estimates for the various plant structures are given in the following subsections.

H.6.1 Reactor Building And Primary Containment Vessel

The biological shield wall is 1.54 meters thick and heavily reinforced with four courses of #18 rebar (5.7cm) on 24 cm centers, horizontally and vertically. With overlaps, it is virtually a series of steel walls. This reinforcing would seriously interfere with drilling for explosives from the sides. It would also seriously interfere with diamond drilling, coring, or sawing, since the steel "eats up" the diamonds. Limited testing at Satsop, Washington (WNP-5) has indicated that the largest hydraulic hammers cannot penetrate from the side.

The vertical "walls" of rebar in 4 courses spread across 1.54 meters of wall thickness indicate that there must be spaces between these courses of approximately 20 cm, which would be relatively free of rebar. This is where drilling could reasonably take place. Down-drilling from the top of the wall is the procedure recommended.

Table H.2 Equipment requirements for demolition, WNP-2

Equipment item	Application	Number required
300 ton crane	High lifts of heavy loads	1
100 ton crane	Lifts and ball-and-chain	2
80 ton hydraulic crane	Dismantle roof structures	2
1 m^3 hydraulic excavator	Clean up and loading debris	6
3 m^3 hydraulic excavator	Operates hammer and shear	6
5 m^3 hydraulic excavator	Hammer, shear, grapple & pulverizer	6
Komatsu 1000 excavator	Heavy duty hammer and shear	1
983 track loader	Clean up and rough grading	2
Air track drills	Drilling holes for explosives	4
Air compressors	Air supply for pneumatic tools	6
Hydraulic hammers	Breaking concrete	12
Hydraulic shears	Cutting rebar, structural steel and pipe	12
Hydraulic grapples	Handling of concrete and steel	6
Hydraulic pulverizers	Crushing of concrete	6
Brokk hydraulic units	Remote control breaking of concrete & steel	4
Diamond rope saw	Cutting of massive concrete	1
700 & 900 series bobcats	Rehandling and moving of debris	14
Hydraulic drill	Drilling holes for explosives	2
Oxy/acetylene torch outfit	Cutting steel	20
Plasma arc cutting outfit	Cutting steel and non-ferrous metals	20
Demolition truck/tractor	Hauling debris	6
Rigging	Moving equipment and material	As req.
Breaking balls	Breaking concrete	4
Battering ram	Breaking concrete	1
Misc. equipment & supplies	Safety equipment, hand tools, job trailers, etc.	As req.

For primary breaking, explosives would be used. Hydraulic hammers would be used for secondary breaking of the reactor building. (Secondary breaking here would be as difficult as most primary breaking on other heavy structures.) Hydraulic excavators with hammers, shears and grapples are the tool of choice for breaking and rehandling of heavily reinforced concrete. Their speed, precision, power, and safety make them the favored method for cutting steel reinforcing bar, pipes, and steel beams. They are faster, safer, and less expensive that oxy-acetylene torches or plasma arc torches. In the case of the Reactor (and Turbine) buildings, they are to be used in conjunction with explosives.

An offset drilling pattern would be used to optimally fragment the concrete. After each blast, the rubble is cleaned up, the rebar is cut to manageable lengths and segregated, and the material put down chutes or enclosed drops. Walls and floors are to be taken down as the removal of the reactor containment vessel proceeds downward. Outer walls are cut loose at the corners, pulled onto the work floors, broken, and disposed of. Secondary breakage is accomplished with hydraulic hammers and rehandling is done with grapples.

The cost estimate for the demolition of the Reactor Building and Primary Containment Vessel is given in Table H.3.

H.6.2 Turbine Generator Building

Although the Turbine Generator Building is not as tall as the Reactor Building, it is equally massive. The demolition methods used for this building are similar to those for the Reactor Building, described previously. Cost estimates are based on using explosives for the primary breaking, with heavy duty hydraulic hammers doing more primary and the secondary breaking once the structure has been weakened. Further breaking and separation of rebar from concrete will be done with concrete pulverizing attachments and shears.

The structural steel roof structure will be removed by conventional methods utilizing shears as the primary pieces of equipment. Alternatively the pullover method could be used. The cost of removing the steel roof is priced by the square meter. (This was cross-checked with the weight-of-steel basis used for the Reactor Building, and the bases correlate with each other. Square measure is used where weights are not readily available for separate portions of buildings.)

The cost estimate for the Turbine Generator Building is given in Table H.4.

Table H.3 Estimated reactor building and primary containment demolition costs

			Estimated costs (1993 dollars)	
Material/activity	**Amount**	**Unit**	**Unit cost**	**Activity cost**
Reinforced concrete:				
Drilling & blasting	31,368	m^3	$261.60[a]	$8,205,900
Secondary breaking and rubble cleanup	31,368	m^3	78.48[b]	2,461,800
Loading, hauling & disposal	31,368	m^3	52.32[c]	1,641,200
Structural steel				
Removal	1,699	Mg	385.89[d]	655,600
Primary containment vessel, cutting and removal	1,854	Mg	727.68[e]	1,349,100
Total				$14,313,600

(a) Equivalent to $200/yd^3.
(b) Equivalent to $60/yd^3.
(c) Equivalent to $40/yd^3.
(d) Equivalent to $350/ton.
(e) Equivalent to $660/ton.

Table H.4 Estimated Turbine Generator Building demolition costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Reinforced concrete:				
Drilling, blasting and hammering	31,132	m^3	$163.50[a]	$5,090,100
Secondary breaking and rubble cleanup	31,132	m^3	78.48[b]	2,443,200
Loading, hauling & disposal	31,132	m^3	52.32[c]	1,628,800
Structural steel				
Removal and recycling	12,580	m^3	75.36[d]	948,000
Total				$10,110,100

(a) Equivalent to $125/yd^3.
(b) Equivalent to $60/yd^3.
(c) Equivalent to $40/yd^3.
(d) Equivalent to $$7.00/ft^3.

H.6.3 Radwaste And Control Building

The procedures for demolishing the Radwaste and Control building are similar to those used for the Reactor building and the Turbine building. The Radwaste/Control building is Seismic Category 1, with many closely spaced, self-reinforcing cross walls. Explosives combined with hydraulic hammers and pulverizers are the options to be used here.

The cost estimate for demolition of the Radwaste and Control Building is given in Table H.5.

Table H.5 Estimated Radwaste and Control Building demolition costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Reinforced concrete:				
Primary breaking/hammering	19,340	m^3	$117.72[a]	$2,276,700
Secondary breaking and rubble cleanup	19,340	m^3	52.32[b]	1,011,900
Loading, hauling & disposal	19,340	m^3	52.32	1,011,900
Structural steel				
Removal and recycling	6,170	m^3	107.65[c]	664,200
Total				$4,964,700

(a) Equivalent to $90/yd^3.
(b) Equivalent to $40/yd^3.
(c) Equivalent to $10/ft^2

H.6.4 Cooling Towers

Six circular cooling towers are constructed of pre-cast concrete modules on a cast-in-place concrete basin. Drift eliminators and splash bars are made of Cement Asbestos Board (CAB). The CAB is currently required to be handled as asbestos waste. The material must be removed, handled, transported, and disposed of as a hazardous waste. Those costs were incorporated into this study. After removing the CAB, the structures can be dismantled and broken with hydraulic shears, grapples, pulverizers, and hammers.

The cost estimate for demolition of the Cooling Towers is given in Table H.6.

H.6.5 Diesel Generator Building

The Diesel Generator Building is a Seismic Category 1 structure of reinforced concrete. Three diesel oil storage tanks are located below the ground floor slab. The demolition procedures are similar to other Seismic Category 1 structures.

The cost estimate for demolition of the Diesel Generator building is given in Table H.7. The contingent costs of having to clean up contaminated earth related to the storage tanks is not included in the breakdown; but is recognized as a contingency cost. Special costs associated with tank removal are also recognized as a contingency, and are covered by the contingency allowance.

H.6.6 Plant Support Structures

The plant structures directly supporting operations are discussed and estimated in this subsection, with the estimated costs given in Table H.8.

Table H.6 Estimated demolition costs for the Cooling Towers

			Estimated costs (1993 dollars)	
Material/activity	Amount	Unit	Unit cost	Activity cost
Reinforced concrete:				
Primary breaking	10,436	m^3	\$78.48[a]	\$819,000
Loading, hauling & disposal	10,436	m^3	39.24[b]	409,500
Cement asbestos board				
Removal and packaging	5,985[c]	Mg	115.74[d]	692,900
Total				\$2,911,100

(a) Equivalent to \$60/yd³.
(b) Equivalent to \$30/yd³.
(c) Equivalent to 6,599 tons.
(d) Equivalent to \$127.60/ton.
(e) Equivalent to \$150/ton.

Table H.7 Estimated Diesel Generator Building demolition costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Reinforced concrete:				
Primary breaking/hammering	3,016	m^3	$117.72[a]	$355,000
Secondary breaking and rubble cleanup	3,016	m^3	52.32[b]	157,800
Loading, hauling & disposal	3,016	m^3	52.32	157,800
Total				$670,600

(a) Equivalent to $90/yd^3$.
(b) Equivalent to $40/yd^3$.

Table H.8 Estimated demolition and removal costs for plant support structures

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Plant support facility	9,755	m^3	$91.50[a]	$892,600
Plant engineering building	9,383	m^3	80,73[b]	757,500
Makeup water pumphouse	718	m^3	104.64[c]	75,100
Spray pond complex	4,700	m^3	104.64	491,800
Records management building	1,914	m^3	69.97[d]	133,900
Document storage building	3,003	m^3	69.97	210,100
Warehouses	10,400	m^3	55.98[e]	582,200
Total				$3,143,200

(a) Equivalent to $8.50/ft^2$.
(b) Equivalent to $7.50/ft^2$.
(c) Equivalent to $80.00/yd^3$.
(d) Equivalent to $6.50/ft^2$.
(e) Equivalent to $5.20/ft^2$.

H.6.6.1 Plant Support Facility

This is a heavily reinforced building designed to provide backup to the Operations Facility located in the main reactor complex. Its demolition will utilize the procedures applicable to the main complex, except that it is not a fully Seismic 1 structure. Hydraulic hammers together with pulverizers and grapples are adequate to remove it.

The cost estimate for demolition of this structure is given in Table H.8

H.6.6.2 Plant Engineering Building

The Plant Engineering Building is of moderately heavy construction, with tilt-up walls and concrete roof panels. It can be demolished by hydraulic excavators equipped with hammers, shears, pulverizers, and grapples.

The cost estimate for demolition of this structure is given in Table H.8

H.6.6.3 Makeup Water Pumphouse

The Makeup Water Pumphouse is located on the bank of the river. It is constructed of reinforced concrete and contains a sump pit substructure and a superstructure. The concrete can be broken and left in the below grade void. A hydraulic hammer and shear could dispose of the structure.

The cost estimate for demolition of this structure is given in Table H.8

H.6.6.4 Spray Pond Complex

Two spray ponds and two standby service water pumphouses form a complex of Seismic Category 1 structures. Each pond is constructed integrally with a pumphouse. Each pair of structures, consisting of pond and pumphouses, is adjacently located, but structurally separated. The spray pond structures are rectangular reinforced concrete, consisting of a structural slab and four perimeter walls. The pump houses are cast in place reinforced concrete. Demolition would be done by hydraulic excavator equipped with hammer, shears, pulverizer, and grapple.

The cost estimate for demolition of this structure is given in Table H.8

H.6.6.5 Records Management Building

A one story structure on a concrete slab, on grade, with insulated steel walls and roof. Demolish with hydraulic excavator, sort debris, steel, and concrete.

The cost estimate for demolition of this structure is given in Table H.8.

H.6.6.6 Document Storage/Office Records Management

A one story structure on a concrete slab, on grade, with insulated steel walls and roof. Demolish with hydraulic excavator, sort debris, steel, and concrete.

The cost estimate for demolition of this structure is given in Table H.8

H.6.6.7 Warehouses

These structures are open high bay buildings with concrete slabs on grade and insulated steel sides and roof structure. They can be readily removed by conventional methods.

The cost estimate for demolition of this structure is given in Table H.8

H.6.7 Service Building

Exterior above grade walls of the Service Building are made of pre-cast concrete panels. Interior walls are steel stud composition type. All floors are reinforced concrete. The roof is of insulated metal decking supported by steel trusses. Demolition would be by hydraulic excavators equipped with shears, grapples, hammers, and pulverizers.

The cost estimate for demolition of the Service Building is given in Table H.9

H.6.8 Circulating Water Pumphouse

The Circulating Water Pumphouse has a structural steel and insulated metal sided superstructure and a reinforced concrete substructure, rectangular in plan, associated with the Cooling Towers. It can be demolished by a hydraulic excavator equipped with hammer, shear, grapple, and pulverizer.

The cost estimate for demolition of this structure is given in Table H.10

H.6.9 Rifle Range

The rifle range is 175 feet long with side walls of creosoted railroad ties 15 feet high. The ties are criss-crossed at 90 degree angles, starting at 45 degrees, to form side walls along the length of the range to a height of 15 feet. They are backfilled with sand. It is estimated that half of the ties will be contaminated with lead bullets, which currently classifies them as hazardous waste. The other half are contaminated with creosote, which classifies them as contaminated waste. Each must be disposed of at certified landfills. In addition, some 100 tons of sand are considered to be lead contaminated.

The cost estimate for demolition and disposal of the Rifle Range is given in Table H.11.

Table H.9 Estimated Service Building demolition costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Reinforced concrete:				
Primary breaking/hammering	1,838	m^3	$100.72[a]	$185,100
Loading, hauling & disposal	1,838	m^3	52.32[b]	96,200
Debris removal and disposal	612	m^3	65.40[c]	40,000
Structural steel				
Removal	395	Mg	168.81[d]	66,700
Total				$388,000

(a) Equivalent to $77/yd³.
(b) Equivalent to $40/yd³.
(c) Equivalent to $50/yd³.
(d) Equivalent to $150/ton.

Table H.10 Estimated Circulating Water Pumphouse demolition costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Reinforced concrete:				
Breaking/disposal in place	2,593	m^3	$104.64[a]	$271,300
Structural steel				
Removal	112	Mg	165.34[b]	18,500
Total				$289,800

(a) Equivalent to $80/yd^3.
(b) Equivalent to $150/ton net.

Table H.11 Estimated Rifle Range demolition costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Demolition and disposal of creosote contaminated ties	54	Mg[a]	$165.38[b]	$9,000
Demolition and disposal of lead contaminated creosoted ties	54	Mg	330.764[c]	18,000
Loading and disposal of lead contaminated earth	91	Mg[d]	330.76	30,000
Demolition and disposal of wood surfaces	139	m^2	32.30[e]	4,500
Total				$61,500

(a) Equivalent to 60 tons.
(b) Equivalent to $150/ton.
(c) Equivalent to $300/ton
(d) Equivalent to 100 tons
(e) Equivalent to $3.00/ft^2.

H.6.10 Miscellaneous Structures

There are numerous structures on the site for which demolition costs are based on square footage or for which a lump sum estimate was made. These structures are listed in Table H.12. Unit costs were based on the type of structure and construction and the general difficulty of demolition. Estimates for most simple structures of concrete block or steel siding are based on the building's "footprint" area. Multi-story structures are usually based on a unit cost for floor area. All estimates assume disposal of concrete rubble on site.

The cost estimates for demolition of these structures are given in Table H.12.

Table H.12 Estimated demolition costs for miscellaneous structures

Description/Name	Bldg #	Total area (m^2)	Estimated costs (1993 dollars) Unit cost	Activity cost
Technical support building	5	523	\$115.72[a]	\$60,500
Health physics access point	6	229	69.97[b]	16,000
R.R.C. pump ASD building	8	201	55.98[c]	11,200
Maintenance services	11	934	69.97	65,300
Security	13	578	55.98	32,400
Laborers storage	15	130	55.98	7,200
Lube storage/paint shop	19	78	55.98	4,400
Backflow preventer building	21	19	55.98	1,000
Gas bottle storage	22	58	83.97[d]	4,900
Diesel polishing building	23	57	55.98	3,200
Sewage treatment plant	24	166	91.65[e]	15,300
Alternate access point (A.A.P.)	25	465	69.97	32,500
Outage contract shop	32	697	55.98	39,000
Water filtration building	33	176	55.98	9,800
Decontamination laundry	35	260	55.98	14,600
Electrical building #1	38	204	55.98	11,400
Electrical building #2	39	204	55.98	11,400
Pumphouse #2	40	37	55.98	2,100
Pumphouse #1	41	37	55.98	2,100
Document storage facility	47	254	77.02[f]	19,500
Meterological tower building	49	186	55.98	10,400
Meterological warehouse	50	186	55.98	10,400
Fire brigade training	59	116	55.98	6,500
Fire brigade/storage	60	84	55.98	4,700
Primary access point (P.A.P.)	62	372	69.97	26,000
Secondary guardhouse	63	72	59.20	4,300
Battery shop/maintenance	72	214	55.98	12,000
Oil and solvent storage	74	372	55.98	20,800
Operations/carpeters	75	595	55.98	33,300
Vacant	85	63	55.98	3,500
Inlet structure (in river)	IS	58	139.95[g]	8,100
Blowdown box	BB	58	139.95	8,100
Total				\$511,900

(a) Equivalent to \$10.75/ft^2.
(b) Equivalent to \$6.50/ft^2.
(c) Equivalent to \$5.20/ft^2.
(d) Equivalent to \$7.80/ft^2.
(e) Equivalent to \$8.50/ft^2.
(f) Equivalent to \$7.15/ft^2.
(g) Equivalent to \$13.0/ft^2.

H.6.11 Site Restoration

In addition to the buildings and structures described in the previous sections, there are many other man-made structures that must be removed. These include parking lots, roads, and railroads. All man-made structures will be removed to a depth of 1 meter below grade, back-filled with earth and reseeded with native ground cover. The backfilling is to be 0.85 m with fill dirt and the top 0.15 m with topsoil.

The cost estimate for restoration of the WNP-2 site is given in Table H.13.

Table H.13 Estimated site restoration costs

Material/activity	Amount	Unit	Estimated costs (1993 dollars) Unit cost	Activity cost
Loading, hauling, placing, grading earth fill	37,519[a]	m^3	$26.16[b]	$981,500
Loading, hauling, placing, grading topsoil and seeding	11,329	m^3	39.24[c]	444,500
Total				$1,426,000

(a) Equivalent to 466,300 ft^2.
(b) Equivalent to $25/$yd^3$.
(c) Equivalent to $40/$yd^3$.

H.7 Areas For Potential Cost Reduction

Research into the nature of concrete and steel and their responses to various applications of heat is believed to hold the potential for multi-million dollar savings in non-radioactive demolition of the primary structures.[1,2] This research could assure a backup method if present technology should fail; or it could supplant present technology.

H.8 References

1. J. M. McFarland, "*Demolition of Concrete Structures by Heat - A Preliminary Study*," Sun Val_y Conference, American Nuclear Society, Sun Valley, Idaho. September 1979.

2. J. M. McFarland, "*Demolition of Concrete Structures by Heat - A Preliminary Study II*," Second International Rilem Symposium on Demolition and Reuse of Concrete and Masonry, Japan Building Research Institute, Tokyo, Japan, November 7-11, 1988.

Appendix I

Comments and Responses on Draft BWR Report

Appendix I

Comments and Responses on Draft BWR Reevaluation Report

The NRC expresses its appreciation to all of those who took the time to read the draft report and to provide the many detailed comments on its contents. Those comments have all been carefully reviewed, responses prepared, and changes have been made to the subject report, where appropriate, to improve the quality of the report.

Eight letters were received by the NRC in response to their request for comments on the draft BWR reevaluation study report. Of those 8 letters, 1 requested an extension of time for the review and comment period, which was granted by the NRC, 4 offered some general comments and essentially resubmitted their previous comments on the draft PWR report, and 3 contained specific comments regarding the draft BWR reevaluation report. There was a general concern that the previous comments provided on the draft PWR report had not been considered during the preparation of the draft BWR, and thus their review time had not been beneficially used. That concern was correct, in the sense that the PWR comments were not considered until after the draft BWR report had been completed. However, those comments and the responses to those comments were carefully considered in the preparation of this final BWR reevaluation report. Those persons interested in the comments and responses for the draft PWR reevaluation report are referred to the final PWR reevaluation report, NUREG/CR-5884, Appendix M, where each comment received and its response was presented.

The letters received are listed below. Each letter and its comments has been assigned a number based on the chronological sequence of receipt by NRC and on the sequence of the comments in the letter, e.g., 002-1 is the first comment in the second letter received. Following the listing of commentors are the individual comments and the responses to those comments. When a letter contained no specific comments, no responses were prepared, and the sequence number for that letter is absent from the set of comments and responses.

001 Nuclear Energy Institute (formerly NUMARC); requested an extension of the comment period to permit more thorough review and comment. No comments at that time.

002 TLG Services,Inc.; resubmitted PWR comments that were previously directed to NUREG/CR-5884.

003 State of Illinois Department of Nuclear Safety; expressed concerns about low-level waste disposal costs and future availability of disposal sites and their costs.

004 Nuclear Energy Institute; expressed concern that the reference plant was not typical of the industry, concerns about the decommissioning funding regulatory process and that the process should be reevaluated, and resubmitted their PWR comments that were previously directed to NUREG/CR-5884.

005 PECO Energy Company; expressed concern that post-shutdown operating costs are not being considered as decommissioning costs, and concern about future low-level waste disposal site availability and cost.

006 Commonwealth Edison Company; expressed concern that the study did not include examination of the differences in technical, regulatory, and economic factors due to geographic location, and that non-radioactive demolition costs needed more visibility.

007 The Utility Decommissioning Group (submitted by Winston & Strawn); expressed concern that the use of the report in the regulatory process was not clearly defined, that the demolition costs for clean facilities and costs for spent fuel storage should be clearly identified as for informational purposes only, and resubmitted their PWR comments that were previously directed to NUREG/CR-5884.

008 Virginia Electric and Power Company; expressed concern that the spent fuel pool might be needed longer than suggested in the study, that post-operation spent fuel storage costs are not included in decommissioning costs, and that the current Decommissioning Rule may need significant revision, and resubmitted their PWR comments that were previously directed to NUREG/CR-5884.

RESPONSES TO COMMENTOR 003

003-1 Comment: In the document, the authors state that low-level radioactive waste (LLRW) disposal cost is a significant component of the total decommissioning cost. In preparing this report, the authors did not adequately estimate the cost of LLRW disposal or the restrictions envisioned by some LLRW disposal facility operators. The reference reactor is located in the Northwest Compact which is serviced by the Richland, Washington LLRW disposal facility (operated by US Ecology, Inc.). This facility is a shallow land burial disposal facility. Because of this simplistic disposal technology and the fact that US Ecology's disposal rates are regulated, the cost for LLRW disposal at this facility is relatively low. The authors performed an alternative LLRW disposal cost evaluation using the higher costs from the Barnwell, South Carolina disposal facility. This was to represent what the authors believed to be more representative of the disposal costs for the new LLRW disposal facilities being developed. At this point in time, there are 12 host states for LLRW disposal facilities that plan to operate after 1996. The disposal designs selected by these host states include 1 traditional shallow land burial facility, 1 improved shallow land burial facility, 1 modular concrete canister disposal in earthen trenches facility, 4 engineered disposal in concrete vault facilities, and 5 undecided with a prohibition on shallow land burial. One of the undecided is even considering mined cavity disposal. As can be seen from this list, the majority of the planned new disposal facilities will not be shallow land burial facilities.

Response: The current (1993 \$) costs for LLW disposal at the only two operating commercial LLW disposal sites were utilized in the analyses. In addition, a sensitivity analysis on LLW disposal costs was carried out, over the range of costs from $\$50/ft^3$ to $\$1000/ft^3$, to illustrate the possible range of costs in the future. The impacts of some of the rather physically restrictive facility designs for future facilities on packaging and disposal activities were not evaluated, since the study was directed to look at current conditions. Considering the wide range of possibilities listed by the commentor, a comprehensive analysis of D&D costs that included the impacts of increased segmentation and specialized packaging containers for each of those possibilities would be a whole new study in its own right.

003-2 Comment: The LLRW disposal costs projected for the new Illinois disposal facility would exceed those estimated Barnwell costs by at least 50 percent. If LLRW disposal volumes decrease further than they have in recent years, those disposal prices would increase even more. Given that the LLRW disposal cost, is such a large percentage of the overall decommissioning cost, the total decommissioning costs presented for the reference reactor should be considered to be the lower end of potential decommissioning costs and not realistic for the likely case.

Response: The current sensitivity analyses encompass the projected Illinois facility disposal rates. Raising disposal rates tends to drive users toward more and more volume reduction efforts. Thus, some disposal sites may price themselves out of business eventually, forcing some combination of several waste compacts into a single compact whose disposal facility will have sufficient volume to remain economically viable without excessive rates.

003-3 Comment: A second issue related to LLRW disposal that the authors did not consider was the LLRW acceptance criteria. These criteria will place restrictions on the LLRW that will be accepted at the disposal facility. The shallow land burial facilities did not have disposal package size restrictions or surface dose rate limits. This allowed the disposal of intact steam generators and other large components and packages with high surface dose rates (sometimes exceeding 30,000 R/hr).

Chem-Nuclear Systems, Inc. (CNSI) has been selected to develop new LLRW disposal facilities in Illinois, North Carolina and Pennsylvania. Their proposed designs require that all LLRW accepted for disposal fit into a concrete overpack and have surface dose rates that do not exceed 500 R/hr. The cylindrical overpacks have an interior dimension of 83 inches in diameter and 88 inches in height. The rectangular overpacks have interior dimensions of 77 inches in width, 99 inches in length, and 110 inches in height. These overpacks will obviously not accommodate an intact steam generator. Large components will require disassembly so they will fit into a standard overpack. This was not considered by the authors and will add cost to the decommissioning effort.

Also, some of the waste packages identified in the NUREG had projected surface dose rates greater than 500 R/hr. These items would need to be repackaged or have internal shielding to reduce the surface dose rate below the acceptable limit.

Since these restrictions were proposed by CNSI as part of their license application, the restrictions would be part of the license issued to CNSI. If CNSI wanted to change these criteria, they would need to file for a license amendment. CNSI would probably consider this if the amendment would not result in the facility failing to meet the regulatory requirements and the waste generator would pay for the license amendment.

Response: These analyses are based on current disposal facility capabilities and limitations. At some point in time, LLW disposal facility operators will have to take a hard look at the necessity for these additional restrictions on waste characteristics, to see if the reduced risk to public health and safety is sufficient to justify the additional cost arising from meeting these restriction.

RESPONSES TO COMMENTOR 004

004-1 Comment: After careful review of the BWR draft study, we have determined that generic concerns identified during the PWR reevaluation review process were not incorporated into the BWR draft study. The following summarizes our concerns with draft NUREG/CR-5884 that also apply to NUREG/CR-6174: the reference plant is not typical for PWR [or BWR] decommissioning cost estimates. The report fails to adequately include many variables that can significantly affect cost estimates, such as: different plant characteristics, site location, site size, internal size of containment, constraints to cutting, removing and packaging large components, work sequences, location of spent fuel pool, site radiological characterization, plant operating experience, decommissioning project schedule, an sufficient staff to complete the decommissioning project. These factors should be included in the reevaluation report because they can account for differences of tens of millions of dollars in the estimates of decommissioning costs of similarly sized nuclear power reactors. The PWR and BWR cost reevaluations must be revised to incorporate those factors necessary to achieve proper cost consideration.

Response: The analyses in the BWR Reevaluation report were tailored to the reference BWR, i.e., WNP-2, and represent the conditions at that facility reasonably well. Every reactor site is somewhat different from every other site; there is no 'typical' reactor plant that would represent all reactor plants adequately. The Cost Estimating Computer Code (CECP) developed to facilitate these types of analyses is very flexible and can accommodate site-specific conditions if properly input to the program. Thus, a plant owner wishing to use the NUREG/CR-6174 estimate methodology can readily do so and obtain an estimate that includes consideration of their specific site conditions.

004-2 Comment: Given that the BWR reevaluation study was issued about a year after the PWR study, sufficient time to permit inclusion of the generic recommendations received on the PWR reevaluation study, the industry is very much dismayed that this was not done. Valuable NRC, industry and public resources were not effectively utilized.

Response: Given the schedule pressures to complete the draft BWR reevaluation report for comment, the contractor was directed to not review the PWR comments until the draft BWR report was completed. The PWR comments and responses were carefully considered in the preparation of this final BWR reevaluation report. The largest changes were the incorporation of additional inventories of piping hangers and electrical equipment into the plant inventories. The editorial comments on the draft PWR report were also applied to the BWR final report, to improve clarity and correct any misstatements. Thus, while it would have been desirable to have utilized the draft PWR comments to improve the draft BWR report, the efforts expended to produce the comments on the draft PWR were very valuable and useful in the production of the final BWR reevaluation report.

004-3 Comment: The industry strongly believes, as stated in the PWR comments, that the entire decommissioning funding regulatory process should be reevaluated. The current rule has demonstrated that substantial difficulties are associated with implementation of this rule. The principal difficulties are: the rule inaccurately reflects the minimum cost estimate for assuring appropriate funds to achieve license termination; it lacks appropriate flexibility to accommodate the variability in decommissioning cost that specific experience has demonstrated; the rule inappropriately requires the total fund be accumulated at cessation of operation instead of by the time they are needed to pay for decommissioning activities; and fails to properly locate detailed recurring features in regulatory guidance, instead in the rule. The industry believes that these generic regulatory concerns are valuable input to the NRC 's reevaluation of 10 CFR 50.75(c) decommissioning funding requirements.

Response: The NRC will take this suggestion under consideration.

004-4 Comment: The industry continues to strongly agree that NRC regulations should not include the removal or disposal of non-radioactive materials and structures as part of the NRC regulated decommissioning process. Funding for activities beyond the site cleanup criteria are outside the NRC's responsibility. The NRC should also continue to recognize the propriety of existing funding assurances for nuclear spent fuel. The Nuclear Waste Policy Act mandates a trust fund for disposal of spent fuel which nuclear utilities continue to fund.

Response: Thank you for the comment.

004-5 Comment: In summary, NEI strongly recommends that the NRC review the public comments provided for the PWR study and incorporate them into the PWR and BWR cost reevaluation estimates so that the documents can support a valid comprehensive review of decommissioning costs. In reevaluating funding requirements, NRC should give careful consideration to valid cost estimates, the use of valid reference plants to draw broadly applied conclusions, real experience with fund collections and use, and requirements associated with state financial regulatory oversight. We recommend that a decommissioning funding workshop be held to discuss in open dialogue appropriate NRC regulatory funding requirements to assure sufficient funds are available to decommission the facility in a manner that protects public health and safety.

Response: Thank you for the comment.

RESPONSES TO COMMENTOR 005

005-1 Comment: The draft NUREG assumes that the Department of Energy (DOE) begins accepting Spent Nuclear Fuel (SNF) in 1998, and that the reference BWR will begin shipping its SNF in the year 2011, in accordance with DOE's current acceptance queue for SNF. These assumptions are the most significant ones in the draft NUREG, and any changes to these assumptions, e.g., in delays in DOE's schedules, can have significant impacts on utilities' future costs for maintaining shutdown plants until all SNF is removed and then completing decommissioning activities. The analyses show that continued plant operation in the shutdown condition for this reference BWR would continue for nine (9) years until the year 2033 in order to remove all the SNF from the site. Because of a finite SNF acceptance rate by DOE and because of the large backlog in SNF in utilities' spent fuel pools, the analyses show that other BWRs will remain in the shutdown condition for periods ranging from 5 to 26 years until all SNF is removed from each of their sites. The operating cost, while in the shutdown condition for this reference BWR, is estimated to be 7 million dollars per year until the SNF inventory is reduced to zero. BWRs that will operate for longer periods of time in the shutdown condition, that is, up to 26 years, will incur significant costs. These shutdown operating costs may be driven higher if the is any delay in DOE's overall acceptance plan for SNF. Also, any premature decommissionings of nuclear power plants due to economics could adversely affect DOE's acceptance queue.

Response: The analyses presented in NUREG/CR-6174 were focussed specifically on the situation that would exist at WNP-2 at the end of its operating lifetime. The situation at any given plant may be quite different and could dictate a different decommissioning strategy. It was not feasible to explore all of the possible permutations and combinations as regards to DOE acceptance of spent fuel from utilities and the effect these have on decommissioning costs. Annual operating costs at a spent fuel pool are significantly more expensive than at a dry passive spent fuel storage facility. However, the capital cost associated with establishing a dry facility are not trivial, and for some years after shutdown it will be less expensive to operate the pool than to establish a dry facility. For extended storage periods, there will be a cross-over point where a dry storage facility (including the initial capital cost) becomes less expensive than continuing to operate the pool. All of these types of analyses are very site-specific.

005-2 Comment: Disposal of the low-level radwaste at this reference BWR is assumed to be at Hanford, i.e., local, and at 1993 actual costs. Shipping the radwaste to Barnwell for disposal would be as much as 147 million dollars more. For most BWRs that will undergo future decommissioning, disposal of radwaste won't be local. Also a base disposal cost of under 50 dollars per cubic foot is unlikely in the future and appears to be escalating at a much faster rate than general inflation. A disposal rate of 300 dollars per cubic foot will increase the total decommissioning cost by an additional 140 million dollars. At 500 dollars per cubic foot, the additional cost would be about 300 million dollars.

The present uncertainty about DOE meeting its obligation of accepting SNF, the additional cost to ship low-level radwaste to a more remote disposal facility, the likelihood that future disposal costs will be much higher than 50 dollars per cubic foot, and the large cost associated with operating a shutdown plant, which is not currently included in the decommissioning cost estimates, are factors that can greatly affect the funds needed to maintain a shutdown nuclear power plant until all SNF is removed and decommission it. The NUREG should provide more discussion and analysis on the likely range of these total costs.

Response: The report contains a sensitivity analysis on LLW disposal rate charges, over the range of $\$50/ft^3$ to $\$1000/ft^3$, and a sensitivity analysis on the effect of longer transport distances on decommissioning costs. Thus, these concerns are covered in the report, at least to first order. For individual plants, using the Cost Estimating Computer Program (CECP) that was developed to generate D&D cost estimates with site-specific transport distances and disposal facility-specific disposal rates will allow a wide range of possibilities to be evaluated.

RESPONSES TO COMMENTOR 006

006-1 Comment: ComEd supports the Nuclear Energy Institute (NEI) responses to both BWR draft NUREGs. ComEd with six PWR and six BWR units firmly believes that the methodology for both the BWRs and PWRs for determining decommissioning funding is so closely interrelated that the approach must be as common to both as possible with only site specific and/or regional issues requiring additional attention. It is for this reason that the industry, including ComEd, found it somewhat difficult to effectively review and provide realistic comments on both BWR NUREGs since the industry comments provided to the NRC on the PWR NUREGs in February, 1994 were not incorporated into the BWR drafts. As you are well aware, there are many generic issues which are similar to both reactor and overall plant designs. The approach to determine adequate decommissioning funding should therefore also be consistent.

Response: Please see the response to Comment 004-2. For responses to the comments on the draft PWR reevaluation report, see Appendix M of the final PWR reevaluation report.

006-2 Comment: ComEd has played an integral role in industry discussions on decommissioning and been an active participant on the NEI Decommissioning Issues Task Force. We believe we have provided "value-added" input on all decommissioning issues including the present generic issues on High Level and Low Level Waste. As a result, ComEd would like to emphasize two areas affecting cost estimate methodology and decommissioning funding. First, there is a need for the PWR and BWR NUREGs to incorporate the technical, regulatory, and economic differences between regions, for example, waste disposal costs and labor costs when determining cost estimates that ultimately impact decommissioning funding. Waste disposal costs alone have shown a large variation in cost from region to region. Second, although not required by NRC's regulations in determining the minimum funding requirements, non-radiological or demolition costs are a major contributor to the total decommissioning cost. ComEd agrees with the Commission that this area falls under the jurisdiction of the States. However, we also believe that this significant cost contribution should become more visible to the public through the enhanced process of NRC regulations, in this case, revised NUREGs. This approach would better serve the public in understanding the constituent elements of decommissioning funding and the need to adjust these costs on a periodic basis.

Response: First point; the study was focussed on a reference plant, WNP-2, and utilized those costs factors appropriate for that plant. Performing a study that included an analysis of all the permutations and combinations of the technical , regulatory, and economic factors that may differ among various plant locations would be a massive task, better evaluated individually by the individual plant owners for their set of conditions. The Cost Estimating Computer Program (CECP) used in the reference PWR and BWR reevaluation studies can easily be used by the individual plant owners who can input those parameters peculiar to their location and obtain an estimate tailored for their plant.

Second point; the study includes an estimate of the cost of demolishing all of the clean and decontaminated structures on the reference site. That estimate is developed in Appendix H, a paragraph is devoted to demolition costs in the executive summary, and the presence of that information is also indicated in the abstract. This material is provided for informational purposes only, since demolition of the clean and decontaminated structures at the plant are outside the scope of NRC responsibilities. It is agreed that the demolition/restoration costs are a significant cost item, and that there has been a long-term lack of understanding by the public and others regarding what activities are included or excluded from the amount of funding required by NRC to be placed into the decommissioning fund.

006-3 Comment: In conclusion, Commonwealth Edison appreciates the opportunity to provide comments on the BWR draft NUREGs on decommissioning cost methodology. It is important that we, in the nuclear industry, totally understand the basis behind developing these cost estimates so we can better serve the public who are the ultimate payees. To that end it is imperative that this methodology be clearly defined and as consistent as possible between PWR and BWR plants so that the public understands the basis for these costs.

Response: Every effort was made in the preparation of these reports to clearly delineate which costs were considered for decommissioning purposes and which costs were outside the scope of NRC's responsibilities. Some of the misunderstandings regarding NRC and industry estimates could be reduced if the industry estimates were more specific about whether or not their estimates included such activities as post-shutdown spent fuel management, structures demolition and site restoration, which are considered not part of decommissioning funding requirements.

The same methodology (the CECP) was employed in the analyses performed for both the PWR and the BWR reevaluation reports. While there are versions of the program specifically for a PWR and for a BWR, the basic methodology and application is the same for both. However, plant-specific inventories, structures, etc., were used, so that the results were specific to the reference plants (Trojan, WNP-2).

RESPONSES TO COMMENTOR 007

007-1 Comment: The NRC Should Clarify That This Report Is For Informational Purposes Only and Contains Many Items That Are Not Required For Purposes of Compliance With NRC Decommissioning Requirements.

As stated in the Introduction to Draft NUREG/CR-6174, 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.

Draft NUREG/CR-6174 at 1.1. The NRC acknowledges in the Foreword to this report that it is provided for informational purposes and does not require licensee action. Draft NUREG/CR-6174 at xxix. However, this statement is somewhat contradictory to the stated purpose of using this report to evaluate licensee cost estimates, or other licensee submittals. Thus, to the extent the report is in any fashion to be used to judge the adequacy of licensees' compliance with the NRC's decommissioning rule, that purpose -- and the limitations of the report -- should be clearly defined. Therefore, in order to ensure that the regulatory significance of this study is not overstated, we suggest that the following paragraph be inserted in the Foreword to NUREG/CR-6174 or at the end of Section 1.0 of the Introduction to more explicitly state the informational, non-binding nature of this report:

"This report is provided for information only, and is not a substitute for NRC regulations. Licensees are not required to comply with the approaches and/or methods described in this report. Many items discussed herein do not relate to the NRC's decommissioning requirements (e.g., non-radiological demolition costs). Moreover, several items discussed in this report are subject to site-specific variations (e.q., LLW disposal costs). Licensees may refer to this study as one example of an acceptable methodology for estimating costs to the extent associated with the decommissioning funding obligations imposed by the NRC; other approaches may be equally acceptable."

An explicit disclaimer such as this is necessary to minimize the possibility that the approaches, methods and amounts detailed in this report would be viewed by the NRC Staff or other regulatory bodies as prescriptive, and thus imposed as de facto regulatory standards or requirements.

Response: The NRC is using the PNL studies to assess current information for estimating the cost of decommissioning of large reactors. The NRC plans to use this information for assessing if there is any need to change the financial assurance requirements as are specified in 10 CFR Part 50.75.

Efforts were made in several places to make it clear that the report is for informational purposes only, and that the material contained has no compliance implications. The statement "NUREG/CR-6174 is not a substitute for NRC regulations, and compliance is not required. The approaches and/or methods described in this NUREG/CR report are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein" is included in the disclaimer on the inside of the front cover, and is repeated again in the Foreword to the report.

007-2 Comment: The NRC Should Clarify Its Intended Use of NUREG/CR-6174

As we explained in our comments on Draft NUREG/CR-5884, the NRC should clarify how the revised PNL study will be used and should consider whether the intended uses are appropriate. Draft NUREG/CR-6174 states that the study, "provide[s] 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)." Draft NUREG/CR-6174 at xv. We believe the NRC should clarify the use intended for this study in general, and should pay particular attention to the specific issues discussed below.

Comment: a. The NRC Should Identify the Licensee Submittals That Will Be Reviewed Using the Information In This Report

It is unclear what "licensee submittals" the NRC intends to review using the updated PNL studies. As we explained with reference to the PWR study, licensees of operating plants have already submitted certification letters in accordance with 10 C.F.R. §§ 50.33(k) and 50.75(b). No further licensee submittals would be necessary until the preliminary decommissioning plan and spent-fuel management plan are submitted approximately five years prior to the end of plant operation (10 C.F.R. §§ 50.75(f), 50.54(bb)). In fact, while site-specific decommissioning cost estimates must be submitted at that time, it is not clear that it would be appropriate to use the cost estimates for the reference reactors from the updated PNL studies to serve as definitive criteria by which to judge site-specific estimates.

Response: The NRC is using the PNL studies to assess current information for estimating the cost of decommissioning of large reactors. The NRC plans to use this information for assessing if there is any need to change the financial assurance requirements as are specified in 10 CFR Part 50.75.

Comment: b. When Deciding Whether To Revise the Certification Amounts Required Under 10 C.F.R § 50.75, the NRC Should Reiterate the Distinction Between a Cost Estimate and a Certification Amount

As the Commission explained in the Statement of Considerations accompanying the 1988 decommissioning rule: "the amount listed [in the regulation] as the prescribed [certification] amount does not represent the actual cost of decommissioning for specific reactors but rather is a reference level established to assure that licensees demonstrate adequate financial responsibility . . . thus providing adequate assurance . . . that the facility would not become a risk to public health and safety when it is decommissioned." (53 Fed. Reg. 24,018, 24,030 (1988)).

While the PNL study may provide a more current prediction of decommissioning costs, differences between the old and new estimates do not necessarily implicate the validity of the existing certification amounts for providing adequate assurance of licensees' financial responsibility for decommissioning. As explained by the Commission, the certification approach is only the "first step" in providing reasonable assurance of availability of funds for decommissioning. The second step occurs five years prior to end-of-life, when licensees must submit a site-specific estimate of the cost of decommissioning. 53 Fed. Reg. at 24,030-31. The Commission determined that "[m]ore detailed consideration by NRC early in life beyond the certification is not considered necessary because of the [two-step process] discussed above."(53 Fed. Reg. at 24,031).

In view of the general "reference level" purpose of the certification amounts, as explained above, the revised PNL cost estimate does not necessarily implicate the certification amounts in 10 C.F.R. Part 50.75 themselves. However, other factors, such as potentially significant site-specific variations in elements of the cost estimate may suggest that the NRC consider means for accommodating those variations. Accordingly, we urge the Commission to be clear, both in the publication of this report, and in any subsequent rulemaking, as to the respective purposes of these reports and the certification amounts.

Response: The NRC is using the PNL studies to assess current information for estimating the cost of decommissioning of large reactors. The NRC plans to use this information for assessing if there is any need to change the financial assurance requirements as are specified in 10 CFR Part 50.75.

Comment: c. The NRC Should Explain That the Non-Radioactive Demolition Cost Estimates Are Provided For Informational Purposes Only

Both draft NUREG/CR-6174, and a recently published supplement to draft NUREG/CR-5884, contain specific cost estimates for the demolition of decontaminated structures and restoration of a site to a natural state. These estimates apparently have been included at the request of the Commission. See Staff Requirements Memorandum ("SRM"), dated July 14, 1993, at 1. Although the studies acknowledge that these estimates have been included for the sake of "completeness" and that the cost estimate figures do not include the costs of restoring the site to a "green field," we believe that the NRC should better explain the purpose of including this information in the study, and whether it intends to use these figures within the current regulatory scheme.

Under the current decommissioning rule, the NRC should have no use for these figures. The decommissioning rule explicitly states that the certification amounts "are based on the definition of 'Decommission' in § 50.2 ... and do not include the cost of removal and disposal of spent fuel or of nonradioactive structures and materials beyond that necessary to terminate the license." 10 C.F.R. § 50.75(c),n.1. Since the certification amount is based on the NRC's definition of "decommission", any contemplated revision of the certification amount to include funding for removal of non-radiologically contaminated structures or materials, including the restoration to a "green field," would require a complete revision of the current regulatory framework for decommissioning and formal notice and opportunity to comment as required by the Administrative Procedure Act. More importantly, the NRC's jurisdiction under the Atomic Energy Act over decommissioning activities beyond those already described in the current definition of decommissioning is doubtful at best.

Response: It is clearly stated at the end of the abstract, at the end of the executive summary, and in the introduction to Appendix H that demolition and site restoration are outside the scope of the NRC's authority, and that the information on estimated costs for demolition and site restoration are included for informational purposes only.

Comment: d. Estimates of Spent Fuel Storage-Related Costs Should Be Provided For Informational Purposes Only

The study treats as decommissioning costs 10% of costs incurred during the five year post-shutdown spent-fuel-cooling period and allocates the remaining 90% of these costs to operations. Draft NUREG/CR-6174 at 2.3, 3.14. This allocation of costs is inconsistent with the current regulatory scheme governing decommissioning. The NRC's current definition of decommissioning activities specifically excludes the removal and disposal of spent fuel, which are considered operational activities. 53 Fed. Reg. at 24,019, 24,031. Furthermore, in the NRC's separately published summary, analysis and response to comments on the decommissioning rule, the NRC explicitly stated that "the storage of spent fuel at a reactor is outside the scope of this rule." NUREG-1221, "Summary, Analysis, and Response to Public Comments on Proposed Amendments to 10 CFR Parts 30, 40, 50, 51, 70, and 72," p. B-3 (1988). Finally, the NRC requires licensees to submit a separate spent fuel management and funding plan covering spent-fuel storage-related operations during the period following shutdown and prior to transfer of title and possession to the Department of Energy for disposal in a repository. 10 C.F.R § 50.54(bb).

The NRC needs to recognize that unless and until it modifies the decommissioning regulations, the suggested allocation of spent fuel storage-related costs is irrelevant to satisfaction of NRC decommissioning requirements. We note that this matter is being explored as part of the NRC's ongoing assessment of whether spent fuel storage and disposal costs should be included in decommissioning costs. See 59 Fed. Reg. 10,267, 10,268 (1994). Until such time as this topic is properly addressed in the regulatory context, the NRC should acknowledge that the discussion in the study is irrelevant to current NRC decommissioning requirements.

Response: The 10% allocation of spent fuel pool operation costs to safe storage activities during the short storage period was intended to recognize that the owner will not have two separate groups of staff on site, one group to operate the pool and the other group to do the periodic inspections, etc., associated with safe storage, but will have one group of staff who primarily operate and maintain the pool and carry out the safe storage inspections on a part-time basis. This allocation approach was not intended to imply that the spent fuel storage fund was paying for the safe storage decommissioning activities.

Comment: e. The NRC Should Recognize the Uncertainty Associated With Disposal of Low-level Waste

The study recognizes low-level waste ("LLW") disposal costs as one of the key contributors to decommissioning costs. Draft NUREG/CR-6174 at xx. The LLW in question, of course, is that resulting from decommissioning as that term is defined in NRC regulations. The study evaluates the effect on LLW disposal costs of distance to a disposal facility and increases in disposal rates. Draft NUREG/CR-6174 at xx-xxii, 3.53-3.57. However, the study does not address issues related to the timing and availability of LLW disposal facilities. The NRC should clarify that uncertainties associated with decommissioning LLW will be addressed in any subsequent review or evaluation of the decommissioning rule.

Response: The NRC will take this suggestion under consideration.

007-3 Comment: Incorporation By Reference of Our Earlier Comments on Draft NUREG/CR-5884.

The comments we submitted regarding the updated PWR cost estimate study in Draft NUREG/CR-5884 are equally applicable to the BWR cost estimates in Draft NUREG/CR-6174. To the extent those comments are not included in our analysis above, we hereby adopt and incorporate by reference the remaining comments applicable to Draft NUREG/CR-6174. For ease of reference, those comments are summarized briefly below.

Comment: • The NRC should clarify whether "pre-shutdown planning/engineering and regulatory reviews" are considered part of decommissioning, and whether licensees will be able to undertake such activities, and withdraw decommissioning funds to support such activities, without prior NRC review or

Response: The NRC has issued a proposed rule entitled "Decommissioning of Nuclear Power Reactors" in 60 FR 37374, July 20, 1995. This proposed rule discusses the use of moneys from the decommissioning fund for decommissioning activities prior to permanent shutdown.

Comment: • The NRC should articulate the bases for redefining the phases of the decommissioning alternatives and the resultant artificial separation and rigid sequencing of the various phases of each alternative.

Response: The bases for redefining the phases of decommissioning are current conditions in the industry, recognizing that prompt removal of all spent fuel from the reactor spent fuel pool following shutdown is not viable under today's regulations governing spent fuel shipment and dry storage. The alleged 'artificial separation and rigid sequencing of the various phases of each alternative' are simply rational ways to identify time periods whose activities are significantly different. The particular sequencing selected for these studies was that which made sense for the conditions postulated for the analysis. If different scenarios are devised that are more appropriate for a given plant, then those are the ones that should be evaluated for that plant. There is no implication intended from these analyses that these are the only set and sequence of activities that might be appropriate for decommissioning a large power reactor plant.

Comment: • The assumption that spent fuel must be cooled for a period of five years appears to be overly conservative and misinterprets the standard DOE contract for spent fuel disposal in 10 CFR Part 961, App. E.

Response: Please see the extensive responses on this topic to Comment 008-4c in Appendix M of the final report for the PWR reevaluation study, NUREG/CR-5884.

RESPONSES TO COMMENTOR 008

008-1 Comment: Dry Transfer System for Spent Nuclear Fuel - The study assumes that an acceptable dry transfer system will be available to remove spent nuclear fuel from the dry storage facility and place it into licensed transport casks when the time comes for the Department of Energy (DOE) to accept the spent nuclear fuel for disposal. We agree that this will be applicable to MPC technology when it becomes commercially available. However, we believe that it is not applicable to the storage containers in use today. This assumption seems non-conservative relative to establishing a schedule for decommissioning activities and also for estimating costs. Without a dry transfer system available, the fuel pool will be needed longer, the transfer will be more complex, and the costs will be higher.

Response: For these analyses, the assumption was made that the dry storage system deployed at the site would be compatible with a dry transfer system. The exact dates of the design and capabilities of the Dry Transfer system are not well defined at present. For those utilities that already have spent fuel stored on-site in conventional storage casks because their pools are nearly full, the pools would have to remain in service until the fuel in the pool has been accepted into the federal spent fuel disposal system, and the relatively short additional period of pool operation needed to unload the existing storage casks would be fairly small. Otherwise, the utility would have to make a significant investment in additional dry storage units in order to empty the pool earlier. The choice would most likely be made on which approach would be the least costly over the time period involved.

008-2 Comment: Dry Fuel Storage Operation Beyond Part 50 License Termination - The study considers these costs as operations costs. We disagree. These costs should not be viewed in the narrow context of the termination date of the Part 50 license. We are concerned that it may be difficult to recover these expenses if they are not already included as part of the decommissioning trust collections. We agree that the ISFSI is operating. However, there is no operational electrical generation taking place on site. These activities are not discretionary. They are required to be performed in order to terminate the Part 50 and Part 72 licenses.

Response: The current NRC policy is that post-shutdown spent fuel storage costs are not considered decommissioning costs but are covered under 10 CFR § 50.54(bb).

008-3 Comment: Emptying the Spent Fuel Pool - The study assumes that the spent nuclear fuel is removed from the pool as early as possible and placed into a dry storage facility onsite to facilitate the earliest possible decontamination and dismantlement of the reactor facility. This assumption seems overly optimistic. If the utility has to provide the storage containers, then this would probably not be the low cost option. If the DOE is relied on to provide the storage containers, it seems overly optimistic to presume that the DOE would provide the storage containers before they would be needed for shipment to the DOE. They would probably not be willing to provide the containers "early" just for storage.

Response: The choice of path for spent fuel storage will always be made on the anticipated economics of the situation. The scenario guidance for DECON was to accomplish the Part 50 license termination as quickly as reasonable, and this goal required emptying the pool as early as possible. There is always a cost trade-off between continuing pool operation and procuring dry cask storage capability and operating the associated ISFSI. The 'right' answer will be site-specific.

Comment: Financial Assurance - One of the stated purposes of the study is to reassess the basis for the minimum funding amounts required in 10 CFR Part 50 for financial assurance. However, the report's conclusions are silent on the results of this reassessment. We have a major concern regarding how the NRC may use the results of this study to modify the rule. It would have been helpful if the study report would have commented on this.

Response: The NRC is using the PNL study to assess current information for estimating the cost of decommissioning of large reactors. The NRC plans to use this information for assessing if there is any need to change the financial assurance requirements as are specified in 10 CFR Part 50.75.

Comment: Are Revisions to the Decommissioning Regulations Warranted? - We do have one specific comment regarding 10 CFR 50.75(c). This paragraph of the regulation provides the formula and methodology for calculating the periodic adjustment of the minimum required amount for financial assurance. Because of the current situation regarding low-level waste disposal, the formula and methodology utilized by the regulation seem to be inappropriate and in need of change. Merely moving this material from the rule to a Regulatory Guide, and/or merely revising the minimum required amounts in the rule will not remedy the situation. A more fundamental change seems to be needed.

Response: The NRC is in the process of evaluating the need to amend the regulation.

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10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

With the issuance of the Decommissioning Rule in 1988, nuclear power plant licensees are required to submit to the U.S. Nuclear Regulatory Commission (NRC) decommissioning cost estimates for review. 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 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 NRC consideration 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 at different low-level radioactive waste disposal sites, and to different depths of contaminated concrete surface removed, is also examined.

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