NUREG/CR-5884
PNL-8742
Vol. 1

Revised Analyses of Decommissioning for the Reference Pressurized 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

Prepared by
G. J. Konzek, R. I. Smith, M. C. Bierschbach, P. N. McDuffie

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW., Lower Level, Washington, DC 20555-0001
2. The Superintendent of Documents, U.S. Government Printing Office, P. O. Box 37082, Washington, DC 20402-9328
3. The National Technical Information Service, Springfield, VA 22161-0002

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC bulletins, circulars, information notices, inspection and investigation notices; licensee event reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the Government Printing Office: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, international agreement reports, grantee reports, and NRC booklets and brochures. Also available are regulatory guides, NRC regulations in the *Code of Federal Regulations,* and *Nuclear Regulatory Commission Issuances.*

Documents available from the National Technical Information Service include NUREG-series reports and technical reports prepared by other Federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions. *Federal Register* notices, Federal and State legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Administration, Distribution and Mail Services Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, Two White Flint North, 11545 Rockville Pike, Rockville, MD 20852-2738, for use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018-3308.

DISCLAIMER NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results of such use, of any information, apparatus, product, or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NUREG/CR-5884
PNL-8742
Vol. 1

Revised Analyses of Decommissioning for the Reference Pressurized 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

Manuscript Completed: June 1995
Date Published: November 1995

Prepared by
G. J. Konzek, R. I. Smith, M. C. Bierschbach, P. N. McDuffie

Pacific Northwest Laboratory
Richland, WA 99352

G. J. Mencinsky, NRC Project Manager

Prepared for
Division of Regulatory Application
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code B2902

DISCLAIMER

NUREG/CR-5884 is not a substitute for NRC regulations, and compliance is not required. The approaches and/or methods described in this NUREG/CR are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

PACIFIC NORTHWEST LABORATORY

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

Abstract

With the issuance of the final Decommissioning Rule (July 27, 1988), owners and operators of licensed nuclear power plants are required to prepare, and submit to the U.S. Nuclear Regulatory Commission (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 provide some of the needed bases documentation.

This report contains the results of a review and reevaluation of the 1978 PNL decommissioning study of the Trojan nuclear power plant (NUREG/CR-0130), including all identifiable factors and cost assumptions which contribute significantly to the total cost of decommissioning the nuclear power 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 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, and to different depths of contaminated concrete surface removal within the facilities is also examined.

Report Contents Outline

Volume 1 (Main Report)

Volume 2 (Appendices)

Contents

Figures

Tables

Executive Summary

In the 1976–1980 time frame, two studies were carried out for the U.S. Nuclear Regulatory Commission (NRC) by the Pacific Northwest 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 (53FR 24018), owners and/or operators of licensed nuclear power plants are required to prepare and submit plans and cost estimates for decommissioning their facilities to the U.S. Nuclear Regulatory Commission 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 provide current technical bases for the NRC's review of the reasonableness of licensee-submitted decommissioning cost and radiation dose estimates associated with license termination activities for typical pressurized water reactor (PWR) power stations. Included in this reevaluation was an examination of the range of parameters that influence costs and radiation doses. The results will be used to provide part of the bases for potential revisions to the funding certification amounts to be 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 analyses and may not represent the actual situation at any given PWR power station. However, the cost analyses and the computer program developed herein are 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 PWR 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 (~7 years) before the projected high burnup (48,000–60,000 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

- 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.

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: 1) DECON (decontamination/dismantlement as rapidly after reactor shutdown as possible, to achieve termination of the nuclear license); 2) SAFSTOR (a period of safe storage of the stabilized and defueled facility, followed by final decontamination/dismantlement and license termination); and 3) 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 will 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 strong incentives to decontaminate and dismantle the retired reactor facility as promptly as possible, i.e., future availability and cost of LLW disposal, need to reuse or dispose of the site, thus necessitating transfer of the stored SNF from the pool to a dry storage facility on the reactor site which is licensed under 10 CRF 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 the U.S. Department of Energy 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.

- DECON is comprised of four distinct periods of effort: 1) pre-shutdown planning/engineering and regulatory reviews, 2) plant deactivation and preparation for storage (no dismantling activities are conducted during this period that would affect the safe operation of the spent fuel pool), 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 concrete bioshield 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 concrete bioshield 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 costs.

- 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 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 permits 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 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.

  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.

Evaluation of DECON, SAFSTOR, and ENTOMB for the Reference PWR

Each of the decommissioning alternatives described above has been evaluated for the reference PWR (Trojan Nuclear Plant, an 1175-MW(e) 4-loop Westinghouse reactor) in terms of estimated cost, schedule (based on two-shift operations unless otherwise stated), 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 PWR is a single reactor facility, and the assumption that the low-level radioactive wastes are transported from the reference PWR location at Rainier, Oregon, 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 PWR 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 has 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* presently 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: transport and disposal of a set of previously retired steam generators (~$5 million), structures demolition and site restoration activities, which could increase the total decommissioning cost as much as an additional $38 million or more (see Appendix L), 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

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

Shutdown alternative (years)	Estimated cost (millions 1993 $)[a,b] (Constant $)	Estimated cost (millions 1993 $)[a,b] (Present value $)[c]	Waste volume disposal (m^3)	Radiation dose (person-rem)	Post-shutdown (years)
DECON	133.3	108.4	8,246	953.1	8.6
SAFSTOR1[d]	173.9	93.4	833	318.8	60
SAFSTOR2[e]	237.9	103.7	8,246	325.2	60
ENTOMB1[f]	162.1	103.3	913	803.0	60
ENTOMB2[g]	164.6	105.2	1,362	851.9	60
ENTOMB3[h]	470.4	109.8	913	803.0	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 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.

estimated to cost about $4 million per year (in 1993 dollars) and could add another $50 million or more to the cost to decommission. 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 cost-estimating computer program (CECP), which was designed for use on an IBM personal computer or equivalent 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, depth of contaminated concrete surface removed, length of piping segments 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, South Carolina, are compared with the same costs for disposal of LLW in the U.S. Ecology facility at Hanford, Washington, in Table ES.2.

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		
		Hanford	Barnwell	Difference (Barnwell - Hanford)
DECON:	Transport	5.3	13.5	8.2
	Disposal[b]	24.5	110.1	85.6
	Total	29.8	123.6	93.8
SAFSTOR1	Transport	1.7	3.0	1.3
	Disposal	5.8	16.4	10.6
	Total	7.5	19.4	11.9
SAFSTOR2:	Transport	5.3	13.5	8.2
	Disposal[b]	24.1	108.1	84.0
	Total	29.4	121.6	92.2

(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.

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 $94 million greater than for Hanford disposal for DECON, $12 million for SAFSTOR1, and $92 million for SAFSTOR2. 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.

For Hanford disposal, total decommissioning costs for SAFSTOR1 and SAFSTOR2 are higher than DECON costs. For Barnwell disposal, SAFSTOR2 costs are higher than DECON, but SAFSTOR1 costs are lower. The reason for this is simply that the Barnwell transportation and burial charges are significantly higher than for Hanford. A comparison of Barnwell SAFSTOR1 and DECON shows that the costs saved in energy, transportation, and waste burial ($105,126,470, with contingency) more than compensate for the additional costs in labor, materials, taxes, and insurance ($63,872,155, with contingency). For Hanford, however, the costs saved in energy, transportation, and waste burial ($23,766,335, with contingency) do not compensate for the additional labor, materials, taxes and insurance costs ($64,369,405, with contingency).

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 Hanford, using the CECP. The calculations were performed for base disposal rates of $\$50/\text{ft}^3$, $\$100/\text{ft}^3$, $\$300/\text{ft}^3$, $\$500/\text{ft}^3$, and $\$1000/\text{ft}^3$. The associated disposal facility fees, surcharges, and taxes were held constant. All other parameters of the CECP calculation were also held constant. The results of the analysis showed that the total cost for DECON increased almost linearly with increased disposal cost, from $138.72 million for the $\$50/\text{ft}^3$ rate to $506.27 million for the $\$1000/\text{ft}^3$ rate, all values including a 25% contingency. A contingency is 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 fractions of cost attributable to labor and materials (A), energy (B), and LLW disposal (C), and the adjusted DECON cost (total DECON cost minus property taxes and nuclear insurance) employed in the formula for DECON cost escalation, as discussed in Section 3.7, are illustrated in Figure ES.1 as functions of the LLW disposal charge rates.

As the disposal rates increase, the incentive for volume reduction efforts increases, and it is likely that the LLW disposal costs would not increase in direct proportion to the disposal rate increases due to the probable LLW volume reductions. 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 total license termination cost is the amount of contaminated concrete surface removed during facility decontamination. In the original PWR study (NUREG/CR-0130), a very conservative assumption was made that a 2-inch depth of concrete surface was removed from essentially all floors in the three potentially contaminated buildings (Containment, Auxiliary, and Fuel buildings). In this reevaluation study, the base assumption is to remove a 1-inch depth of surface from those areas anticipated to require surface removal, 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

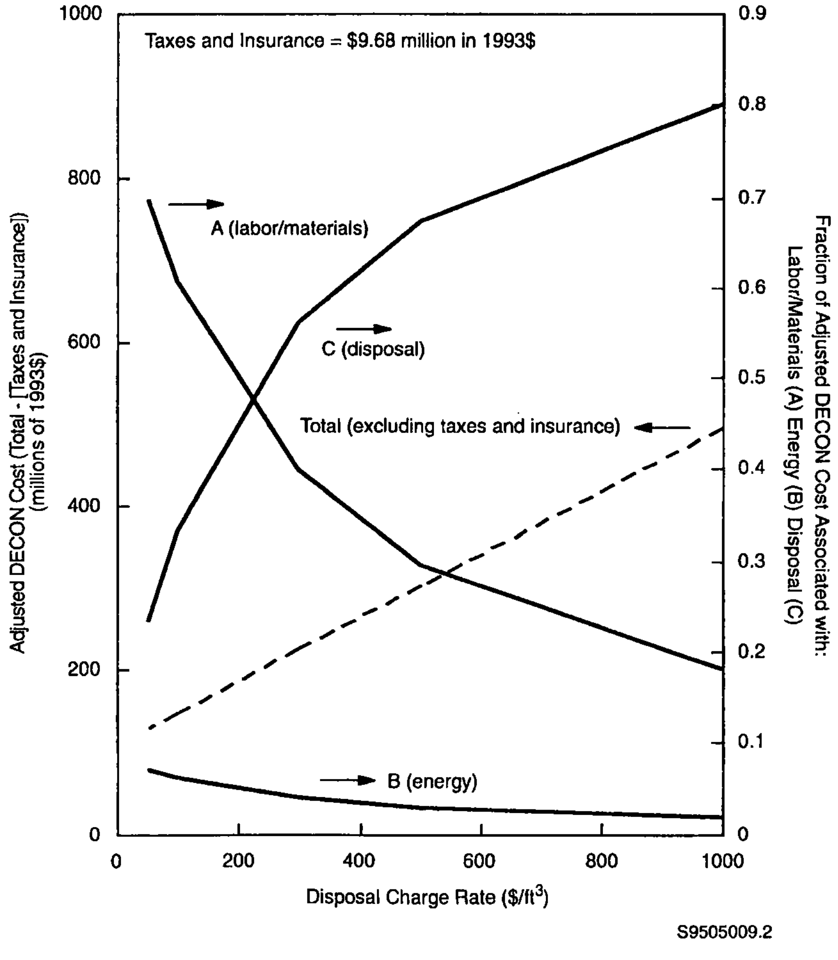


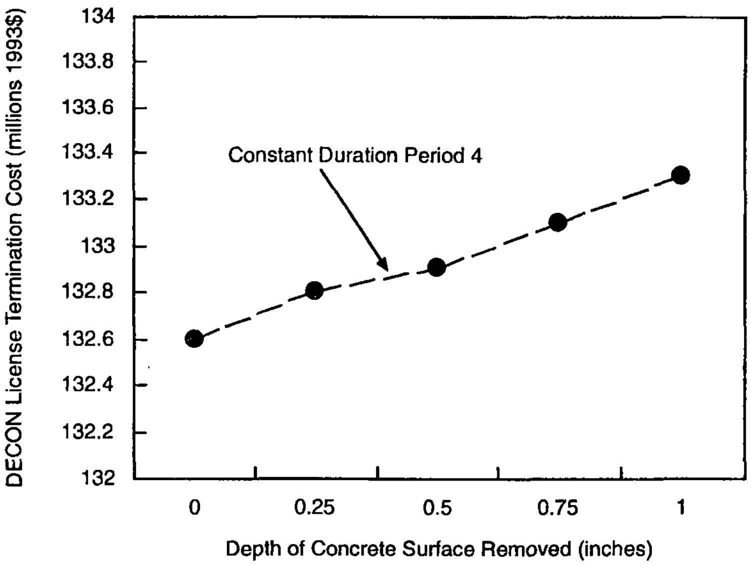
Figure ES.1 Variation of DECON escalation formula terms as functions of low-level waste disposal charge rates

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 total license termination cost is not very sensitive to the depth of concrete removed for the depths examined. For removal depths from 0 in. to 1.0 in., the total DECON cost increases by only $0.67 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. The only parameter changed in the analysis was the length of the cut pipe segments. 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 $3.970 million, including contingency. Because the volume of dry active waste, the amount of laundry used, and the quantity of small tools and equipment used are factored from the direct labor hours, the costs associated with these cost elements also increased, by about $0.903 million. Thus, the increase in the total DECON cost resulting from cutting the piping into 5-ft lengths instead of the 15-ft lengths postulated in the base analysis was about $4.873 million, including contingency.

Associated with the increased number of pipe cutting operations was an increase in the worker radiation dose. Because pipe cutting tends to be performed in higher radiation fields than many other DECON activities, the cumulative radiation dose to workers more than doubled, from 931 person-rem for the base analysis (15-ft pipe lengths) to 1910 person-rem for the sensitivity case (5-ft pipe lengths).



S9505009.3

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 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 in this study, 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 PWR 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: $108.4 million for DECON; $93.4 million for SAFSTOR1 and $103.7 million for SAFSTOR2; and $103.3 million, $105.2 million, and $109.8 million for license termination at 60, 60, and 300 years, for ENTOMB1, ENTOMB2, and ENTOMB3, respectively. The present values of the distributed expenditures (except for ENTOMB3) are illustrated in Figure ES.3.

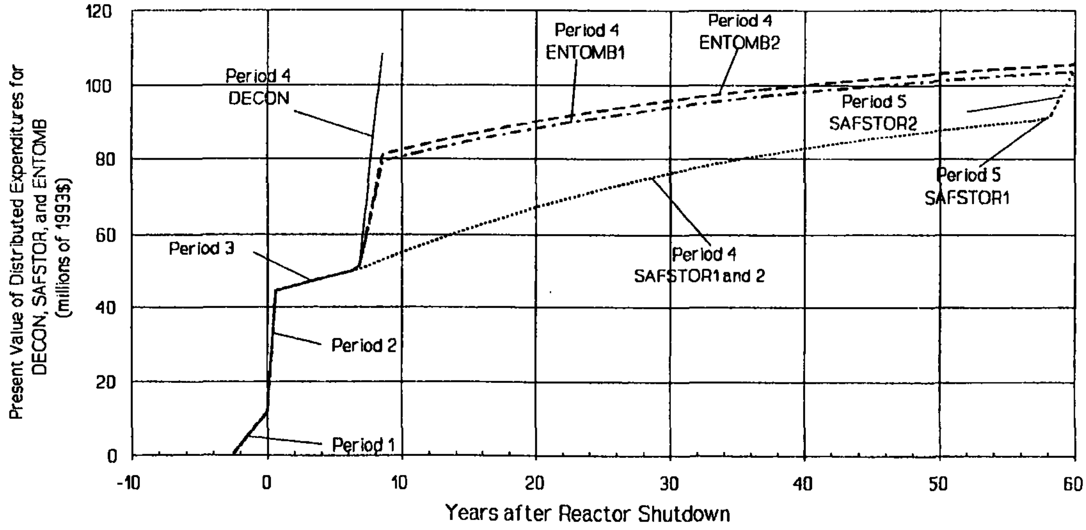


Figure ES.3. Present value of time-distributed expenditures for DECON, SAFSTOR, AND ENTOMB

For the 3% net discount rate postulated for these analyses, the SAFSTOR scenarios have present values that are smaller or are equivalent to DECON. The ENTOMB scenarios have the largest present values and would require the most money in the decommissioning fund. Discount rates greater than the 3% per year assumed in these calculations would favor the delayed dismantlement scenarios even more. Smaller discount rates would reduce the differences and would tend to favor DECON. However, the differences between the present values of the alternatives are rather small, with a span of about $17 million. As a result, the present value cost is not a strong discriminator for selecting a decommissioning alternative.

The costs associated with SNF storage onsite until acceptance into the federal waste management system are also examined using a present-value analysis. The costs for extended pool storage was compared with a 7-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 16 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 spent fuel pool decommissioning actions for at least 5 years following reactor shutdown due to the need to store SNF in the reactor pool for that period of time, and a resulting increase in decommissioning costs accumulated during the short safe storage period while the SNF pool continues to operate.

Review of the constant dollar costs and the present value costs for the three alternatives suggests that while DECON is the least expensive choice in constant dollars, it is more costly than or about equivalent to the SAFSTOR scenarios in present value. ENTOMB is the most expensive choice in both constant dollar cost and present value cost. When present value costs are used for all alternatives, it appears that there is little cost difference between any of the alternatives. Using present value analysis, having about $110 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:	280,934 ft^3, 7,955 m^3 (96.47%)
Class B/C:	9,900 ft^3, 280 m^3 (3.40%)
GTCC:	386 ft^3, 11 m^3 (0.13%)

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 (8,246 m^3) of LLW requiring disposal.

For the SAFSTOR1 scenario, if decay of all radioactive materials (except the reactor pressure vessel and concrete bioshield) to unrestricted release levels is assumed, the SAFSTOR LLW volume is reduced from that of DECON by about a factor of 10, to about 833 m^3. With similar assumptions, the LLW disposal volume for the ENTOMB2 scenario is about 1,363 m^3. The LLW disposal volume for the SAFSTOR2 scenario (8,246 m^3) is equivalent to that of DECON, since all of the originally radioactive materials are assumed to be removed following storage. For ENTOMB1 and ENTOMB3, the reactor pressure vessel and bioshield are assumed to be left in-place until decayed to unrestricted release levels, with resulting LLW volumes for disposal of 913 m^3, as compared with 8,246 m^3 for DECON. 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.

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 pressurized water reactor (PWR) decommissioning study and its addendums used to support the decommissioning regulations. It uses the latest information available on the technology, safety, and cost estimates to decommission a large reference PWR. A companion document reevaluating the same parameters for the reference boiling water reactor (BWR) will be published in the near future. When completed, the two reevaluation reports will provide the NRC with an information database on decommissioning costs for LWRs. Based on the results of the studies and public input, the NRC will determine if amendments to the decommissioning regulations are warranted.

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

Thomas O Martin

Thomas O. Martin, Chief
Regulation Development Branch
Division of Regulatory Applications
Office of Nuclear Regulatory Research

Acknowledgments

The authors gratefully acknowledge the assistance provided by individuals at the Pacific Northwest Laboratory during the course of this study and preparation of the draft report. Dennis R. Haffner provided a technical review of the entire study. Dr. Carl Feldman and George J. Mencinsky of the Nuclear Regulatory Commission provided constructive criticism and guidance throughout the study. The editorial review prior to publication was contributed by David R. Payson, Pacific Northwest Laboratory. Marlene Hale, Erica Brown, Jean Cheyney, Laurie Ann Empey, Margie Hutchings, Joan Slavens, Rose Urbina, Margot White, and Pat Young, all of Pacific Northwest Laboratory, prepared the final manuscript. Finally, those many individuals who contributed information that subsequently led to the completeness of this reevaluation study are greatly appreciated and are specially acknowledged in Appendix A (Volume 2).

1 Introduction

In the 1976–1980 time frame, two studies were carried out for the U.S. Nuclear Regulatory Commission (NRC) by the Pacific Northwest 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 PWR reports were escalated to 1986 dollars in subsequent addenda reports,(3-7) the technical and regulatory bases for the analyses remained as developed in the original studies. Many things have changed since 1980 that have a strong influence on when and how power reactors can best be decontaminated and decommissioned and on how much the effort will cost.

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

The purpose of this study is to provide current bases for evaluation of the reasonableness of decommissioning cost estimates and radiation doses associated with PWR 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.

1.1 Major Factors Considered in this Study

The major factors considered in this re-evaluation of the estimated costs and schedules for license termination at the reference PWR 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 (~7 years) before the projected high burnup (48,000–60,000 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 all of it has been accepted into the federal waste management system. However, this latter choice would delay final decontamination and decommissioning of the reference PWR 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.

---

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

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 L, and are presented for information only. The demolition and restoration costs 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 $4 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 (~ $38 million), and removal of any excess retired steam generators (~ $5 million) could increase the total decommissioning cost significantly, depending upon the situation at the plant location.

1.2 Decommissioning Alternatives

In the original PWR 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 discharge in the pool for up to 7 years (see Appendix D) before transfer of that SNF 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 won't 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 PWR[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 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 PWR 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 PWR location at Rainier, Oregon, to the U.S. Ecology facility on the Hanford Reservation in Washington State for disposal. All costs are given in constant dollars of early 1993, regardless of when the expenditures occur in time.

The sensitivities of license termination costs to: 1) transporting to and disposing of decommissioning wastes at the Chem-Nuclear facility at Barnwell, South Carolina; 2) increased disposal charge rates at a LLW disposal facility; 3) cutting contaminated piping into 5 ft lengths rather than the nominal 15 ft lengths postulated for the basic analysis; and 4) removing varying depths of contaminated concrete surface throughout the plant; 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 information supporting Volume 1 is contained in Volume 2 (Appendices). The supporting information is presented in a manner that facilitates its use for examining decommissioning actions other than those included in this study.

1.4 References

1. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. 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] The Portland General Electric Company's (PGE) Trojan nuclear plant, at Rainier, Oregon, is used as the reference PWR power station for this reevaluation study, just as it was used in the earlier studies. Trojan is an 1175- MW(e) single-reactor power station that utilizes a four-loop pressurized water reactor manufactured by the Westinghouse Electric Corporation in the nuclear steam supply system. Trojan's premature shutdown was announced by PGE on January 4, 1993. The analyses contained in this report assume that the Trojan plant has operated for the full term of its license, in order to be more representative for large PWRs in general.

3. R. I. Smith and L. M. Polentz. 1979. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130 Addendum, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

5. 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-0130, Addendum 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

6. E. S. Murphy. 1984. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Classification of Decommissioning Wastes.* NUREG/CR-0130, Addendum 3, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

7. G. J. Konzek and R. I. Smith. 1988. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule.* NUREG/CR-0130, Addendum 4, 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 pressurized water reactor (PWR) decommissioning studies, NUREG/CR-0130 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 the 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 per day, 5 days per 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-0130 were reviewed and it was concluded that the safety analyses presented in that original PWR 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 PWR 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 7 years in this analysis), 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 cool the SNF in the reactor storage pool until the cladding temperature limits for dry storage 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 (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 3.27)
- 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 3.11).

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 PWR 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-0130(1) for decommissioning the reference PWR power station (Trojan)[1] are used as the point of reference for developing decommissioning costs and occupational radiation exposure in this reevaluation study. For ease of reference, these 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 (Trojan), with no other nuclear facilities on the site at the start of decommissioning; thus, no support from shared facilities is assumed. This is required to meet the NUREG/CR-0130 objectives and the primary basis stated earlier. (Decommissioning a multiple-reactor site may be quite different, as delineated in NUREG/CR-1755.(6, 7))

- Trojan's current operating license expires in CY-2011, 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 Trojan plant is CY-2015. This license end-date used by the EIA assumes that the 40-year licensing period began at the start of commercial operation of the Trojan plant, not at the start of construction.(8) The EIA's shutdown date of CY-2015 is used throughout this study for the purpose of developing decommissioning schedules, even though the plant was permanently shut down in January 1993.

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

- The radiation dose rates used in the analyses remain essentially unchanged from those estimated in the original study, NUREG/CR-0130, 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.

---

[1] The Portland General Electric Company's (PGE) Trojan nuclear plant, at Rainier, Oregon, is used as the reference PWR power station for this reevaluation study, just as it was used in the earlier studies. Trojan is an 1175- MW(e) single-reactor power station that utilizes a four-loop pressurized water reactor manufactured by the Westinghouse Electric Corporation in the nuclear steam supply system. Trojan's premature shutdown was announced by PGE on January 4, 1993. The analyses contained in this report assume that the Trojan plant has operated for the full term of its license, in order to be more representative of large PWRs in general.

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

- The waste disposal costs presented in this study were specifically developed for the reference PWR, 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 PWR 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-0130 were reevaluated, with the results presented in Appendix L. 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 (48,000 to 60,000 MWD/MTU) projected for some of the assemblies from the final core discharge from the reference PWR could require cooling in the spent fuel pool for up to 7 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 ISFSI 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.

---

[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 PWR were used to develop and test the program. (See Appendix C for details.)

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 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 on the site, 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 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.

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. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. R. I. Smith and L. M. Polentz. 1979. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130 Addendum, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

3. 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-0130, Addendum 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

4. E. S. Murphy. 1984. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Classification of Decommissioning Wastes.* NUREG/CR-0130, Addendum 3, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

5. G. J. Konzek and R. I. Smith. 1988. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule.* NUREG/CR-0130, Addendum 4, 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 PWR Power Station

The principal alternative considered in this reevaluation of the cost and radiation dose resulting from decommissioning of the reference pressurized water reactor (PWR) 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 about 7 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 a 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 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. References are listed in Section 3.8.

3.1 Pre-Decommissioning Engineering and Planning--Period 1

The assumption was made in the original PWR study (NUREG/CR-0130$^{(1)}$) that the pre-decommissioning engineering and planning was performed by the utility's inhouse staff, and no specific cost was assigned to that activity. In this study, these activities are carried out by a DOC. The postulated Utility and DOC staffing structures are shown in Figure 3.2. In this study, the labor costs for the utility and the DOC during that initial pre-shutdown period, based on annual salaries presented in Appendix B, are presented in Tables 3.2 and 3.3. These costs are estimated to be about \$4.8 million for the DOC and about \$0.6 million for the utility, in 1993 dollars, without contingency, over the 2½-year period. Special equipment purchased for the project is costed during Period 1 (~ \$3.2 million), and the cost of regulatory activities (~ \$0.4 million) is included in the total Period 1 cost of about \$9 million, without contingency.

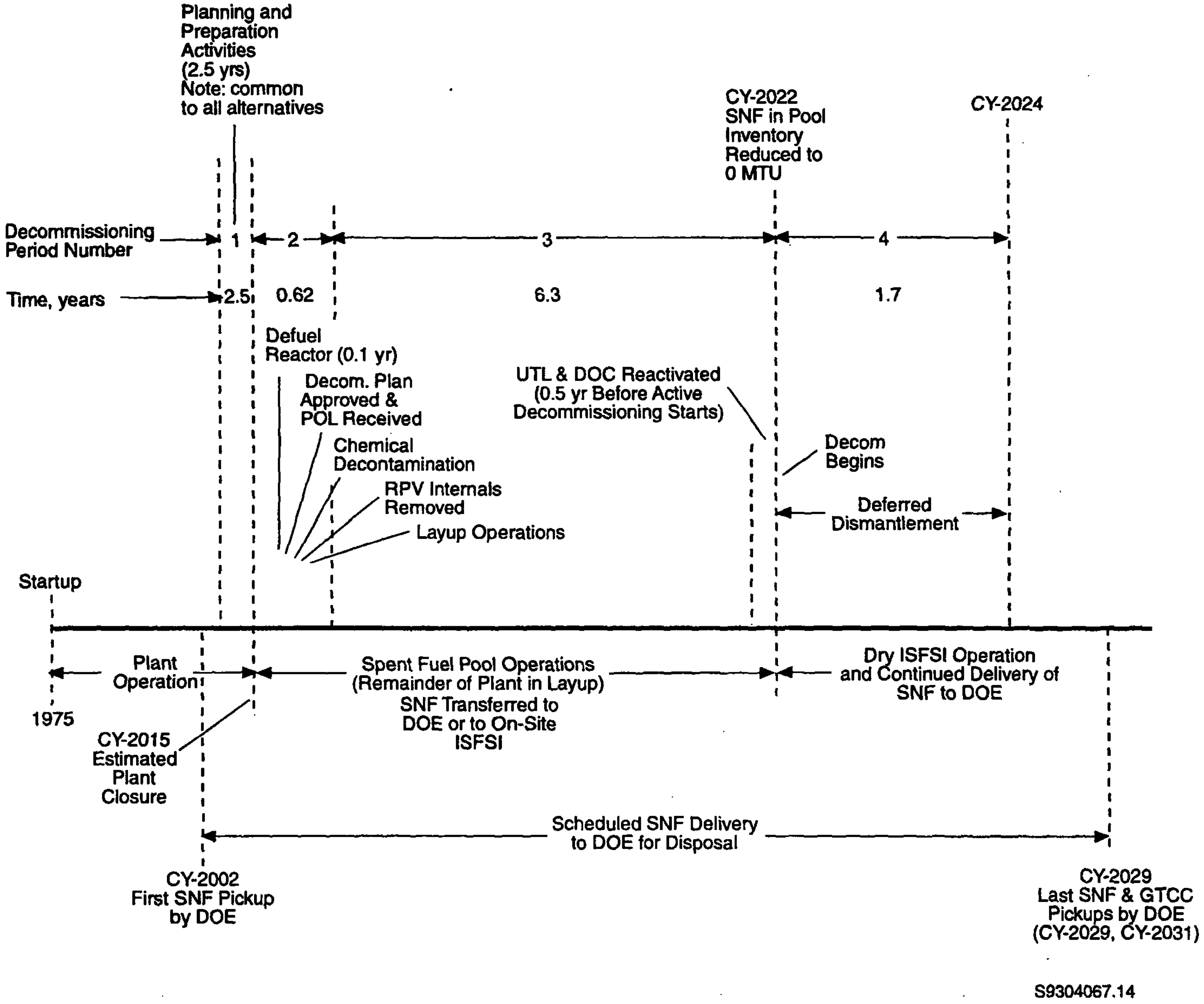


Figure 3.1 Schedule of activities during the four periods of DECON

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	--	--	--	--	--	9,107,715	9,107,715	--
2	0.62	14,324,600	473,160	106,149	1,109,278	3,431,437	9,493,178	28,937,802	208.76
3	6.3	--	--	--	--	--	6,862,503	6,862,503	20.53
4	1.7	2,346,220	11,800,060	2,206,652	3,160,019	16,163,902	26,029,031	61,705,884	723.80
Subtotal	11.12	16,670,820	12,273,220	2,312,801	4,269,297	19,595,339	51,492,427	106,613,904	953.09
							25% Contingency	26,653,476	
							Total	133,267,380	

(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) (6.3 yr)		Period 4 (1.7 yr)		Pool opn. (P3)(b)		ISFSI opn. (P4)		ISFSI opn. (P5)	
Plant Manager	129,518	0.125	16,190	0.62	80,301	0.63	81,596	1.7	220,181	5.67	734,367	--	--	--	--
Asst. Plant Manager	104,824	0.125	13,103	0.62	64,991	0.63	66,039	--	--	5.67	594,352	1.7	178,201	5.3	555,567
Secretary	29,110	0.125	3,639	3.69	107,416	0.63	18,339	1.7	49,487	5.67	165,054	--	--	--	--
Clerk	27,150	--	--	9.85	267,428	3.15	85,523	6.8	184,620	28.35	769,703	1.7	46,155	5.3	143,895
Chemistry Supervisor	74,735	0.250	18,684	0.62	46,336	--	--	--	--	--	--	--	--	--	--
Chemistry Tech.	43,012	--	--	2.46	105,810	0.63	27,098	0.4	17,205	5.67	243,878	--	--	--	--
Quality Assurance Manager	86,819	0.625	54,262	0.62	53,828	--	--	--	--	--	--	--	--	--	--
Quality Assurance Engineer	49,288	--	--	2.46	121,248	--	--	1.7	83,790	--	--	--	--	--	--
Quality Assurance Tech.	43,012	--	--	4.92	211,619	0.63	27,098	--	--	5.67	243,878	--	--	--	--
Health Physics Manager	79,449	0.125	9,931	0.62	49,258	0.63	50,053	--	--	5.67	450,476	--	--	--	--
H. P. ALARA Planner	73,045	--	--	0.62	45,288	--	--	1.7	124,177	--	--	--	--	--	--
Sr. Health Physics Tech.	73,045	--	--	2.46	179,691	1.89	138,055	--	--	17.01	1,242,495	1.7	124,177	5.3	387,139
Health Physics Tech.	45,028	--	--	9.85	443,526	--	--	--	--	--	--	--	--	--	--
Plant Operations Manager	97,440	0.125	12,180	0.62	60,413	0.63	61,387	--	--	5.67	552,485	--	--	--	--
Planner/Schedule Engineer	74,735	--	--	0.62	46,336	--	--	--	--	--	--	--	--	--	--
Operations Supervisor	86,819	--	--	2.46	213,575	0.63	54,696	3.0	260,457	5.67	492,264	1.7	147,592	5.3	460,141
Control Operator	72,988	--	--	9.85	718,932	2.52	183,930	4.5	328,446	22.68	1,655,368	1.7	124,080	5.3	386,836
Equipment Operator	51,787	--	--	9.85	510,102	3.78	195,755	4.5	233,042	34.02	1,761,794	1.7	88,038	5.3	274,471
Maintenance 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	10.6	644,374
Administration Manager	86,819	--	--	0.62	53,828	0.63	54,696	--	--	5.67	492,264	--	--	--	--
Contracts/Procure. Spec.	69,026	0.625	43,141	1.85	127,698	0.63	43,486	1.7	117,344	5.67	391,377	--	--	--	--
Licensing 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	--	--	5.3	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	5.3	325,574
Custodian	32,248	--	--	1.23	39,665	1.26	40,632	3.4	109,643	11.34	365,692	--	--	5.3	170,914
Security Manager	86,819	0.125	10,852	0.62	53,828	0.63	54,696	0.2	17,364(c)	5.67	492,264	1.5	130,229(c)	5.3	460,141
Security Shift Supervisor	38,439	--	--	2.46	94,560	1.89	72,650	0.6	23,063(c)	17.01	653,847	4.5	172,976(c)	15.9	611,180
Security Patrolman	34,875	--	--	19.69	686,689	5.04	175,770	1.6	55,800(c)	45.36	1,581,930	12.0	41,850(c)	42.4	1,478,700
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	122.4	6,702,811

(a) Salary rates include 42% overhead on utility salaries.

(b) Costs are allocated 10% to Safe Storage and 90% to SNF storage.

(c) Costs are allocated 12% to Dismantlement and 88% to SNF storage.

Table 3.3 Estimated DOC staffing and costs for DECON

		Person-years per period and period costs in 1993 dollars							
Position	Annual salary[a]	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	--	--	--	--	--	--	9.0	1,328,877
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
Crew Leader	114,060	--	--	--	--	--	--	1.5	171,090
Craftsman	103,386	--	--	--	--	--	--	3.0	310,158
Utility Operator	88,075	--	--	--	--	--	--	3.0	264,225
DOC Overhead Totals		47.5	4,827,733	--	--	9.5	965,549	105.1	12,056,993

(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.

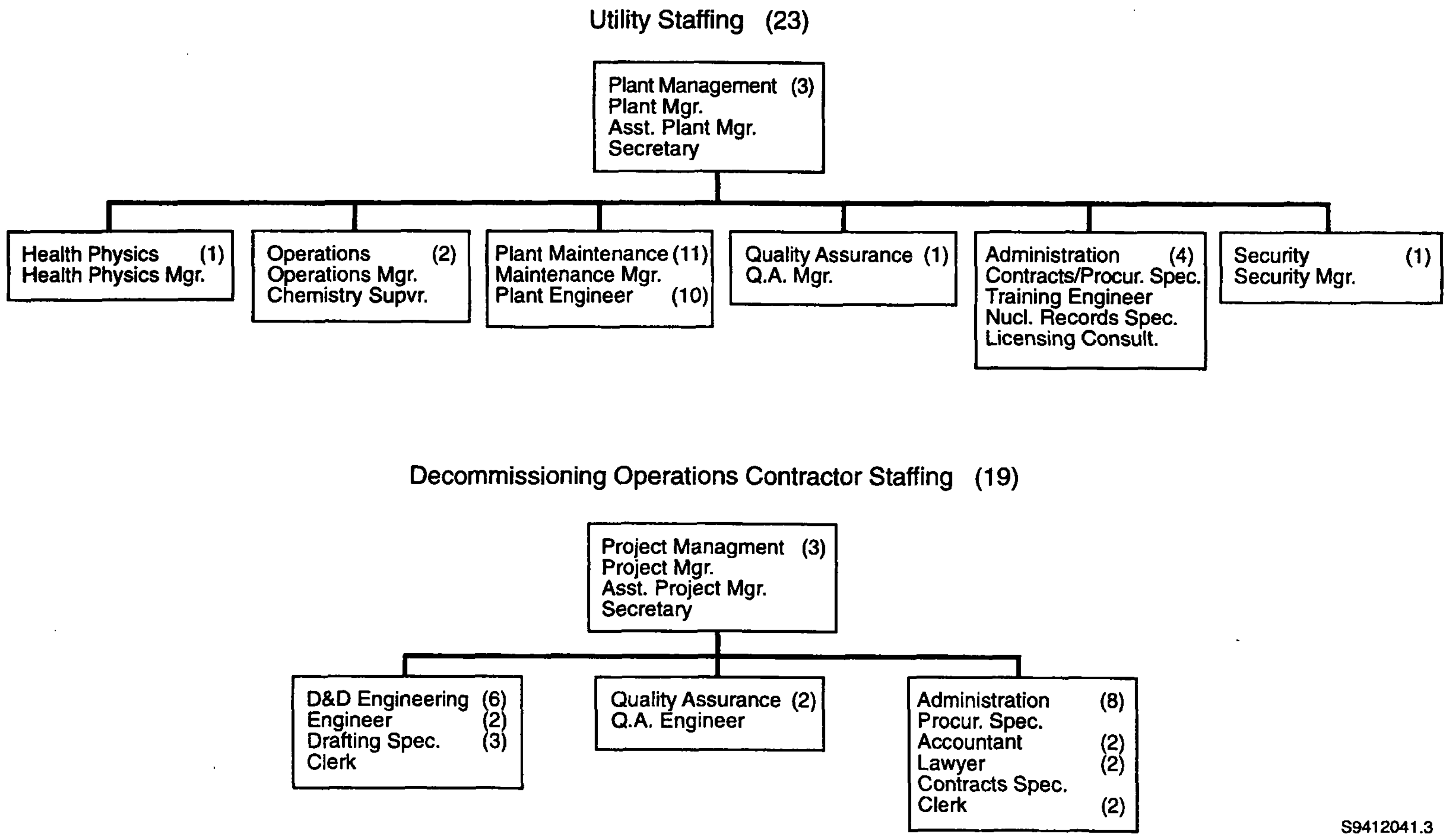


Figure 3.2 Utility and DOC staff structure and staffing levels during pre-decommissioning: Period 1

3.2 Reactor Deactivation for Safe Storage--Period 2

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

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

- the RCS water is deborated, and the concentrated boron solutions are packaged and shipped to disposal
- the reactor coolant piping systems are chemically decontaminated to reduce the radiation dose rates throughout the plant
- the residual RCS water is cleaned and released
- the highly irradiated reactor vessel internal structures are removed, segmented, and packaged in canisters for storage in the pool/onsite ISFSI, pending eventual shipment of the Greater-Than-Class-C materials to a geologic repository and shipment of the Class C and less materials to an LLW disposal facility
- systems and services not necessary for the SNF storage operations are drained, dried, and deactivated.

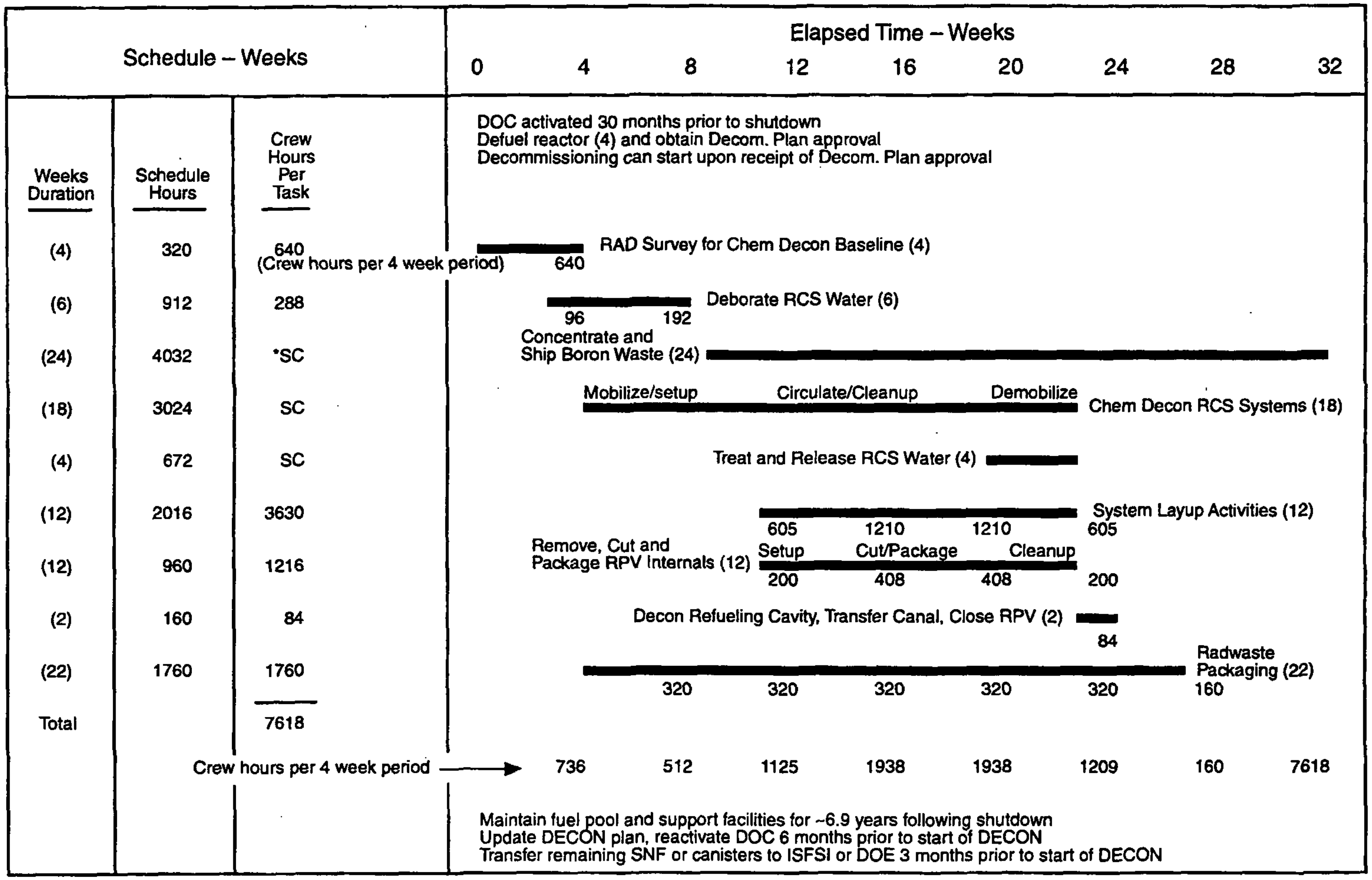
After the activated reactor vessel internals are removed and packaged, the refueling pool and the fuel transfer canal are drained, decontaminated, and dried. The postulated schedule for the activities occurring during Period 2 is illustrated in Figure 3.3.

Once 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 chemical decontamination, vessel internals sectioning, systems deactivation, 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, with the estimated staff costs compiled in Table 3.2. This reduced staffing level is predicated in part upon an analysis of the plant deactivation activities(2) considered for the Rancho Seco plant. 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 concentrated boron solutions resulting from primary coolant deboration operations have been packaged and shipped, 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. At this point, 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 operation (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

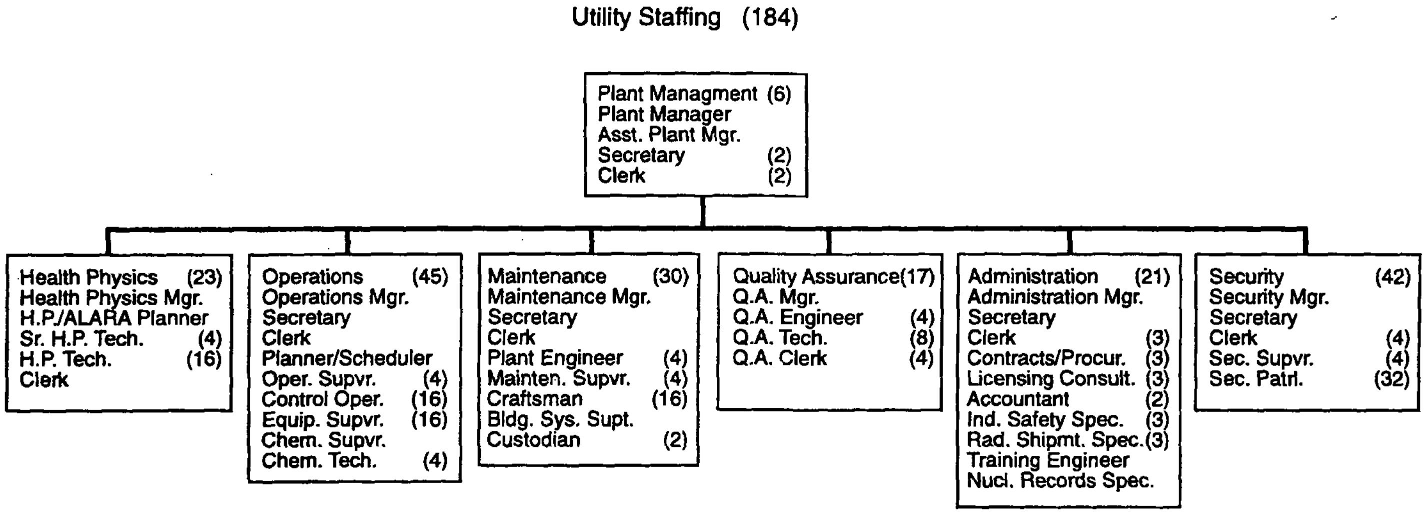
With all plant operations shut down except for the storage and shipping of spent fuel from the spent fuel pool, the utility staffing levels are reduced further, to the structure and levels shown in Figure 3.5. The safe storage of the laid-up plant and the SNF pool storage operations of Period 3 continue 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 7 years following shutdown for the duration of pool storage of the hottest fuel is given in Appendix D.



* SC = Specialty Contractor

S9304067.20

Figure 3.3 Schedule of activities during deactivation: Period 2



S9412041.1

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

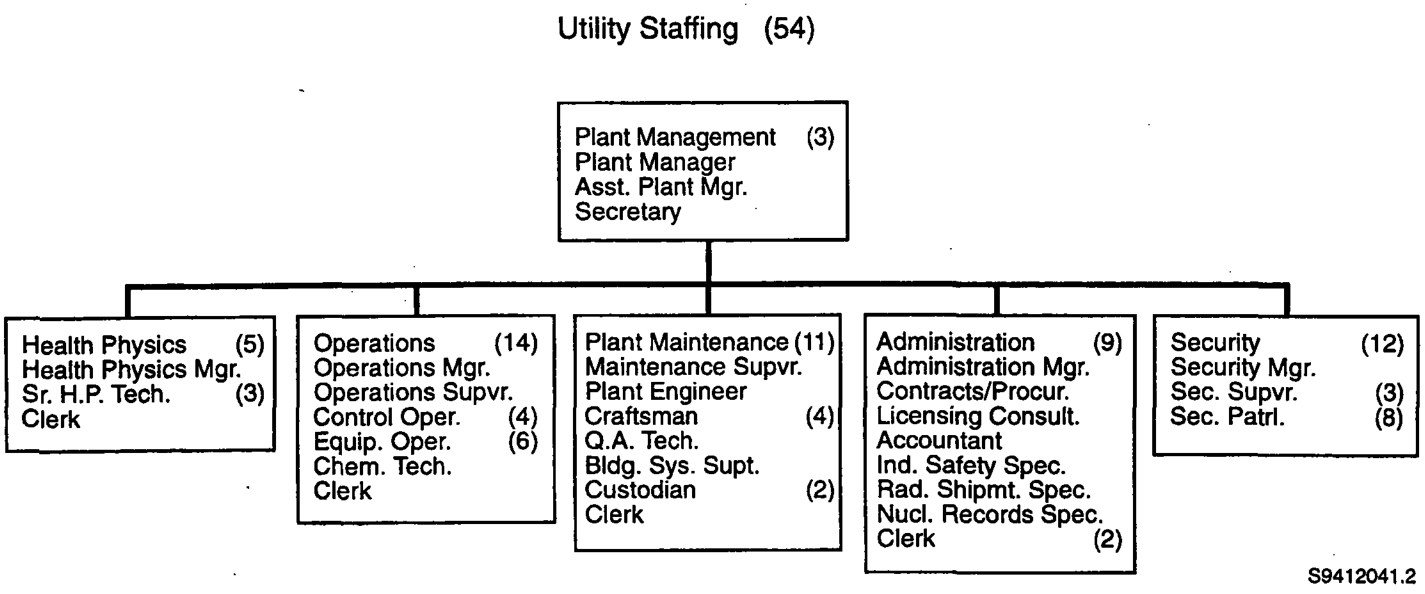


Figure 3.5 Utility staffing structure and levels during safe storage/SNF pool operations: Period 3

Table 3.4 Estimated costs and radiation doses during deactivation: Period 2

Cost element	Cost (millions 1993$)	Radiation dose (person-rem)
Chemical Decontamination (Appendix G)	13.716	45.70
RPV Internals Removal (Appendix E)	4.455[(a)]	63.99
Conc. Boron Solution Disposal	1.100	12.00
Subtotals	19.271	121.69
Undistributed Costs		
Utility Support Staff	6.009	87.07
Regulatory Costs	0.371	--
Plant Power	0.739	--
Environmental Monitoring	0.030	--
Dry Active Wastes	0.173	--
Small Tools	0.009	--
Laundry Services	0.316	--
Energy (chem. decon)	0.303	--
Nuclear Insurance (Appendix B)	1.717	--
Subtotals	9.667	87.07
Totals	28.938	208.76

(a) Does not include removal/disposal of RPV ($1.002 million, Table 3.6).

The utility staff costs during Period 3 (safe storage with spent fuel pool operations) are given in Table 3.2. The estimated costs associated with the ramp-up of the DOC staff, which is postulated to occur during the 6 months prior to the start of deferred dismantlement, are presented in Table 3.3. The total costs by cost element, and 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 are 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 PWR power station are the Containment Building, the Fuel Building, and the Auxiliary 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 Containment Building and proceed sequentially through the Fuel and Auxiliary Buildings, with a number of activities occurring within several buildings simultaneously.

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	0.031[b]	--
Regulatory Costs	0.023[b]	--
Utility Support Staff	1.906[c]	20.53
DOC Ramp-up Staff	0.966[d]	--
Plant Power Usage	0.043[b]	--
Laundry Services	0.058[b]	--
Nuclear Insurance	3.780[e]	--
Property Taxes	0.057[b]	--
Totals	6.863	20.53

(a) Cumulative cost over the 6.3 years of safe storage.
(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.

Removal and disposal of residual asbestos is carried out simultaneously with the initial radiation survey activities. While perhaps 50,000 lb of asbestos is present in the site buildings, the bulk of that material is non-friable and is located outside of the three main buildings. Preliminary estimates developed by Portland General Electric suggest a total cost of about $165,000 for removal and disposal of these materials. These costs are classified as cascading costs in this report. These costs do *not* include the cement-asbestos boards contained in the cooling tower. These latter materials are removed during demolition of clean structures and are discussed in Appendix L.

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 between 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 about 7 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 levels 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 Containment, Fuel and Auxiliary Buildings during the decontamination and dismantlement effort.

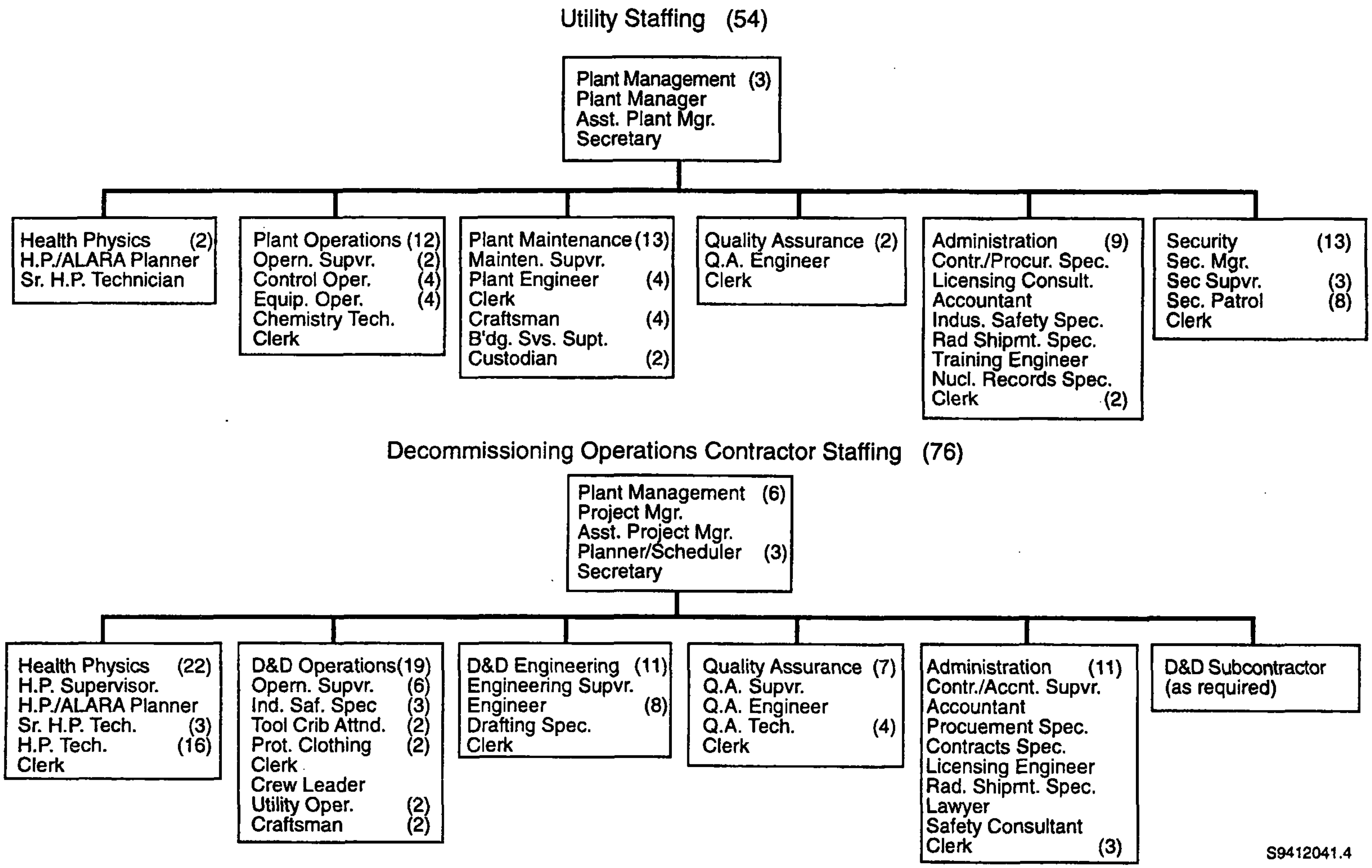
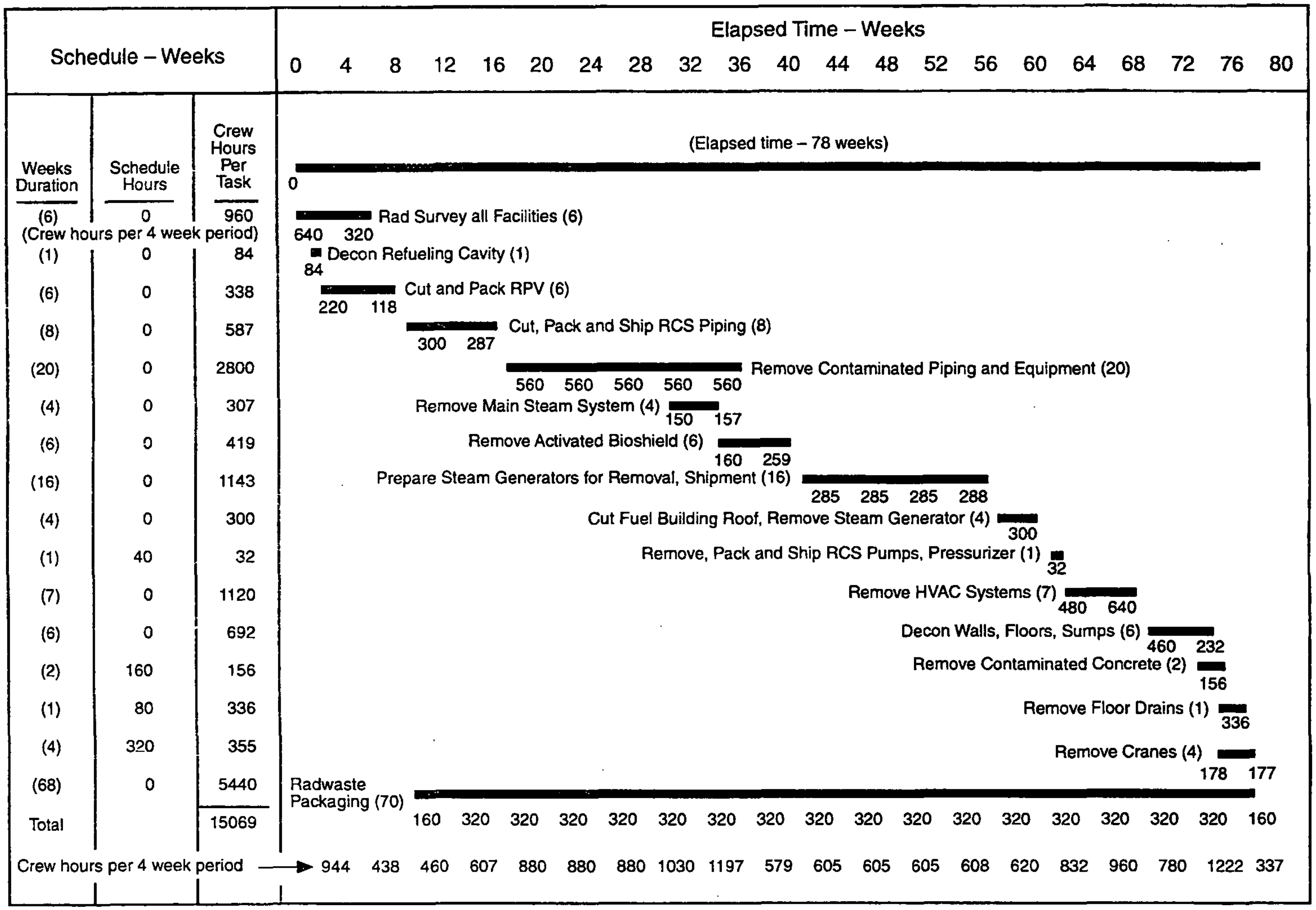
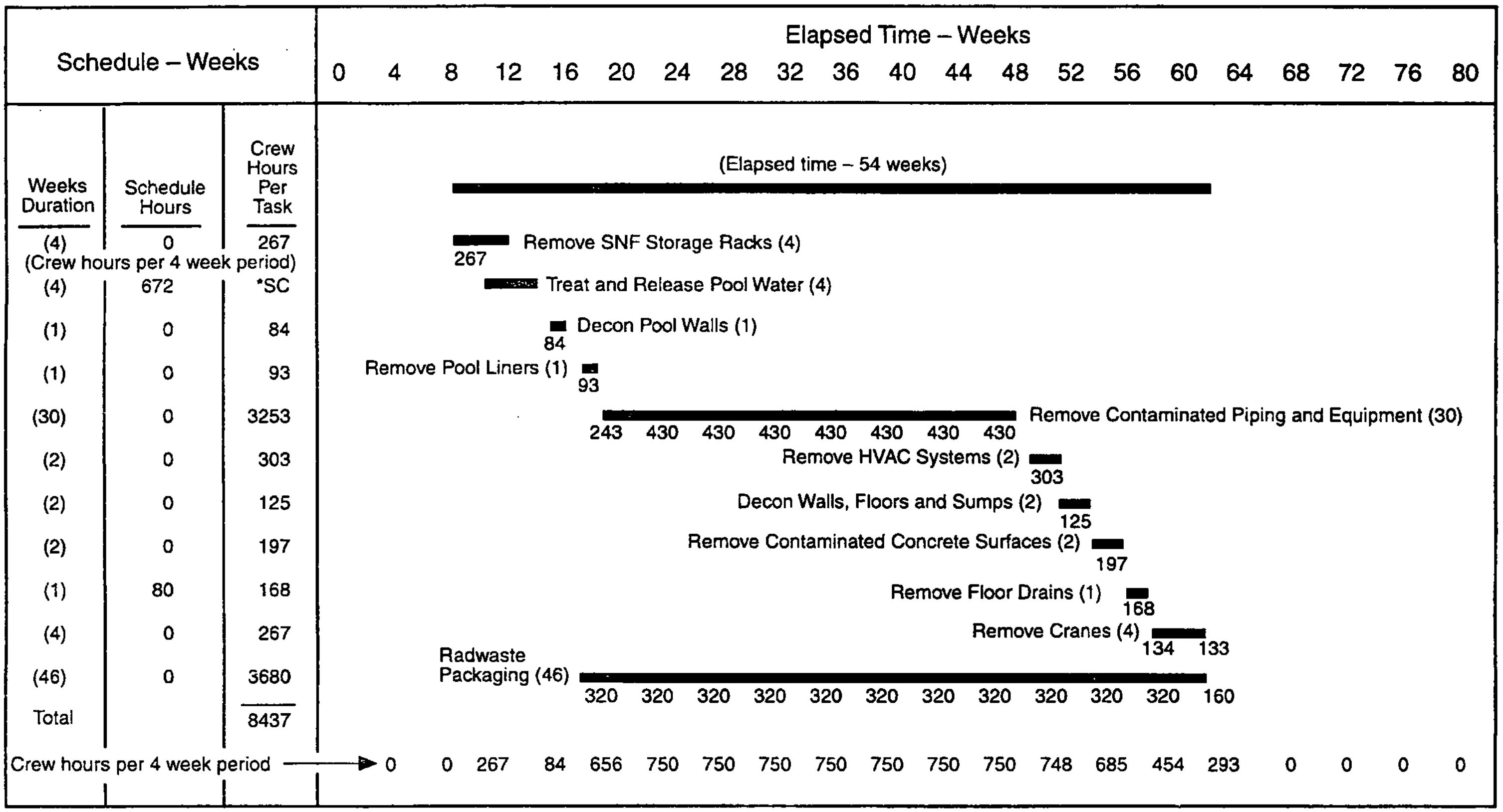


Figure 3.6 Utility and DOC staff structures and staffing levels during dismantlement: Period 4



S9304067.21

Figure 3.7 Schedules and staffing for dismantlement activities in the Containment Building



* SC = Specialty Contractor

S9304067.22

Figure 3.8 Schedules and staffing for dismantlement activities in the Fuel Building

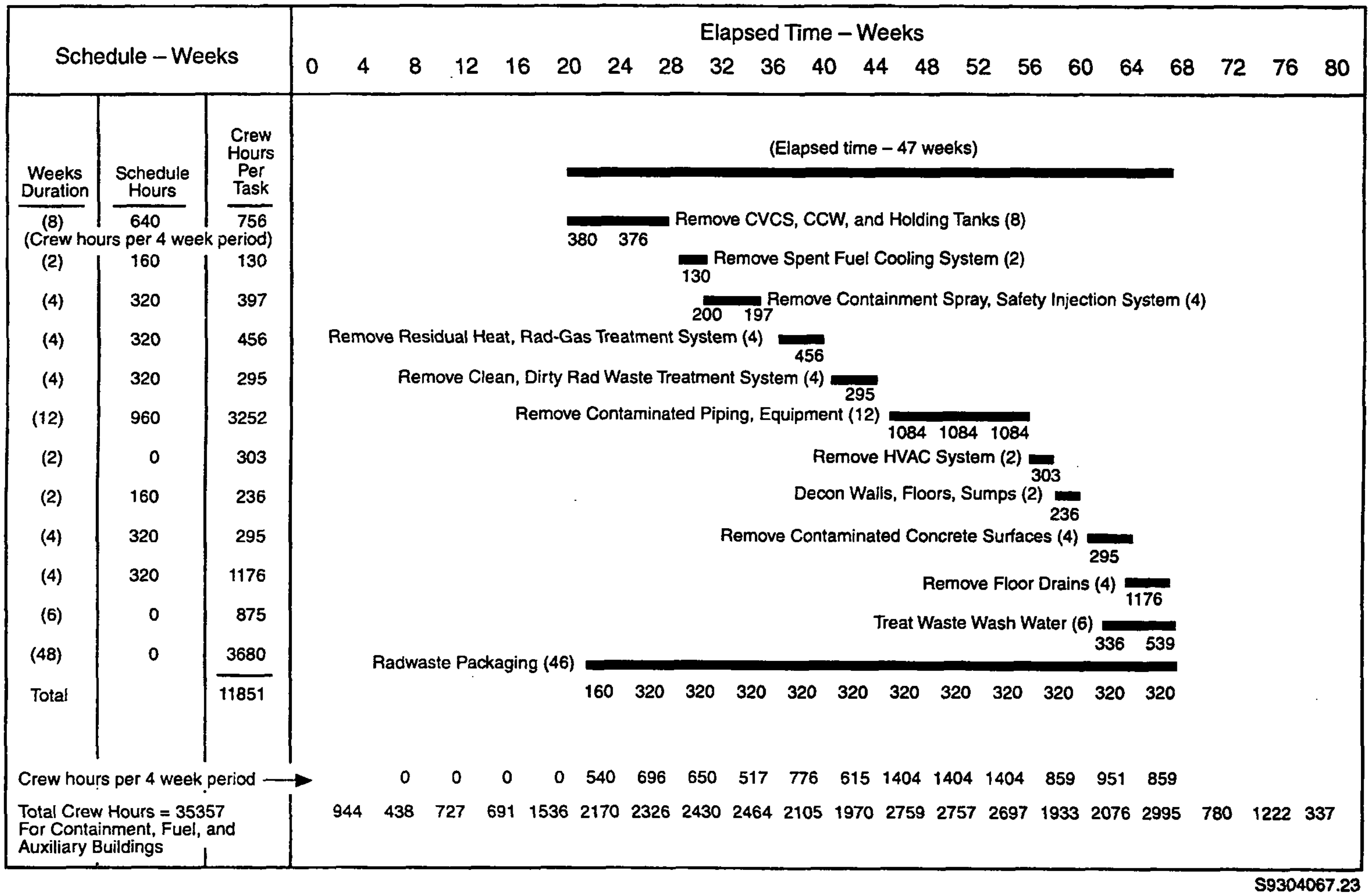


Figure 3.9 Schedules and staffing for dismantlement activities in the Auxiliary Building

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

Reactor pressure vessel (RPV) removal is discussed in detail in Appendix E and summarized briefly in Section 3.4.2. Removal of the steam generators 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 separately 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 activated concrete from the biological shield surrounding the reactor vessel is discussed in Section 3.4.6. Removal of the contaminated HVAC ductwork and associated equipment, including the containment air coolers, is discussed in Section 3.4.7. Decontamination of remaining contaminated surfaces throughout the Containment, Fuel, and Auxiliary Buildings is discussed in Section 3.4.8.

Removal of the cranes from the Containment and Fuel 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.

3.4.1 Removal of Process Systems and Piping

The systems identified for complete or partial removal are:

- Component Cooling Water
- Chemical and Volume Control
- Containment Spray
- Clean Radioactive Waste Treatment
- Dirty Radioactive Waste Treatment
- Main Steam (within containment)
- Radioactive Gaseous Waste
- Residual Heat Removal
- Safety Injection
- Spent Fuel Cooling
- Stainless Steel Piping.

The detailed inventories of system components and valves for each system and the stainless steel piping inventory are presented in Appendix C. The weights and volumes of the components and piping are derived from construction drawings, handbooks, and other similar sources. 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

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	10.061	533.36
Reactor Pressure Vessel	1.002[(a)]	17.68
Steam Generators	11.598[(b)]	60.00
RCS Piping/Components	1.982	23.96
SNF Pool Racks	1.748	1.20
Activated Concrete	1.004	31.22
HVAC System	3.724	2.59
Contaminated Surfaces	1.368	9.92
Bridge Cranes	0.576	0.31
Undistributed Costs	24.809	40.10
Termination Survey	1.220	0.00
Dry Active Waste	0.885	0.00
Waste Water Treatment	1.377	2.71
Cascading Costs	0.355	0.75
Totals (w/o contingency)	61.709	728.80

(a) Does not include removal/disposal of RPV internals ($4.455 million, Table 3.4).
(b) Does not include any undistributed or cascading costs.

are estimated using a conservative approximation to calculate 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 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. Because the stainless steel piping is primarily associated with the reactor coolant system and associated safety and support systems, all of the stainless steel piping is assumed to be removed during decommissioning. In addition to the piping, 12,812 potentially contaminated pipe hangers were identified. These hangers range in size from simple U-bolts used for sample piping to massive structures (1000 pounds or more) designed to support the 28-inch steam lines. The total cost to remove the hangers is $4,071,547, without contingency.

The heat exchangers in the various systems are postulated to be removed, their exteriors decontaminated, and their interiors filled with ultra-low-density grout prior to transport, to reduce radiation levels and concerns about dispersal of radioactive contaminants in the event of an accident during transport, and to prevent eventual subsidence problems at the disposal site due to shell collapse following disposal.

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. Thus, only those portions of the carbon steel piping associated with the main steam system and the containment air coolers that are within the Containment Building are assumed to be removed to facilitate the final cleanup and decontamination of the Containment Building. Because the remaining carbon steel systems that serve the turbine, service cooling water, potable water, sanitary sewer, etc., are assumed to be uncontaminated, they 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.

The costs and radiation doses to decommissioning staff for removing the various process systems and associated piping are developed in Appendix C and summarized briefly in Table 3.7.

3.4.2 Removal of the Reactor Pressure Vessel

Removal of the activated RPV from the Containment Building requires sectioning, packaging, and transport of the vessel segments to a licensed LLW disposal site, and is estimated to require about 1½ months. The detailed discussions of the sectioning, packaging, transport, and disposal are contained in Appendix E, and are summarized briefly as follows:

- Estimated Cost (without contingency), $1,002,223
- Estimated Worker Radiation Dose, 17.68 person-rem

3.4.3 Removal of Steam Generators

Removal of the steam generators from the Reactor Containment Building 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. A one-piece removal is postulated for each steam generator, with barge transport to Richland, Washington, and heavy-haul transport to the U.S. Ecology LLW disposal facility on the Hanford Reservation. Because of the large size and weight of the steam generators, it is necessary to modify the polar crane in the Containment Building, and to break ventilation confinement during movement from the Containment Building into the Fuel Building and out through the roof of the Fuel Building. A summary of the estimated costs and radiation doses associated with the removal, transport, and disposal of the steam generators is given in Table 3.8. The preparations and removal tasks are estimated to require about 4 months, and the transport and disposal tasks to require about an additional 2 months.

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 and the steam generators, which are discussed individually in Appendices E and F. Specifically included are: the large piping connecting the steam generators and primary coolant pumps with the RPV, the pressurizer, the pressurizer relief tank, the primary coolant pumps, and the piping of various sizes that interconnect the RCS with 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 from the Containment Building requires sectioning, packaging, and transport of the packaged segments to the LLW disposal facility. 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), $1,982,185
- Estimated Worker Radiation Dose, 23.96 person-rem

The assumptions listed on page 3.21 are made to facilitate the analysis.

Table 3.7 Estimated costs and radiation doses for removal of contaminated systems during dismantlement: Period 4

Removal of:	Cost (1993 $)	Radiation dose (person-rem)
Component Cooling Water	679,908	10.59
Chemical and Volume Control	572,909	22.00
Containment Spray	101,146	1.98
Clean Radioactive Waste Treatment	211,492	5.46
Dirty Radioactive Waste Treatment	55,806	1.44
Main Steam (within containment)	309,094	7.70
Radioactive Gaseous Waste	135,767	0.57
Residual Heat Removal	138,927	4.63
Safety Injection	928,049	8.00
Spent Fuel Cooling	86,947	6.39
Retrofit Materials	28,006	4.01
Electrical Components	549,446	0.03
Control Rod Drives	3,517	0.00
Stainless Steel Piping	2,188,574	459.03
Pipe Hangers	4,071,547	1.53
Totals (w/o contingency)	10,061,134	533.36

Table 3.8 Estimated costs and radiation doses for disposal of four steam generators

Cost element	Cost (1993 $)	Radiation dose (person-rem)
Decon and Removal	6,235,743	60.00
Packaging	437,363	--
Transport	1,575,067	--
Disposal	3,349,743	--
Totals	11,597,916	60.0

- The time, cost and exposure for cutting the large RCS piping are all accounted for in this chapter, including severing the piping from the RPV, the primary pumps, and the steam generators.

- The piping is cut to fit within modified maritime containers, into segments nominally 15 feet in length, thereby reducing the number of cuts needed to remove the piping.

- Scaffolding was required for all piping cuts, to provide appropriate access to the work.

- Cutting of the piping and the pressurizer relief tank is accomplished 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 sectioning operations.

- The primary pumps and the pressurizer are removed and shipped to the LLW disposal site at Hanford in one piece by barge, in the same manner as the steam generators.

- The pressurizer relief tank is cut into sections approximately 3.5 ft x 7.5 ft and packaged into a 20 ft x 8 ft x 4 ft modified maritime container for transport and disposal.

- The primary piping, miscellaneous piping, pressurizer relief tank, and miscellaneous insulation are packaged in modified maritime containers for transport to the LLW disposal facility.

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

Following separation of the RPV, steam generators, primary pumps, and pressurizer from their piping connections, those components are removed sequentially from the Reactor Building. Subsequently, the primary piping, the miscellaneous piping, and the pressurizer relief tank are cut and packaged for disposal. The insulation associated with these components is packaged as a part of the component removal operations.

Primary Pumps

The insulation enclosing the pump bowl is removed and packaged for disposal. The pump is separated from the primary piping, cooling and drain lines, and associated sensor and control lines, and is rigged for lifting. Plates are

Table 3.9 Composition of RCS piping and components removal crews

Pers-hrs/crew-hr	Category	Labor rate ($/pers-hr)	Cost[a] ($/crew-hr)	Dose rate (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.

welded over the inlet and outlet ports of the pump bowl. The load is taken up by the reactor hall crane and the pump support and seismic constraints are removed. The pump and motor are lifted as a single unit to the operating deck and placed horizontally in a shipping cradle, preparatory to removal from the Containment Building via the equipment hatch and lifting out of the Fuel Building through the roof for transport to the barge slip, placement on the barge, and transport to the licensed LLW disposal facility.

The activities necessary to remove each pump and place it on the operating deck in its shipping cradle are estimated to require about 16 crew-hours, 57 exposure hours and 0.69 person-rem, $3,112 in labor costs, and $5,000 in material costs (shipping cradle). Thus, the total estimated cost for removing and preparing 4 primary pumps with motors for shipment is $32,448. The total estimated crew labor hours is about 65, the total estimated exposure hours is about 229 and the total estimated radiation dose is 2.76 person-rem.

The cost of lifting the cradled pumps onto the barge is contained within the cost of steam generator disposal, since the heavy-lift equipment and personnel are required at the reactor site for a period of two months, regardless of how much time is actually devoted to direct work. The cost of transporting the pumps by barge, together with the pressurizer, on a single barge shipment is limited to the barge/transport cost, $88,752 + 30% markup, or $115,378. If divided among the five components on that barge shipment, the unit transportation cost would be $23,076 each, or a total of $92,302 for the four pumps. Removal of the pumps from the barge and ground transport to the disposal facility is estimated to cost $67,673. Local site services associated with that ground transport are estimated to be about $132,300 for each of the four pumps. Thus, the cost of barge transport to Hanford and subsequent ground transport to the disposal facility is $689,175. The estimated fee for disposal is $203,678. The total estimated cost for removal and disposal of the primary pumps is $925,301, without contingency.

Pressurizer

The insulation enclosing the pressurizer is removed and packaged for disposal. The pressurizer is separated from its piping, sensor and control lines and electrical connections and rigged for lifting. Plates are welded over the openings in the pressurizer shell. The load is taken up with the reactor hall crane and the pressurizer supports and seismic constraints are removed. The pressurizer is lifted in one piece to the operating deck and placed horizontally in a shipping cradle (a modified steam generator cradle), preparatory to removal from the Containment Building via the equipment hatch and lifting out of the Fuel Building through the roof to transport to the barge slip, placement on the barge, and transport to the disposal facility.

The activities necessary to remove the pressurizer and place it on the operating deck in its shipping cradle are estimated to require about 16 crew-hours, 57 exposure hours and 0.69 person-rem, $3,112 in labor costs, and $5000 in material costs (shipping cradle modification). The total estimated cost for removing and preparing the pressurizer for shipment is $8,112. From the preceding section, the pressurizer's share of the barge transport cost would be $23,076. Removal of the pressurizer from the barge and ground transport to the LLW disposal facility is estimated to cost $16,918. Hanford site services associated with that ground transport are estimated to cost about $132,300 per transport. The LLW disposal fee is estimated to be $118,327. Thus, the total cost for removal and disposal of the pressurizer is estimated to be $298,733, without contingency.

Miscellaneous RCS Piping

The miscellaneous piping is comprised of approximately 2,220 linear feet of Nuclear Grade I piping, ranging in diameter from 3/4 in. to 14 in., with most of the piping less than 4 in. in diameter. The removal activities include removal and packaging of insulation; cutting the piping free from the primary piping, the pressurizer, the pressurizer relief tank, and associated components; cutting the piping into sections nominally 15 ft in length, and placing the segments into a modified maritime container for transport by truck to the LLW disposal facility.

The activities necessary to remove the miscellaneous piping and place it in a modified maritime container on the operating deck are estimated to require about 341 crew-hours, 1,415 exposure hours, and 14.37 person-rem. The total estimated cost for removing and preparing the miscellaneous RCS piping for shipment is $65,576. Cost of the modified maritime containers is estimated to be $4,215. Transport by truck to the LLW disposal facility is estimated to cost $1,131, and the disposal fee is estimated to be $37,424. Thus, the total estimated cost for removal and disposal of the miscellaneous RCS piping is $108,345, without contingency.

Sensitivity to Length of Pipe Cuts

A sensitivity analysis was performed to examine the effect of cutting the contaminated piping into nominal 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 $3.970 million, including contingency. Because the volume of dry active waste, the amount of laundry used, and the quantity of small tools and equipment used are factored from the direct labor hours, the costs associated with these cost elements also increased, by about $0.903 million. Thus, the increase in the total DECON cost resulting from cutting the piping into 5-ft lengths instead of the 15-ft lengths postulated in the base analysis was about $4.873 million, including contingency.

Associated with the increased number of pipe cutting operations was an increase in the worker radiation dose. Because pipe cutting tends to be performed in higher radiation fields than many other DECON activities, the cumulative radiation dose to workers more than doubled, from 953 person-rem for the base analysis (15-ft pipe lengths) to 1933 person-rem for the sensitivity case (5-ft pipe lengths).

Pressurizer Relief Tank

The insulation is removed from the tank and packaged for disposal. The tank is cut into segments approximately 3.5 ft x 7.5 ft and packaged in a modified maritime container for transport and disposal.

The activities necessary to remove and package the pressurizer relief tank for disposal are estimated to require about 30 crew-hours, 105 exposure hours and 1.27 person-rem, and $5,868 in labor and material costs. Modified maritime container cost is $3,650. Transport by truck to the LLW disposal facility is estimated to cost $979, and the disposal fee is estimated to be $30,645. Thus, the total estimated cost for removal and disposal of the pressurizer relief tank is $41,142, without contingency.

Primary Piping

The insulation is removed from the remaining portions of the piping and packaged for disposal. Each piping segment is individually rigged for lifting. The reactor hall crane is used to lift the piping segments to the operating deck where they are placed into modified maritime containers for transport. The segments that connect the RPV with the steam generators and the primary pumps are removed intact and placed in modified maritime containers. The sections that connect the steam generators to the primary pumps are cut into two segments to facilitate fitting into modified maritime containers. The containers are transported to the LLW disposal facility by truck.

The activities necessary to remove and package the primary piping for disposal are estimated to require about 115 crew-hours, 631 exposure hours and 4.87 person-rem, $21,802 in labor costs, $342 in material costs, for a total estimated cost for removing and preparing the primary piping for shipment of $22,144. The cost of modified maritime containers is $30,336. The estimated cost of transport of the containers by truck to the LLW disposal facility is $8,137. The fee for disposal of the primary piping is $254,706. Thus, the total estimated cost for removal and disposal of the primary piping is $315,323, without contingency.

RCS Insulation

The insulation removed from the various RCS components is packaged in modified 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 $39,720. Transport of the containers by truck to the LLW disposal facility is estimated to cost $5,327. The disposal fee is estimated to be $248,293. Thus, the total estimated cost for disposal of the removed insulation is $293,341, without contingency.

RCS Piping and Components Summary

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

Table 3.10 Summary of component package numbers, weights, volumes and shipments

Component	No. of packages	Weight/ package (lb)	Volume/ package (ft^3)	No. of shipments	Disposal volume (ft^3)
Primary Pumps	4(a)	190,600	1,050	1(c)	4,200
Pressurizer	1(a)	195,500	2,440	1(c)	2,440
Misc. RCS Piping	0.87(b)	31,410+3,000	640	1	557
Press. Relief Tank	0.70(b)	27,200+3,000	640	1	448
Primary Piping	6.11(b)	37,000+3,000	640	6	3,910
Misc. Insulation	8(b)	400+3,000	640	4	5,120

(a) Packaged as own container, openings welded closed, placed in shipping cradle.
(b) Packaged in modified maritime containers, 20 ft x 8 ft x 4 ft, 3000 lb empty.
(c) Shipped by barge, 4 primary pumps and the pressurizer in one shipment.
(d) Represents the decimal volumes associated with the decimal number of containers.

Table 3.11 Estimated costs for removal and disposal of RCS components

Component	Labor/materials cost	Package cost	Transport cost	Disposal cost	Total cost	Exposure hours	Radiation dose (person-rem)
Primary Pumps	$32,448	--(a)	$159,975 + $529,200(c)	$203,678	$925,301	229	2.76
Pressurizer	$8,112	--(a)	$39,994 + $132,300(c)	$118,327	$298,733	57	0.69
Misc. RCS Piping	$65,576	$4,215(b)	$1,131	$37,424	$108,345	2,415	14.37
Press. Relief Tank	$5,868	$3,650(b)	$979	$30,645	$41,142	101	1.27
Primary Piping	$22,144	$30,336(b)	$8,137	$254,706	$315,323	631	4.87
Misc. Insulation	included above	$39,720(b)	$5,327	$248,293	$293,341	included above	included above
Totals	$134,148	$77,921	$877,043	$893,073	$1,982,185	2,433	23.96
Protective Clothing					$9,747(d)	NA	NA

(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 4 ft, 3000 lb empty.
(c) Hanford site services associated with ground transport to the LLW disposal facility.
(d) Cost included in Laundry Services in Undistributed Costs.

3.4.5 Removal of Racks from Spent Fuel Storage Pool

Information found in the Trojan reactor's annual reports, generic letters, LERs, and selected Portland General Electric Company (PGE) reports, together with discussions with Trojan licensing staff, was carefully assessed in Reference 4 to identify those plant modifications and design changes that could potentially have an impact on decommissioning. Those changes at the Trojan plant that could impact decommissioning were identified and quantified.

The major change identified in Reference 4 involved reracking in the spent fuel pool (SFP). That change resulted in racks of greater mass being present in the pool than were considered in NUREG/CR-0130.(1) The Trojan spent fuel storage pool was originally designed to hold 280 assemblies. Since the reactor began operating, a succession of plans for disposing of spent fuel (reprocessing, storage in a repository under the National Waste Terminal Storage Program, federal away-from-reactor storage, and storage in a repository under the National Waste Policy Act of 1982) have been considered but not yet realized. To deal with its accumulating inventory of spent fuel, PGE applied for and received licenses from the NRC to increase the at-reactor storage capacity at Trojan to 651 assemblies in 1978 and to 1408 assemblies in 1983.(5) The storage racks used to hold the accumulated fuel become contaminated during the reactor's lifetime and will subsequently have to be removed during decommissioning.

The assumptions made and the methodology used for this analysis, a brief description of the spent fuel racks, the postulated removal and disposal activities, the results of a reevaluation of the anticipated occupational radiation dose for the task, and the estimated costs and schedule 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 4 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, 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 (ORE) and was analyzed in this study.

Spent Fuel Racks (12 each)

The reference SFP accommodates eight racks with 11 x 11 cells and four racks with 10 x 11 cells, for a total of 12 racks to be removed during decommissioning. The 115-1/2-inch-square racks are about 179 inches high. The approximate weight of each of the spent fuel racks is 16,455 kg (36,200 lb), and 18,550 kg (40,800 lb), including the specially designed 1,500-ft^3 shipping container postulated to be used in this study.

Spent Fuel Racks Removal and Disposal

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, since the racks are too large for placement in regular-size maritime containers. Subsequent transport is by oversize truck (one container per truck) to an LLW disposal facility at Hanford, Washington.

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 one month, including one week of training provided by the utility. In addition, the DOC is postulated to provide one health physics technician per crew. Based upon the aforementioned crew makeup, it is estimated that the removal of the spent fuel racks will require about 2,400 direct labor person-hours (approximately half of that time is assumed to be in background radiation areas) at dose rates of about 1 mrem/hr. Thus, the estimated occupational radiation exposure associated with the removal and packaging operations is about 1.2 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. The total cost for this activity is estimated at about $1.75 million, not including contingency.

As mentioned previously, the SFP racks removal, decontamination, and packaging is handled by a specialty contractor who is experienced in spent fuel racks changeout and associated integrated outage activities. The contract for these services is estimated to cost about $661,500, based upon discussion with an industry expert. The contract period of 1 month includes 1 week of indoctrination training provided by the utility, including facility-specific crane qualification training for the contractor staff.

Two distinct waste forms require disposal during the SFP racks removal project: 1) the racks themselves, which are shipped in one piece, one to an oversize truck, and 2) compressible dry active waste (DAW) generated during the rack decontamination effort. The racks and the DAW are postulated to be shipped to the U.S. Ecology, Inc. commercial low-level waste burial ground at Hanford. The details underlying the results in Table 3.12 are given in Table 3.13.

3.4.6 Removal of Activated Concrete

The concrete biological shield, which surrounds the RPV within the Containment Building, becomes activated to varying degrees during the operating lifetime of the reactor and the inner portions of the shield must be removed during dismantlement. Operations necessary for removal of the activated portions of the biological shield are discussed in Appendix C, and a summary of that analysis is given in this section.

Calculations of the activation of materials in the concrete biological shield that surrounds the reactor pressure vessel were reported in NUREG/CR-0130 for the reference PWR (Trojan) for an assumed operating lifetime of 30 effective full-power years (i.e., 75% operating efficiency). These calculations did not include any ^{152}Eu because no

Table 3.12 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	661,500[a]	--	661,500
Packaging	63,270	410	63,680
Transport	16,334	267	16,601
Disposal	1,000,706	5,456	1,006,162
Totals	1,741,810	6,183	1,747,944
Laundry Services[b]	6,300		

(a) Estimate by industry services contractor.

(b) Protective clothing/equipment for contractor staff @ $21/day/person, included in Undistributed Costs.

Table 3.13 Development of transport and disposal costs for spent fuel racks

Component	No. of disposal containers	Container costs ($)(a)	No. of shipments	Transport costs ($)	Disposal Volume (ft^3)	 Cost ($)(b)	Total cost ($)
SFP Racks	12(c)	63,270(d)	12(e)	16,334	18,000	1,000,706	1,080,310
DAW, Compressible	15(f)	410	0.2	267	112.5	5,456	6,133
Totals	27	63,680	12.2	16,601	18,112.5	1,006,162	1,086,443

(a) Based on information in Section B.4 of Appendix B.
(b) Based on information in Section B.7 of Appendix B; includes all surcharges, taxes, and fees, as applicable.
(c) Specially designed containers, see text for details.
(d) Includes specially designed large plastic bags at $1,103 a piece.
(e) Oversize truck shipments, see text for details.
(f) Drums; see Section B.6 of Appendix B for details.

information was available about the likely concentration of ^{152}Eu in the natural materials of the bioshield. However, measurements made at the Elk River Reactor decommissioning suggested that the Ci/m^3 attributable to ^{152}Eu was about the same as the Ci/m^3 associated with ^{60}Co. Thus, the total bioshield activity is postulated to be approximately twice the calculated activity of ^{60}Co, due to the anticipated ^{152}Eu activity.

Examination of the original calculations of activations in the bioshield suggests that, at about 7 years following reactor shutdown, the residual activity levels of ^{60}Co and ^{152}Eu in the bioshield will be approximately as shown in Figure 3.10. From the figure, it is seen that varying thicknesses of concrete will have to be removed to achieve different levels of residual activity level at the inner surfaces of the bioshield (i.e., 4 ft for 13.4 pCi/g; 5 ft for 0.5 pCi/g; and 6 ft for 0.025 pCi/g. The costs associated with removal and disposal of that activated material were calculated using the unit cost factor algorithm for activated bioshield concrete removal presented in Section C.2.15 of Appendix C, and the cost estimating computer program (CECP). The length of the decontamination and dismantlement effort (Period 4) was assumed to be unaffected by the increased duration of the shield removal task. Only the costs of direct labor, packages, transport, and disposal were allowed to change during this sensitivity analysis. The packaged volumes for disposal, the costs (including removal, packaging, transport, and disposal), and the worker radiation dose, are estimated to be 135 B-25 boxes, $1.004 million, and 31.22 person-rem to achieve a residual activity level of 13.4 pCi/g; 176 B-25 boxes, $1.298 million, and 38.74 person-rem for 0.5 pCi/g; and 219 B-25 boxes, $1.647 million, and 53.09 person-rem for 0.025 pCi/g. If the entire bioshield were removed using the same methods as postulated for the partial removals, the estimated volume, cost and dose are 242 B-25 boxes, $1.792 million, and 53.92 person-rem.

If it were decided in the beginning to remove the entire bioshield, it is likely that the removal procedure could be modified to reduce the cost and dose of total removal to something less than was calculated using the incremental layer methodology.

3.4.7 Removal of Contaminated HVAC Systems

The heating and ventilation (HVAC) systems ductwork and equipment within the Containment, Auxiliary, and Fuel 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 is only mildly contaminated, with very small radiation dose rates (1 mrem/hr) associated with the removal activities. 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. For these reasons, the workers removing the ducts are expected to wear masks to prevent

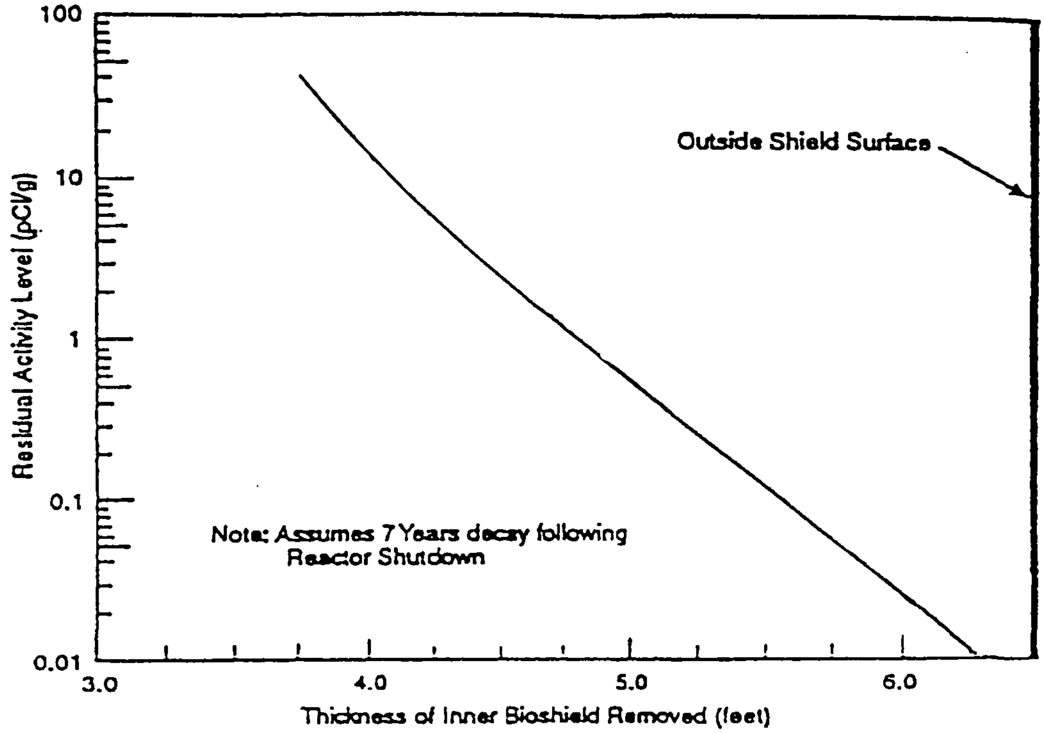


Figure 3.10 **Residual radioactivity in the activated concrete bioshield as a function of the depth of concrete removed during DECON**

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,(6) modified to reflect the situation in the reference PWR, and are developed in the Unit Cost Factor for Duct Removal (see Appendix C). The Means information is for noncontaminated 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 Containment, Auxiliary, and Fuel Buildings was determined by scaling the actual construction drawings for the Trojan facility, including the sizes of the ducts. The duct walls are postulated to range from 20 gauge galvanized steel for the sizes less than 30 in. x 12 in., to 18 gauge for sizes less than 40 in. x 18 in., to 16 gauge for sizes 40 in. x 18 in. and greater. The weights of the duct material are postulated to be 1.656 lb/ft^2, 2.156 lb/ft^2, and 2.656 lb/ft^2 for the 20, 18, and 16 gauge materials, respectively.

For packaging, it is postulated that the rectangular ductwork is flattened, resulting in a slab whose dimensions are (height + width) x length of the section x an effective thickness of 2 in. for the flattened section. Similarly, the round ductwork is postulated to be flattened, resulting in a slab whose dimensions for the flattened section are $\pi D/2$ x length x an effective thickness of 2 in. The flattened

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.

volumes are used in the analyses of packaging and disposal costs. The estimated weights and volumes of compacted ductwork from the Containment, Auxiliary, and Fuel Buildings are given in Table 3.15. The detailed information on the ductwork in the Containment, Auxiliary, and Fuel Buildings was reduced to average values for use in the subsequent analyses of cost and schedule. Given the total length of duct (1,763 ft + 2,803 ft) = 4,566 ft, and the removal rate of 0.279 hours/ft of average duct, 1,273 crew-hours are estimated to be required to remove the ductwork, at an estimated cost of about $107,355, and an estimated radiation dose of 1.62 person-rem. Assuming 2 crews per shift, and a 2-shift operation (i.e., 4 crew-shifts per day), the duration of the ductwork removal is estimated to be 40 days.

Removal of HVAC Equipment Items

There are some 50 equipment items associated with the ductwork. The crews utilized for these removal activities are larger than the ductwork removal crews, as shown in Table 3.16.

There are 14 items that weigh more than 5,000 lb, 22 items weighing between 1,000 and 5,000 lb, and 14 items weighing less than 1,000 lb. These items can be handled using standard lifting apparatus. It is estimated that, on the average, approximately one-half crew-shift per item will be required to remove and package these equipment items for disposal. Thus, about 25 crew-shifts would be required to remove and package the HVAC equipment, exclusive of the containment air coolers, and the ductwork. The cost of removing the HVAC equipment, exclusive of the containment air coolers and the ductwork, is estimated to be about $37,708, and the accumulated radiation dose is estimated to be 0.51 person-rem. A summary of the weights and volumes of that equipment (fans, coils, filter frames) is given in Table 3.17.

Removal of Containment Air Coolers

The four containment air coolers are located at the 205-ft level in the Containment Building, above the Containment Building crane. Assuming the reactor has not suffered a major core accident, these units should be essentially

Table 3.15 Summary of weights and volumes of ductwork from the Containment, Auxiliary, and Fuel Buildings

Parameter	Containment Building	Fuel and Auxiliary Buildings
Duct Weight (lb)	36,860	43,840
Length of Duct (ft)	1,763	2,803
Uncompacted Volume (ft^3)	12,000	11,290
Compacted Volume (ft^3)	1,462	1,717

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	54.82	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 HVAC equipment from the Containment, Auxiliary, and Fuel Buildings

Parameter	Containment Building	Fuel and Auxiliary Buildings
Equipment Wt. (lb)	79,700	50,000
Equipment Volume (ft^3)	27,450	17,220
Equipment Units	28	22

uncontaminated. Each unit consists of two fans, 18 cooling coils, and a steel frame supporting the coils and the enclosing steel skin. The units are supported on a steel frame attached to the Containment Building wall and have steel grating walkways around their perimeters for maintenance access.

Cooling water supply and return lines, which enter the containment at the 45-ft level and run up the Containment Building wall to the 205-ft level, comprise about 1,100 ft of 14-in.-dia. (0.375-in. wall) Class I carbon steel pipe. The distribution lines to the cooler units comprise about 500 ft of 8-in.-dia. (Schedule 40) Class I carbon steel pipe. Lines from the distribution headers to the individual cooling coils comprise about 105 ft of 3-in.-dia. (Schedule 40) Class I carbon steel pipe on each cooler unit, for a total of about 420 ft of pipe.

The cooling coils are mounted on the steel support frame, which is enclosed by the steel skin. Two fans are mounted within each cooler enclosure. The support frame is fabricated from 12-in. I-beams. The cooler support structure is fabricated from 24-in. I-beams.

The containment air coolers are disassembled in-place, using the existing gratings for access. The piping servicing the coolers is removed using oxyacetylene torches which cut at a rate of 12 in./min. The 3-in.-dia. piping from the distribution headers is removed first, followed by the 8-in.-dia. headers, then the steel enclosure skin, the cooling coils, the steel support frame, the fans, and finally, the gratings and the underlying support frame. All components are rigged and lowered to the operating floor below for packaging. The estimated quantities and cumulative volumes and weights of the cooler components are given in Table 3.18.

Table 3.18 Quantities and cumulative volumes and weights of components for the four containment air coolers

Component	Quantity	Volume (ft^3)	Weight (lb)
3-in. pipe	420 ft	21	3,184
8-in. pipe	500 ft	175	14,275
14-in. pipe	1100 ft	1,176	64,174
Cooler coils	72 ea.	1,872	115,200
Enclosure skins	40 pieces	25	12,500
Enclosure frames	204 pieces	282	60,900
Fans	8 ea.	1,017	59,200
Gratings	40 pieces	51	6,375
Support frames	48 pieces	1,648	235,200
Totals		6,267	571,008

The disassembly operations for each component of the containment air coolers are listed in Table 3.19, together with the estimated durations in crew-minutes. Since the crew is comprised of 2 craftsmen and 2 laborers, each crew has two teams which can perform many of the operations in parallel, thus reducing the total elapsed time, as marked in the table. Work difficulty adjustments for height (20%) are included for determining the adjusted work time duration. No adjustment is postulated for respiratory protection. In addition, adjustments for protective clothing (39.4%), break times (9.8%), and ALARA activities (8.2%) are applied to the adjusted work duration, for a total of 1.2 x 1.574 x 1,422 = 2,686 minutes or 44.8 crew-hours per cooler unit.

Table 3.19 Disassembly operations and their time durations for a containment air cooler

Disassembly operation	Duration (min.)
Cut and lower piping for packaging:	
3 in. dia., 72 cuts @ 12 in./min.	60(a)
8 in. dia., 8 cuts @ 12 in./min.	72(a)
14 in. dia., 16 cuts @ 12 in./min.	60(a)
Remove steel enclosure skin	120(a)
Remove cooling coils, 18 ea. @ 30 min. each	270(a)
Remove steel frame, 24 ea. @ 15 min. each	180(a)
Remove fans, 2 ea. @ 40 min. each	80
Remove gratings, 10 ea. @ 20 min. each	100
Remove support structure (1/4 of total structure)	480
	1,422

(a) Crew consists of two 2-person teams for these operations.

With 4 cooler units, the total duration of the cooler removal operation is estimated to be 179 crew-hours, or about 23 crew-shifts, with an estimated cost of about $33,754. With 2 crews per shift and 2 shifts per day, the schedule time for cooler removal is estimated to be about 6 calendar days.

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 an assumed dose rate of 1 mrem/hr to those workers directly handling the materials (i.e., craftsmen and laborers). The remaining crew members are assumed to receive no dose during these activities. The total radiation dose accumulation for removing the HVAC system equipment is estimated to be approximately:

1.62 (ductwork) + 0.51 (equipment) + 0.46 (coolers) = 2.59 person-rem

Packaging of the ductwork and the equipment for disposal is postulated to be in modified maritime containers. The estimated 3,179 ft^3 of compacted ductwork would occupy about 5 modified maritime containers. The estimated 44,670 ft^3 of HVAC equipment, exclusive of the containment air coolers, would occupy an additional 70 modified maritime containers. The estimated 6,267 ft^3 of containment air cooler components would occupy about 16 modified maritime containers, weight-limited. The number of modified maritime containers and their average weights are summarized in Table 3.20. Since none of this material is expected to be heavily contaminated, it will all be in the lowest cost category at the disposal site. The estimated costs for removal, packaging, transport, and disposal of the contaminated HVAC systems are summarized in Table 3.21.

Table 3.20 Summary of numbers of containers and weights for HVAC disposal

Component	Number of containers[a]	Weight of loaded containers
Ductwork	4.97	20,237 lb. ea.
Equipment	69.80	5,858 lb. ea.
Coolers	15.86	40,000 lb. ea.
Totals	90.63	1,143,866 lb.

(a) Packaged in modified maritime containers, 20 ft. x 8 ft. x 4 ft., 3,000 lb empty

Table 3.21 Estimated costs for HVAC removal and disposal

	Estimated costs (1993 $)				
Cost element	Labor	Packaging	Transport	Disposal	Total
Ductwork	107,355	24,662	6,615	167,390	306,023
Equipment	37,708	346,541	92,957	2,166,263	2,643,469
Containment Coolers	33,754	76,623	20,554	643,336	774,267
Totals	178,817	447,826	120,126	2,976,989	3,723,759

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 PWR power station are the Containment Building, the Fuel Building, and the Auxiliary Building.

The activities necessary to remove the piping and equipment from the Containment Building are described in some detail in separate Appendices because of the size and complexity of those efforts. Removal of piping and equipment from the Fuel and Auxiliary Buildings is relatively straight-forward, complicated primarily by the need to cut openings through a number of shielding enclosures to obtain access for dismantlement and egress for removal of the various tanks, pumps, heat exchangers, etc. Once the piping and equipment have been removed, the structures are vacuumed to collect any loose debris and/or radioactive materials. Following the vacuuming, the structures are surveyed to identify areas of significant radioactive contamination, which are then washed using high pressure water/vacuum cleaning systems. The resulting waste water is collected and treated for disposal. After the surfaces have again dried, another survey is conducted to identify areas that are still contaminated. Additional high pressure water/vacuum cleaning and/or surface removal using scabblers is used to remove the remaining contamination on the surfaces, with the waste water treated and the removed concrete collected and packaged for disposal. When surface removal is necessary, the concrete surfaces are assumed to be removed to a depth of 1 inch, based on data gathered in an experimental measurement program conducted at several reactor power stations.(7) 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 the Containment Building are postulated to be vacuumed and washed, including the inner surface of the containment shell itself. The surface orientation fractions are estimated to be about 66% horizontal, 34% vertical. Within the Fuel and Auxiliary Buildings, 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 3.22.

Within the Fuel and Containment Buildings, there are several large areas that are covered with stainless steel lining (spent fuel pool, cask loading pit and gate, fuel transfer canal and gate, cask wash pit, and refueling cavity). Those areas are washed, sectioned and transported to an LLW disposal facility for disposition. The areas involved are listed in Table 3.22. The concrete behind or beneath these stainless steel linings is postulated to be uncontaminated, even though some small areas might have been contaminated by leakage through the lining. The cost of washing these surfaces is estimated to be \$13,568. The radiation dose to workers doing the washing is estimated to be 0.12 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 cutting and packaging is estimated to be \$32,677, and the radiation dose to workers doing the cutting is estimated to be 0.72 person-rem.

The total volume of plate material removed is estimated to be about 210 ft^3, with a weight of about 104,784 lb. This material is placed into modified maritime containers (cost \$14,061) and transported to the LLW disposal facility (cost \$3,771). The disposal cost is \$118,056, including the handling surcharge. The total cost of removing, packaging, transporting, and disposing of the liner material is \$168,565, without contingency.

In addition to the various pool and gate liners, there are many metal stair treads throughout the facility, which have an estimated area of 4,673 ft^2. The stair treads are postulated to be decontaminated by vacuuming and washing using high-pressure water, similar to the pool liners. The

Table 3.22 Surface cleaning, concrete and metal surface removal in contaminated buildings

	Containment surfaces treated			Clean concrete	
				Concrete cutting	
Building	Vacuum/wash (ft^2)	Removed (ft^2)	Volume[a] (ft^3)	(in.-ft)	(ft^3)
Concrete Surface[a]					
Fuel Bldg.	22,864	6,571	548	8,664	3,800
Containment Bldg.	127,122	5,200	433	--	--
Auxiliary Bldg.	43,858	9,827	819	3,960	488
Totals	193,844	21,598	1,800	12,624	4,288
Metal Surfaces[b]					
Fuel Bldg.	15,428	15,428	161		
Containment Bldg.	4,691	4,691	49		
Stair Treads	4,673	--	--		
Totals	24,792	20,119	210		

(a) Average depth of removal is 1 in. Packaged @ 600 lb/55-gal. drum, burial volume of 3,196 ft^3.
(b) Average thickness of metal is 1/8 in.

labor costs for these efforts is estimated to be $2,820, and the associated radiation dose to workers is estimated to be 0.02 person-rem. About 10,000 gallons of water is estimated to be used in the washing process.

The concrete segments cut from selected shielding enclosures to obtain access to tanks and other equipment are generally considered to be clean, and are assumed to be suitable for unrestricted release. This material and the efforts required for removal are considered to contribute to "cascading" costs. The sizes of the openings into the various cells is dictated by the size of the contained equipment. The amount of concrete cutting necessary to obtain access to selected process cells for equipment removal and the volumes of concrete removed as "cascading materials" are presented in Table 3.22. The cost of cutting the various openings into selected process areas is estimated to be about $48,168.

Vacuuming and washing of the concrete surfaces is estimated to cost $123,978. The radiation dose to workers doing the vacuuming/washing is estimated to be 1.09 person-rem.

The costs for removing the contaminated concrete surfaces are estimated to be $283,859, and the radiation dose to workers doing the surface removal is estimated to be 4.81 person-rem. The contaminated concrete surface material is postulated to be packaged in 432 55-gallon drums, resulting in a disposal volume of 3,196 ft^3, and a packaging cost estimated to be $11,641. Transport and disposal of the removed concrete surface material is estimated to cost $9,348 and $155,009, respectively.

The estimated costs and radiation doses for cleaning, removal, transport, and disposal of the contaminated surface materials are summarized in Table 3.23, together with the

Table 3.23 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	123,978	1.09
Surface Removal	283,859	4.81
Packaging	11,641	
Transport	9,348	
Disposal	155,009	—
	583,835	5.90
Metal Surfaces		
Wash	13,568	0.12
Segment	32,677	0.72
Package	14,061	
Transport	3,771	
Disposal	118,056	—
	182,133	0.84
Stair Treads[a]		
Wash	2,820	0.02
Handrails[b]		
Wash	72,548	1.36
Waste Disposal	3,227	
	75,775	
Gratings[c]		
Removal	36,140	0.71
Packaging	16,450	
Transport	4,413	
Disposal	138,118	
	195,121	
Totals	1,043,459	8.83
Undistributed		
Wash Waster Treat/Dispose[d]	490,192	0.71

(a) The cost and radiation dose shown are based on an estimated total of 4,673 ft^2 of stair treads cleaned in the Containment, Fuel, and Auxiliary Buildings.
(b) The cost and radiation dose shown are based on an estimated 11,226 lineal feet of handrails cleaned in the Containment, Fuel, and Auxiliary Buildings.
(c) The cost and radiation dose shown are based on an estimated 11,265 ft^2 of grating removed from the Containment and Auxiliary Buildings.
(d) Based on an estimated volume of waste water of 27,330 gallons.

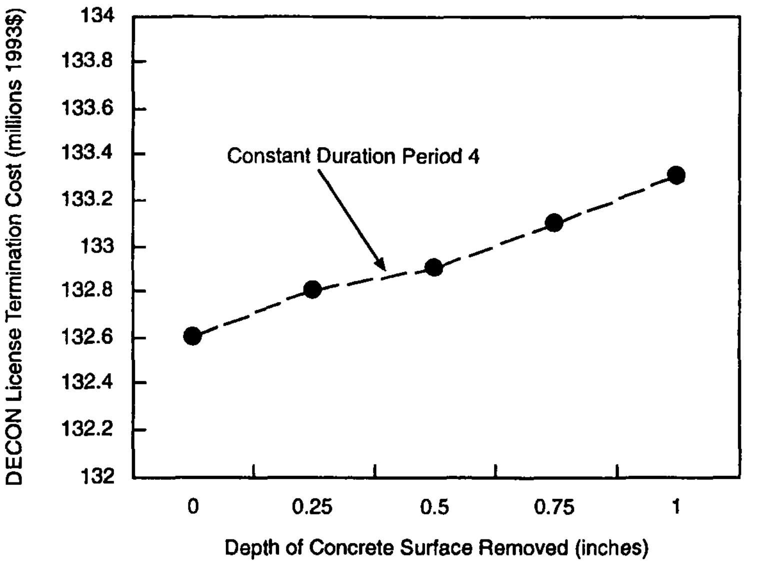
costs for treating and disposing of the contaminated wash water. The clean concrete segments are placed out of the way and left for future disposition during demolition. The total volume of water resulting from the washing operations which requires treatment, packaging, and disposal is about 27,330 gallons. The cost of treating and disposing of the water and its contained solids is estimated to be $490,192, with the radiation dose to workers about 0.7 person-rem.

Another factor affecting total license termination cost is the amount of contaminated concrete surface removed during facility decontamination. In the original PWR study (NUREG/CR-0130), the very conservative assumption was made that a 2-inch depth of concrete surface was removed from essentially all floors in the three potentially contaminated buildings (Containment, Auxiliary, and Fuel Buildings). In this reevaluation study, the assumption is to remove a 1-inch depth of surface from those areas anticipated to require surface removal, a significantly smaller area than in the previous study. The 1-inch depth may also be quite conservative, considering data on contaminant penetration of concrete surfaces given in NUREG/CR-4289.(7) Thus, an analysis of the sensitivity of DECON license termination costs to a range of concrete surface removal depths was performed. The calculation assumed that the length of Period 4 was constant, i.e., constant overhead staff costs, because the concrete surface removal effort is carried out in parallel with other activities on the schedule. The results are illustrated in Figure 3.11. 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 only $0.67 million.

Removal of Steel Floor Grating

It is assumed that contaminated steel floor grating (on stairs, platforms, and walkways) will be removed during decommissioning. Steel floor grating is assumed to weigh 10.4 lb/ft^2. The work is anticipated to require respiratory protection and the workers are expected to wear anticontamination clothing during removal operations. The rates of grating removal used in these analy are developed in the Unit Cost Factor for Removal of Steel Floor Grating (see Appendix C).

Two crews per shift, two shifts per day will be used for the removal operations. During an 8-hour (480 minute) shift (5.083 hours actual productive time), an estimated 291.2 ft^2 of grating can be removed per crew.



S9505009.3

Figure 3.11 **Sensitivity of license termination cost to varying depths of contaminated concrete removal during DECON**

The duration of the removal effort in the Containment and Auxiliary Buildings would be about 9.7 days, based on an estimated 11,265 ft^2 of grating to be removed. About 3.31 modified maritime containers are needed for the resultant waste produced from the removal operations.

The total cost for the removal and disposal of the grating in the Containment and Auxiliary Buildings is estimated to be $195,121, and the radiation dose to workers doing the removal is estimated to be 0.71 person-rem.

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. 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, but the workers are expected to wear anti-contamination clothing during cleansing operations.

The rates of handrail cleansing used in these analyses are developed in the Unit Cost Factor for Decontamination of Handrails (see Appendix C).

Two crews per shift, two shifts per day will be used for the cleansing operations. During an 8-hour (480 minute) shift, the actual cleansing time is estimated to be 5.33 hours (320 minutes). 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.

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. About nine 55-gallon drums are needed for the resultant waste produced from the cleansing operations.

The cost for the decontamination of the handrails in the Containment, Fuel, and Auxiliary Buildings is estimated to be $72,548 plus waste disposal costs of $3,227, and the radiation dose to workers doing the cleansing is estimated to be 1.36 person-rem.

3.4.9 Removal of Building Cranes

There are four major cranes within the facility that must be removed: the Polar crane and the Refueling bridge crane in the Containment Building, and the Building Bridge crane and the Fuel Handling bridge crane in the Fuel Building. The estimated costs and doses associated with removal of the Polar crane and the Fuel Building Bridge crane are developed in Appendix B and are summarized in Table 3.24, together with the costs and doses associated with the removal of the two fuel handling bridge cranes.

The two fuel handling bridge cranes are essentially identical except for length, 30 ft and 42 ft for the Refueling and Fuel Handling crane, respectively, with nominal widths of 6 ft. For purposes of estimating the weight of the bridges, it is assumed that each bridge 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 both bridges and accessories is estimated to be 24,765 lb.

The manipulator assembly and the railings are removed from the bridge, and the bridge is lifted from across the

Table 3.24 Estimated costs and doses for crane removal

Item	Estimated cost (1993 $)	Estimated dose (person-rem)
Polar Crane	326,336	0.0
Fuel Bldg. Bridge	164,889	0.0
Fuel Handling Bridges	84,301	0.31

pool/cavity to the operating floor, where it is cut into sections to fit within a modified maritime container. Based on the sizes of the bridges and their accessories, two of the containers will be required.

The operations to accomplish the refueling bridge(s) removal are estimated to require about 12 crew-hours, which when multiplied by the respiratory protection factor (1.2) and the non-productive time factor (1.574) results in about 23 crew-hours to complete the tasks. Costs for labor, packaging, transport, and disposal are estimated to be $4,309, $9,930, $2,664, and $67,398, respectively. The associated radiation dose is estimated to be about 0.31 person-rem.

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.

The estimated costs for environmental monitoring are presented in Table 3.25, on an annual cost basis. Since these activities are not particularly dependent upon exactly what is happening at the reactor site, these same annual costs are assumed to apply to the dismantlement period of the base scenario, to the extended safe storage period of the SAFSTOR scenario, and to the entombment decay period of the ENTOMB scenario.

3.4.11 Regulatory Costs During Dismantlement: Period 4

There are a number of costs that arise because of regulatory requirements. The exact nature and magnitude of these costs are somewhat dependent upon in which state the facility is located. The regulatory costs given in Table 3.26 are developed for the Trojan reactor in the State of Oregon. 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 $1,220,187, and the radiation dose to workers doing the surveys is essentially zero.

Table 3.25 Estimated annual costs for environmental monitoring

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

Table 3.26. Estimated regulatory costs during dismantlement: Period 4

Regulatory agency	Estimated cost (1993 $)(a)
Oregon State DEQ (onsite inspection)	3,000/yr(b)
Oregon State DOE (onsite inspection)	481,250/yr(c)
Oregon State Health Division, Radiation Control Section License	3,000/yr(d)
NRC (during periods of active decommissioning)	115,300/yr(e)
Total Regulatory Costs	602,550/yr
Certification Survey(f)	159,155(f)

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

(b) The Oregon State Dept. of Environmental Quality (DEQ) conducts inspections of the Trojan sewage treatment plant 1-day/year, based upon the licensee's Water Discharge Permit. These inspections are conducted under the auspices of the Federal Program, National Pollution Discharge Elimination System, delegated by the EPA to Oregon State.

(c) Based on reported billings by the Oregon State Department of Energy for the inspection program at Trojan for the period July 1, 1992, to June 30, 1993 (includes salaries for 3 onsite inspectors).

(d) This annual fee is for the plant's Radioactive Waste Handling License issued by the State of Oregon for cleanup and/or disposal of materials and equipment.

(e) 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.

(f) Listed for completeness. Included in total termination survey costs, not included in the total regulatory costs.

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 PWR 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 reactor site and U.S. Ecology's Washington Nuclear Center in Richland, Washington, and the disposal rates at that facility. However, 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.

To determine the sensitivity of the total license termination cost to disposal facility location, an additional calculation was made using the Cost Estimating Computer Program (Appendix C) under the assumption that the LLW from the reference PWR was transported to and disposed of in the Barnwell facility. The LLW that was postulated to be transported by barge to Richland was instead postulated to be transported by barge to Barnwell, with the remaining

LLW transported by truck. The Greater-Than-Class C radioactive wastes were again postulated to be disposed of in DOE's geologic repository. The disposal rate schedule for the Barnwell facility was used to calculate the LLW disposal costs, and 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 PWR was transported to and disposed of in the Barnwell facility was $181,961,804, without contingency. This cost is comprised of the decontamination, removal, and packaging costs (which remain the same for both situations), the steam generator subcontractor labor costs (which increased from $2,234,700 to $2,632,500 due to additional mobilization, demobilization costs), the transport costs (which increased from $4,269,297 to $10,760,566) and the disposal costs (which increased from $19,595,339 to $88,054,169, without contingency). These results are expected to represent a likely upper bound for those transport/disposal costs because of the distance between the reference PWR and the Barnwell facility.

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 $\$50/\text{ft}^3$, $\$100/\text{ft}^3$, $\$300/\text{ft}^3$, $\$500/\text{ft}^3$, and $\$1000/\text{ft}^3$. The associated disposal facility fees, surcharges, and taxes were held constant. All other parameters of the CECP calculation were also held constant. The results of the analysis showed that the total cost for DECON increased almost linearly with increased disposal cost, from $138.72 million for the $\$50/\text{ft}^3$ rate to $506.27 million for the $\$1000/\text{ft}^3$ rate, all values including a 25% contingency. The results of the calculations are listed in Table 3.27. 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 3.12 as functions of the LLW disposal charge rates.

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

Table 3.27 Sensitivity of DECON cost to LLW disposal charge rates[(a)]

	Costs, with contingency (millions of 1993 $)		Terms for LLW disposal cost escalation formula[(b)]			
Disposal charge rate ($\$/\text{ft}^3$)	Burial	Total DECON	Labor/matls. (A)	Energy (B)	Disposal (C)	Total - [taxes & ins.][(c)] (millions of 1993 $)
50	29.94	138.72	0.696	0.071	0.232	129.04
100	49.29	158.06	0.606	0.062	0.332	148.38
300	126.67	235.44	0.398	0.041	0.561	225.76
500	204.05	312.82	0.296	0.030	0.673	303.140
1000	397.50	506.27	0.181	0.019	0.800	496.59

(a) All other calculation parameters are held constant.
(b) These terms are discussed in Section 3.7.
(c) Taxes & Insurance costs for 1993 = $9.68 million.

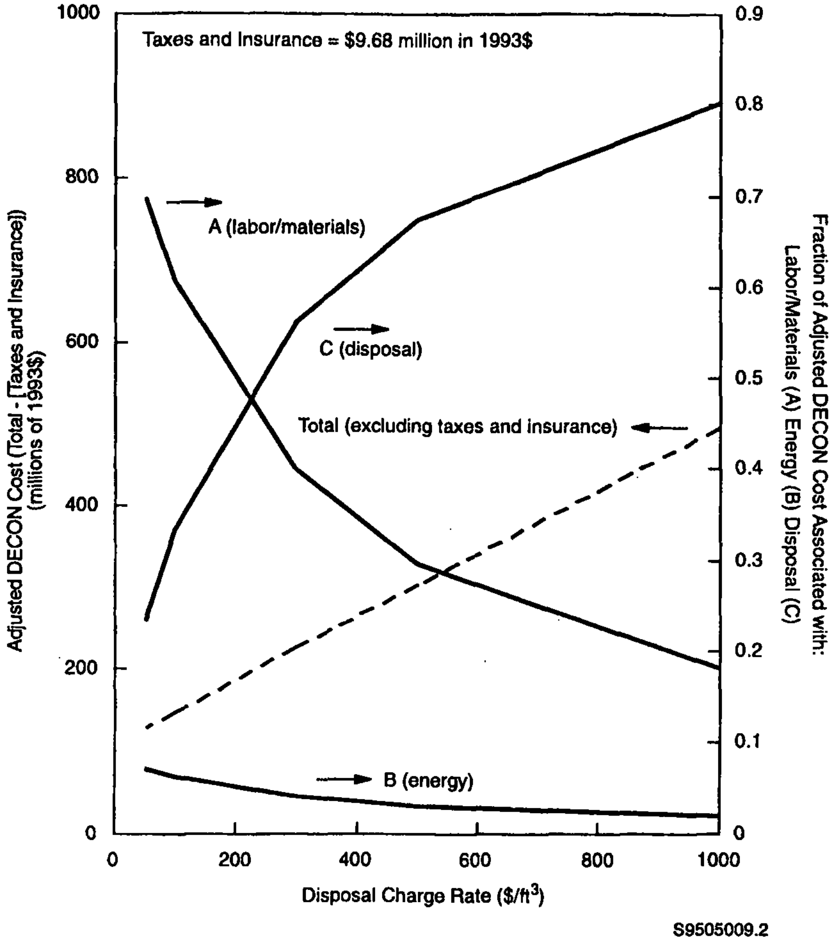


Figure 3.12 Variation of DECON escalation formula terms as functions of low-level waste disposal charge rates

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 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 11 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 this expression results in the present value of the total license termination cost at 2.5 years prior to reactor shutdown being $108.4 million, as compared with the constant dollar value of $133.3 million, both values including a 25% contingency. Thus, requiring the funding needs to be calculated in constant dollars prior to reactor shutdown results in about a 23% 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 PWR can be classified into the four categories defined in 10 CFR 61.55. 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: Class A 280,934 ft^3, 7,955 m^3 (96.47%); Class B/C 9,900 ft^3, 280 m^3 (3.40%); and GTCC 386 ft^3, 11 m^3 (0.13%). 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 PWR, 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 PWR are:

[Total Cost - (T & I Cost)]$_{(1993\ \$)}$ = \$123.6 million
A (labor/materials) = 0.727
B (energy) = 0.075
C (disposal) = 0.198
[T & I](1993 \$) = \$9.68 million

All values include 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 3, *Report on Waste Burial Charges.*(8)

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

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

This factor is derived in Reference 8 for disposal at the Hanford and Barnwell facilities, based on the inventory of decommissioning wastes developed in the original PWR study(1), i.e., Year 0 is 1986. Subsequent revisions to

NUREG-1307 will utilize the waste inventory from this current PWR reevaluation study as the baseline inventory upon which to develop the waste disposal escalation factor, B_x for the reference PWR. 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 4.547, based on the estimated total burial costs at Hanford ($22.4 M) and at Barnwell ($102.0 M), from Tables C.1 and C.2 in Appendix C.

3.8 References

1. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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. 1988. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station: Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule - Addendum 4.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

5. Portland General Electric Company. PGE-1037, *Trojan Nuclear Plant Spent Fuel Storage Rack Replacement Report.* 1983.

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

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

8. *Report on Waste Burial Charges - Escalation of Decommissioning Waste Disposal Costs at Low-Level Waste Burial Facilities.* NUREG-1307, Revision 3, U.S. Nuclear Regulatory Commission, Washington, D.C. May 1993.

4 SAFSTOR for the Reference PWR Power Station

The second alternative considered in this reevaluation of decommissioning of the reference pressurized water reactor (PWR) 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 concrete bioshield) will decay to unrestricted release levels within 60 years following reactor shutdown. The RPV, insulation, and bioshield 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 storage pool. Fuel from the last core is postulated to have to remain in the pool for about 7 years after shutdown until it is sufficiently cooled to permit dry storage, at which time the fuel remaining in the pool is transferred into a dry fuel storage facility onsite. During that period, 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.

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 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 reactor spent fuel pool is unacceptable. In some situations, continued pool storage may be the most cost-effective approach, as discussed in Appendix D.4.3, avoiding the cost of constructing and furnishing a dry storage facility.

Once the pool has been emptied, the pool-related systems are deactivated, and the facility is put into safe storage for 51.4 years, during which time the contaminated materials (not activated materials) are postulated to decay to levels of radioactivity that satisfy the criteria for unrestricted use, (see Regulatory Guide 1.86[(1)]). Selected active dismantlement activities begin upon termination of the extended safe storage period. 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] are discussed and summarized in this chapter. The activities are presented approximately in their order of occurrence, together with estimates of cost and occupational radiation dose. The decommissioning activities are postulated to occur within five designated periods of time, as illustrated by the schedules for SAFSTOR1 and SAFSTOR2, shown in Figures 4.1 and 4.2, respectively. Layup of the spent fuel pool 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

---

[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 $)								
Period number	**Duration[a] (years)**	**DECON[b]**	**Remove[c]**	**Package[d]**	**Transport[e]**	**Disposal[f]**	**Undistributed[g]**	**Total**	**Estimated radiation dose (person-rem)**
1	2.5	--	--	--	--	--	9,107,715	9,107,715	--
2	0.62	14,324,600	473,160	106,149	1,109,278	3,431,437	9,493,178	28,937,802	208.76
3	6.3	--	--	--	--	--	5,896,958	5,896,958	20.53
4	51.38	754,211	--	66,588	789	83,957	84,985,567	85,891,111	88.02
5 (SAFSTOR1)	0.27	--	335,258	206,642	247,525	1,105,745	7,367,605	9,262,774	1.50
5 (SAFSTOR2)	1.7	1,592,009	11,800,060	2,140,064	3,159,231	15,784,218	26,017,694	60,493,276	7.85
Total SAFSTOR1	58.57	15,078,810	808,418	379,379	1,357,591	4,621,139	116,851,023	139,096,361	318.82
Total SAFSTOR2	60.00	16,670,820	12,273,220	2,312,801	4,269,297	19,299,612	135,501,112	190,326,862	325.17
					Total Cost for SAFSTOR1 with 25% contingency			173,870,452	
					Total Cost for SAFSTOR2 with 25% contingency			237,908,578	

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

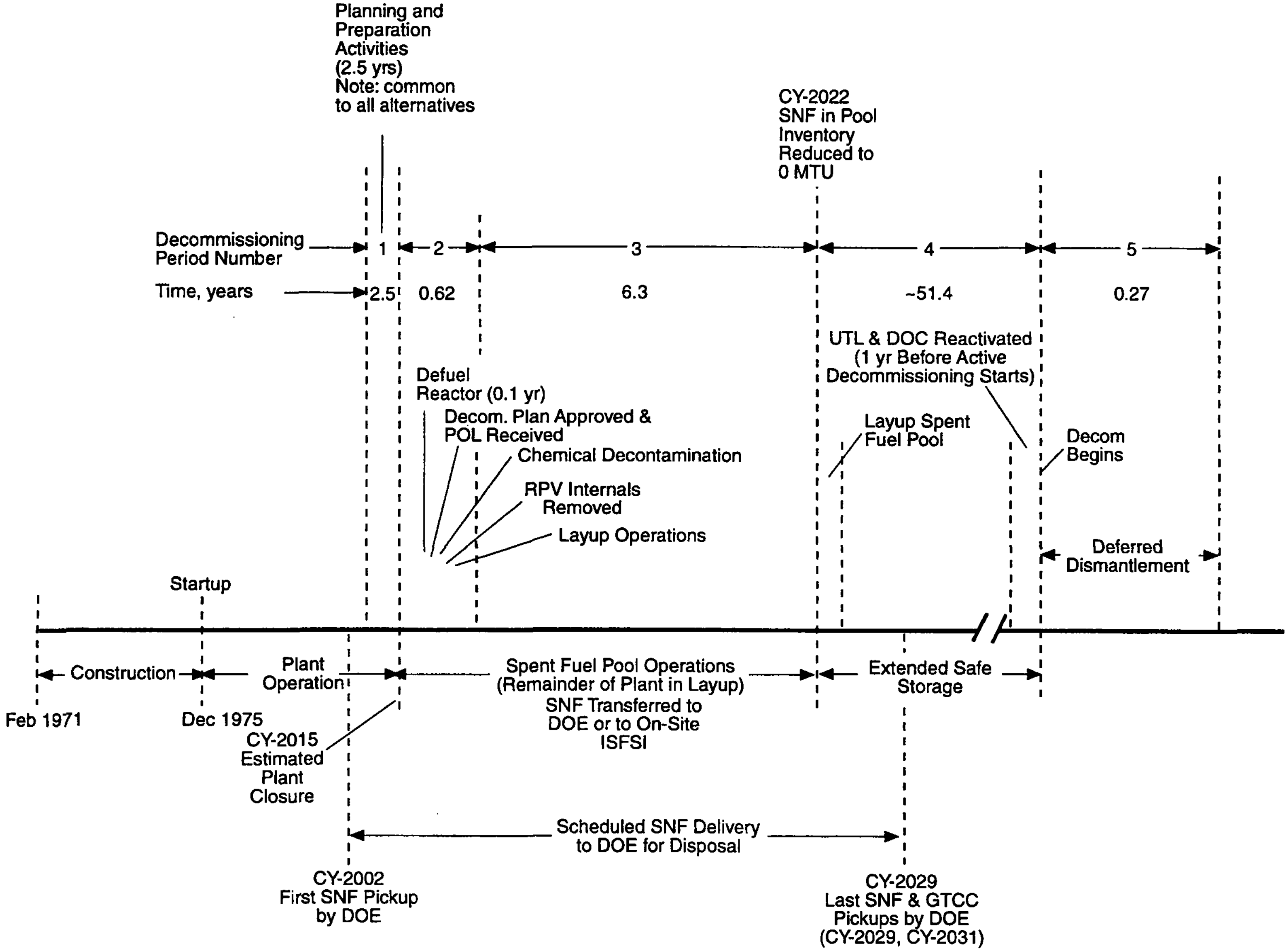
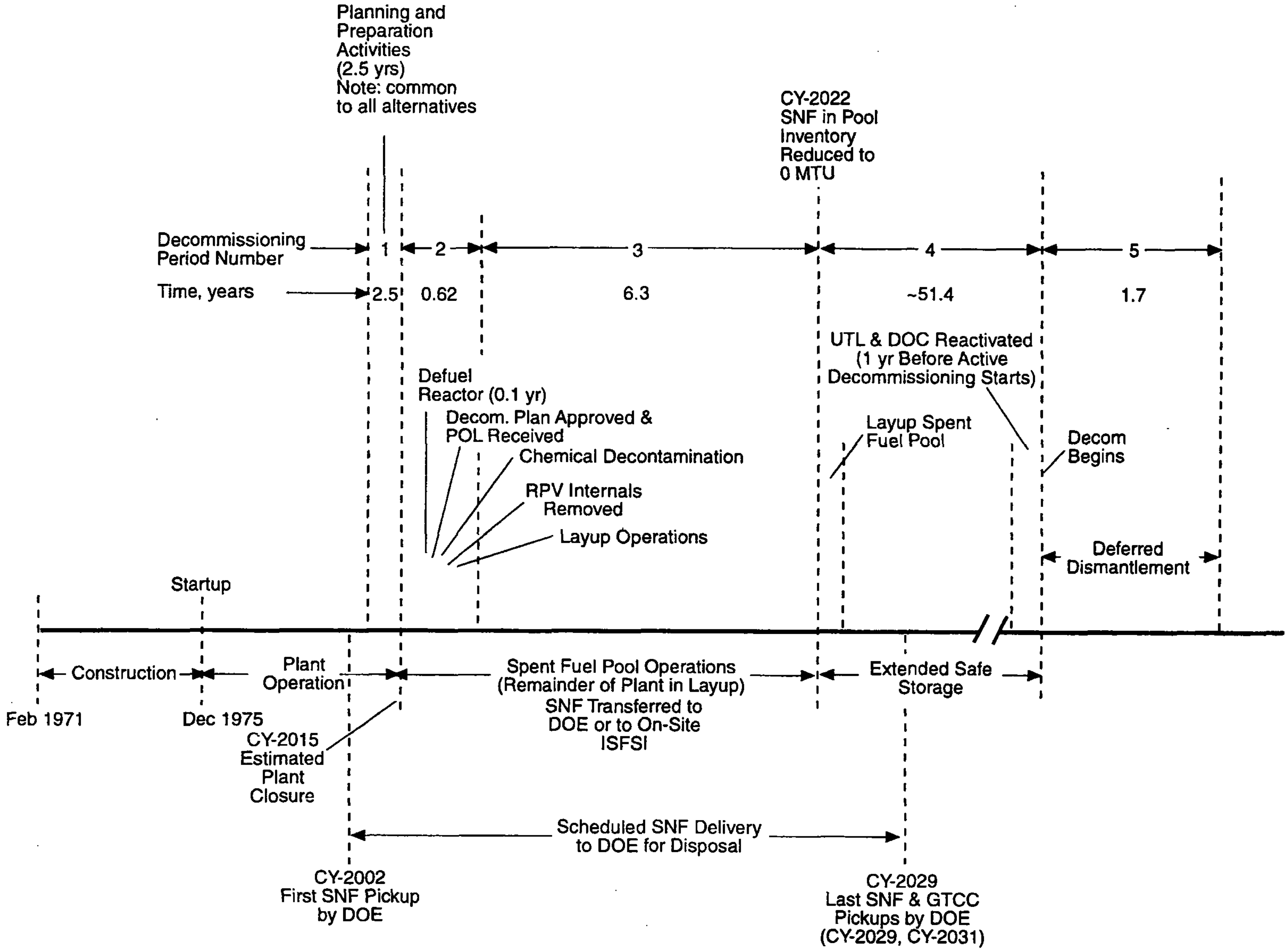


Figure 4.1 Schedule of activities during the five decommissioning periods of SAFSTOR1



S9304067.15b

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

for SAFSTOR1 and SAFSTOR2. The costs and occupational radiation doses associated with these two activities are described below, together with the extended safe storage costs over a period of about 51.4 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 SNF inventory in the storage pool to zero, approximately 7 years after final shutdown (see Appendix D for details), the spent fuel pool (SFP) water cannot be released without some form of additional treatment since all waste solutions are expected to contain measurable radioactivity. Therefore, the 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 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). Protective clothing and equipment for vendor's staff are expected to cost the utility about $11,340.

Since the waste activity concentration 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 these activities. However, for the purpose of this study, a radiation dose of approximately 2 person-rem is assumed for these activities, and it is roughly estimated that about five of the 5.72-m^3 high-integrity containers (HICs) could be required.

Based on information contained in Appendix B, the cost of five HICs is estimated at $39,125, including the transportation cost for the HICs from the manufacturer to the plant site. Cask rental charges for 21 days are estimated to cost $26,250. Burial costs are estimated to be $67,590, based on the assumption that each individual 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 are washed using high-pressure water wash/vacuuming, as described in Section 3.4.8 of Chapter 3. At the calculated generation rate of 1 gallon per minute of system operation (see Section C.2.12 for details), it is estimated that approximately 1,929 gallons of high solids, low activity waste solutions will result from the surface cleansing tasks associated with the spent fuel pool. It is postulated that a transportable evaporator-solidification system, together with specialty contractor operating personnel, will be used to provide this liquid radioactive waste handling capability at the reference PWR. Based on discussions with senior staff at Pacific Nuclear Services, the waste solutions are estimated to be processed for disposal (i.e., evaporated/solidified in eleven 55-gallon drums) at a unit cost of about $10/gallon. Mobilization/demobilization costs add another $20,000, resulting in a total cost of $39,290 for this fixed-price contract. Overall, about 5 days are required to complete the task, including mobilization/demobilization. Occupational radiation exposure is anticipated to be less than 0.1 person-rem. The cost of the drums, cask rental, transportation and final disposal of the drums is the responsibility of the licensee. Based on information contained in Appendix B, the drums are estimated to cost $296; cask rental for 14 days is estimated to be $17,500; total transportation costs are estimated to be $10,890; and disposal costs are estimated to be

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]	750,000	~2
Transportation of HICs to Plant Site from Mfgr.[c]	4,211	--[d]
High-Integrity Containers[e]	39,125	--
Cask Rental[f]	26,250	--
Transportation	--[g]	--
Burial[h]	67,590	--
Totals	887,176	~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.

$9,159. The latter cost is calculated based on the assumption that each drum contains less than 100 curies of radioactivity. The total estimated costs and occupational radiation exposure for this activity are summarized in Table 4.3.

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 4.4. Based on the estimated annual cost of $1,599,578 given in the table, the total basic costs during the 51.38-year safe storage period are $84,985,567. These costs include the ramp-up of the utility and DOC staffs during the final 1 year of safe storage, which are presented in Table 4.5. The estimated cumulative occupational radiation dose during this period of safe storage is less than 88.02 person-rem, based on information for similar activities previously calculated in NUREG/CR-0130.[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

Table 4.3 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 Specialty Contractor(b)	39,390	~0.1
Drums(c)	296	
Cask Rental(d)	17,500	
Transportation(e)	10,890	
Burial(f)	9,159	—
Totals	77,135	~0.1

(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.2.
(d) Based on Table B.3.
(e) Based on direct quote from Tri-State Motor Transport company. Includes transportation charges for the empty cask from Barnwell, SC to Trojan, the loaded cask from Trojan to Hanford, and the empty cask back to Barnwell, SC.
(f) Based on Table B.4.

not require such a force at a facility that does not contain any special nuclear materials, and a reasonable level of industrial security could provided using strongly secured structures and electronic surveillance systems. Thus, security costs could possibly be reduced from the currently estimated $481,136/year to something more in the range of $100,000/year, making a significant reduction in the annual safe storage costs.

4.3 Deferred Dismantlement--SAFSTOR Period 5

It is postulated that about 58 years after the reference PWR is shut down the owner will want to eliminate the responsibilities associated with the possession-only license, and 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.

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 biological 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.

Table 4.4 Estimated extended safe storage costs at the reference PWR(a,b)

Utility staff required	Annual cost (1993 $)(c)
Plant Manager	104,824
Clerk	27,150
Sr. Health Physics Tech.	73,045
Control Operator	72,988
Custodian	32,248
Security Manager	86,819
Security Shift Supervisor (3)	115,317
Security Patrolman (8)	279,000
Subtotal, Personnel Costs	791,391
Operation & Maintenance Allowance	17,379
Laundry Services	11,141
Electric Power (330,000 kWh/yr @ $0.034/kWh)	11,220
Environmental Monitoring	48,603(d)
Oregon State DOE (On-site Inspection Program)	10,000(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	90,000
Nuclear Liability & Property Insurance	600,000(h)
Subtotal, Non-Personnel Costs	808,191
Total, Annual Operating Cost	1,599,578

(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 4.5 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	129,518	1.00	129,518
Secretary	29,110	1.00	29,110
Contracts/Procurement Spec.	69,026	1.00	69,026
Quality Assurance Manager	86,819	1.00	86,819
Health Physics Manager	79,449	1.00	79,449
Nuclear Records Spec.	61,429	1.00	61,429
Plant Operations Manager	97,440	1.00	97,440
Training Engineer	74,735	1.00	74,735
Plant Engineers[b]	72,619	2.00	145,238
Maintenance Manager	95,410	1.00	95,410
Utility Overhead Totals		11.00	868,174
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)			2,799,266

(a) Salary rates include 42% overhead on utility salaries; 110% overhead plus 15% profit on DOC salaries.

(b) Includes an estimated equal level of effort of 0.20 FTE for each of 10 engineers (civil, cost, electrical, environmental, licensing, mechanical, nuclear, planning and scheduling, quality assurance, and radiological assessment).

As can be seen in Table 4.1, Period 5 is much shorter in duration for SAFSTOR1 (0.27 years) than for SAFSTOR2 (1.7 years). This is because in SAFSTOR1, only the RPV, vessel insulation, and the concrete bioshield 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 $139.1 million, and the total decommissioning cost for SAFSTOR2 is estimated to be $190.3 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 C of NUREG/CR-0130[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 PWRs yielded contamination levels that were about a factor of 2 less than the levels used in NUREG/CR-0130. In addition, chemical decontamination of the RCS and associated coolant piping and components would provide another factor of 3 to 10 reduction in the residual contamination levels within the systems. Thus, it appears that the residual levels of radioactivity within the plant systems at the end of the extended safe storage period may be as much as a factor of 10 beneath the limits for unrestricted use, and termination of the license could be accomplished without further efforts. However, should it be determined at the end of the extended safe storage period that the radioactivity on the contaminated materials had not decayed to levels permitting unrestricted use, then all of the removal and disposal activities of DECON Period 4 would be necessary, and the cost would be increased by about $51 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 $74.7 million for SAFSTOR1 and $83.0 million for SAFSTOR2, without 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. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

4. K. S. Abel, et al. 1986. *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.

5 ENTOMB for the Reference PWR 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 PWR 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 RPV internals) present in the facility after termination of spent fuel pool operations are consolidated, packaged, and stored in the lower portion of the Containment 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 and concrete bioshield 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 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 lower portion of the Containment 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 Containment Building remain in place, without disassembly. These differences result in a reduced duration for the decontamination/dismantlement activities that take place during Period 4.

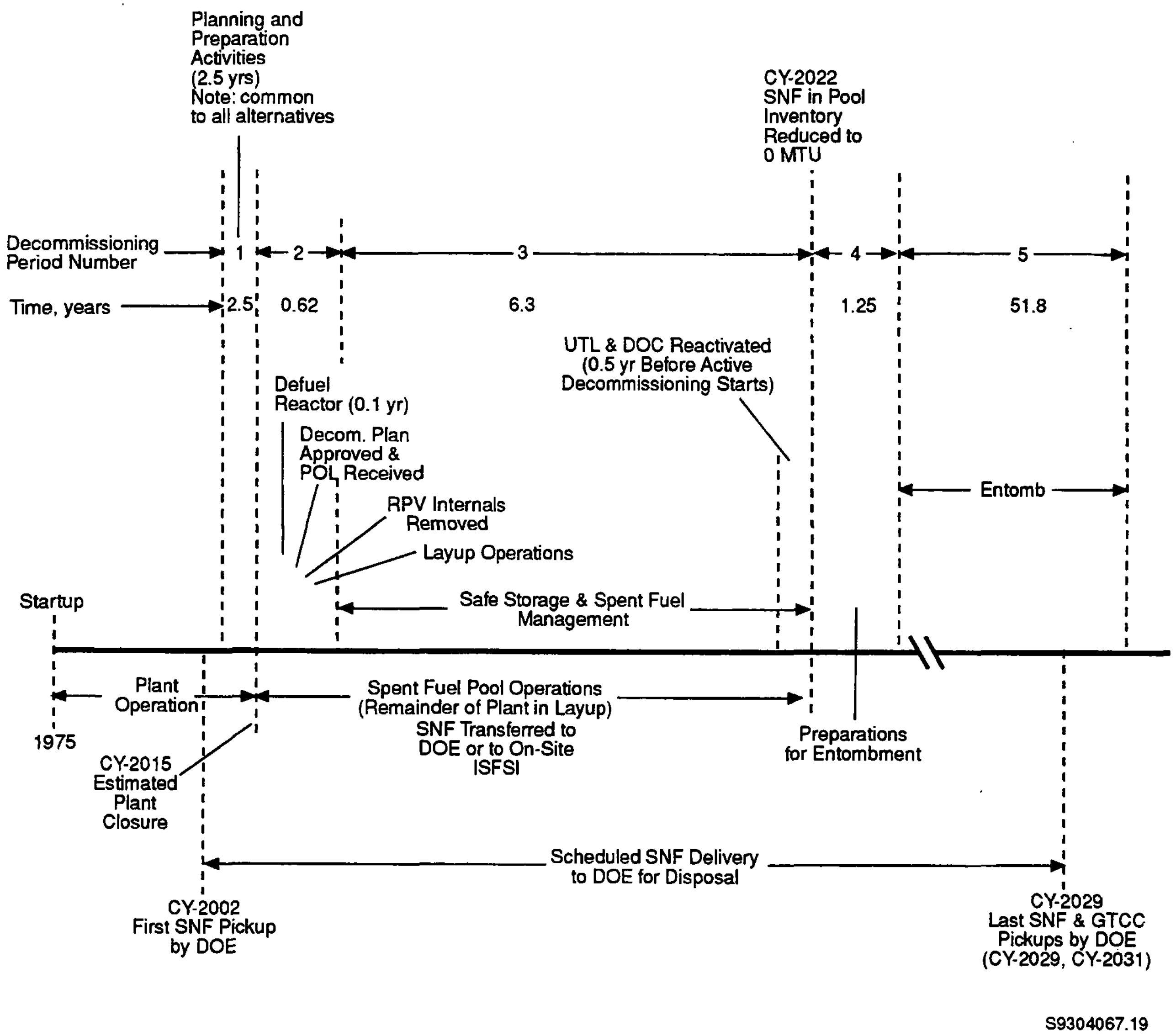


Figure 5.1 Schedule of activities during the five decommissioning periods of ENTOMB

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, insulation, and concrete biological 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 are 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 none of the reactor coolant system (RCS) piping and equipment located within the Containment Building is disassembled or packaged, but is left intact. The RPV, insulation, and concrete bioshield remain in place in the lower containment structure for ENTOMB1 and ENTOMB3, but are removed for disposal in ENTOMB2. The HVAC ductwork and equipment in the lower portion of the Containment Building remains in place in all three scenarios. The steam separators are removed from the steam generators and stored in the lower containment structure, with the rest of the steam generators remaining in place. Activities within the Fuel Building and Auxiliary Building are essentially identical with those given for DECON in Chapter 3, except that the packaged material is placed within the lower portion of the Containment 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 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

Activities in the Fuel and Auxiliary 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 taken to the Containment Building and placed in the lower portion of the building. It is postulated that the effort to accomplish these operations is 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 the Auxiliary and Fuel Buildings. There are reductions in cost because there will be no 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]
Oregon State DOE	Onsite Inspection Program	10,000/yr[b]
NRC	General inspections (2/yr)	11,652/yr[c]
	Security inspection (1/yr)	3,532/yr[d]
Subtotal, Annual Regulatory Costs		25,184/yr
Other costs		
Third Party Safety Inspection		4,660/yr
Nuclear Insurance		600,000/yr[e]
Plant Security (8 persons)		269,576/yr[f]
Property Taxes		90,000/yr
Environmental Monitoring		48,603/y r
Subtotal, Other Costs		1,012,839/yr
Total Annual Costs		1,038,023/yr

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Based on reported billings by the Oregon State Department of Energy for the inspection program at Trojan for the period July 1, 1991, to June 30, 1992.
(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 Containment Building are somewhat different from those given for DECON in Chapter 3 and associated appendices (E and F). Some significant concrete cutting operations are required to open passages through the operating floor (93-foot elevation in the reference PWR) and to remove some concrete shelves, to provide clearance for stacking containers of waste. Openings are postulated to be cut in two locations, on opposite sides of the operating floor, each opening slightly more than 60 ft in length, and about 18 ft wide, with one edge of each opening following the curvature of the containment wall. Directly below these openings, the main steam output and return lines and a concrete shelf (located at the 77-ft elevation) are removed to provide a similar clear space. The stairways located in these areas are also removed, thereby making a clear area all the way to the floor of the Containment Building. The accumulator tanks are removed, segmented, and packaged, to clear the bottom floor area. It is postulated that this space will provide capacity for the modified maritime containers (8 ft x 20 ft x 4 ft) to be stacked 4 containers per layer, 11 layers high, for a total of 88 containers. In addition to the modified maritime containers, space is available for about 88 of the B-25 containers (4 ft x 6 ft x 4 ft) to be stacked beneath the operating floor. Additional space is available in the refueling cavity for up to 42 of the modified maritime containers, or for other LLW packages.

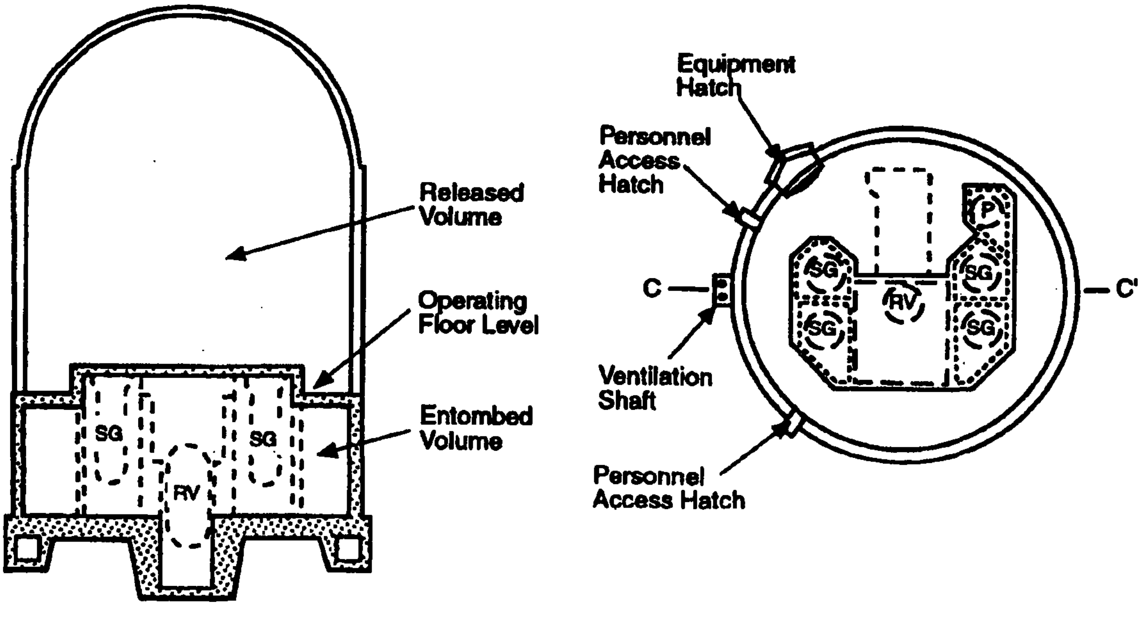
Because the levels of activity in the reactor vessel wall, vessel insulation, and the surrounding biological shield are not expected to decay to unrestricted use levels within the

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 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.

To facilitate enclosing the lower portion of the Containment Building, the steam separator sections of the steam generators are removed, leaving the tube bundle and shell below the top of the steam generator enclosures, which are then sealed with a poured reinforced concrete cap. The pressurizer enclosure is left intact. The steam separator sections are packaged as their own containers. One of the sections is placed into the reactor vessel cavity, above the remnants of the reactor vessel, and the remaining three sections are placed wherever space is available. The containment air coolers are disassembled and packaged for storage within the containment structure.

The size of the spent fuel racks preclude placement of them within the Containment Building and they are removed, packaged, and transported to an LLW disposal facility.

Once the placement of the waste containers within the Containment Building has been completed, the sections of the operating floor that were removed earlier are put back in place, and all openings through the operating floor are sealed by laying a one-foot-thick slab of reinforced concrete over the operating floor. The steam generator enclosures are also capped at this time. A general illustration of the entombment boundary within the Containment Building is shown in Figure 5.2.



Section C-C'

Figure 5.2 Illustration of the entombment barrier

All penetrations through the containment barrier are cut and the openings are filled with concrete and capped by welding plates over the openings, including the emergency personnel exit near the bottom of the Containment Building. To avoid precluding beneficial use of the space above the entombed material, the space above the entombment slab on the operating level is decontaminated. The polar crane is also decontaminated and left in place. The Fuel and Auxiliary Buildings are decontaminated to unrestricted release levels, along with the rest of the site, as described in Chapter 3.

That portion of the Containment 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 Containment Building, only industrial security (2 persons onsite around the clock) will be necessary to assure that no one obtains access to the entombed portion of the building. A comprehensive radiation survey is performed over all of the site except the entombed portion of the containment 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 assure 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 $129.7 million for ENTOMB1, about $131.7 million for ENTOMB2, about $23 and $25 million, respectively, more than DECON, in constant 1993 dollars without contingency. The cumulative radiation dose to workers is about 803 person-rem for ENTOMB1 and about 852 person-rem for ENTOMB2, roughly 100 to 150 person-rem less than DECON. Thus, the ENTOMB scenarios result in a cumulative radiation dose reduction of only about 11 to 15%, and a cost increase of about 22 to 23%.

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 assure 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 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 $376 million, without contingency, and the cumulative radiation dose would be about 803 person-rem.

Table 5.2 Results of cost and dose analyses for ENTOMB

	Est. costs (1993$)		Est. dose (person-rem)	
Cost element	**ENTOMB1**	**ENTOMB2**	**ENTOMB1**	**ENTOMB2**
DECON (w/o contingency)	106,613,904	106,613,904	953.09	953.09
Activities NOT conducted during ENTOMB				
Reduced Dry Active Waste	234,365	234,365	0	0
Shortened Period 4	6,567,047	6,567,047	10.61	10.61
Main Steam (in Contain.)	309,094	309,094	7.70	7.70
Bioshield removal	1,004,407	0	31.22	0
RCS piping/components	1,982,185	1,982,185	23.96	23.96
Hanger removal & packaging	800,000	800,000	0.51	0.51
Steam Gen. & Casc. Cost	11,739,652	11,739,652	60.00	60.00
Refueling Cavity Liner	39,948	39,948	0.19	0.19
Reactor Pressure Vessel	1,002,223	0	17.68	0
Polar crane removal	318,794	318,794	0	0
Contain. Surfaces decon	284,992	284,992	1.90	1.90
Trans./Dispose (Other LLW)[a]	6,174,551	6,174,551	0	0
HVAC Ducts/Equipment	2,720,318	2,720,318	0.94	0.94
Termination Survey (DECON)	1,220,187	1,220,187	0	0
Total Deductions for ENTOMB	34,397,763	32,391,133	154.71	105.81
New activities conducted during ENTOMB preparations				
Concrete cutting openings		26,950		1.87
Steam Separator removal		4,457		0.50
Vessel Penetration sealing		46,243		2.20
Entombment Cap barrier		208,000		0
Polar Crane decontamination		7,542		0
Site Radiation Survey		931,213		0
Additions during ENTOMB Prep.		1,224,405		4.57
Activities during and following ENTOMB preparation	**ENTOMB 1,2**	**ENTOMB3**		
Storage Period Duration	51.8 yrs	291.8 yrs		
Security	13,964,037	78,662,279		NA
Regulatory Costs	1,304,531	7,348,691		NA
Environ. Monitoring	2,517,635	14,182,355		NA
Nuclear Insurance	31,080,000	175,080,000		NA
Property Taxes	4,662,000	26,262,000		NA
License Termination Survey	2,440,374	0		NA
Third-party Safety Inspect.	241,388	1,359,788		NA
Additions for Storage	56,209,965	302,895,113		NA
Total ENTOMB1 (60 years)	129,650,511	--		802.95
Total ENTOMB2 (60 years)	131,657,141			851.85
Total ENTOMB3 (300 years)	--	376,335,659		802.95
ENTOMB1 (w/25% contingency)	162,063,139	--		802.95
ENTOMB2 (w/25% contingency)	164,571,426	--		851.85
ENTOMB3 (w/25% contingency)	--	470,419,574		802.95

(a) Total LLW transportation and burial costs arising from building decontamination activities and removal of contaminated plant systems.

The principal cost drivers for ENTOMB are the cost of plant security and the cost of 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. Under these revised continuing expenditure assumptions, the annual cost during entombment is about \$370,558/yr, and the constant dollar costs for the ENTOMB1 and ENTOMB2 scenarios are about \$116 million and \$118 million, respectively, including a 25% contingency. Similarly, the 300-year ENTOMB3 scenario cumulative cost would be reduced to about \$210 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 C of NUREG/CR-0130(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 PWRs 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 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 \$103.3 million for ENTOMB1 and \$105.2 million for ENTOMB2, as compared with the constant dollar values of about \$162 million and \$165 million, respectively, all values including a 25% contingency. Thus, calculating the funding needs in constant dollars of the year 2.5 years prior to reactor shutdown can overestimate the actual funding needs for ENTOMB by over 56%, depending upon the real discount rate available, and can provide a significant safety margin to cover unforeseen events. For the 300-year ENTOMB3 scenario, the present value cost is about \$109.8 million, as compared with the constant dollar value of about \$470 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 \$86.0 million and \$87.9 million, respectively. For the 300-year ENTOMB3 scenario, the present value cost would be reduced to about \$87.7 million. Thus, it is seen that extending the entombment period from 60 years (ENTOMB1) to 300 years (ENTOMB3) adds relatively little to the estimated present value costs (about \$5 million to the base analysis, and about \$1 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. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

4. K. S. Abel, et al. 1986. *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.

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 up to 7 years following reactor shutdown due to the need to cool the high burnup spent nuclear fuel (SNF) in the reactor pool until the cladding temperature limits for dry storage can be met. This delay produces an increase in decommissioning costs due to the accumulated costs during the short safe storage period while the SNF pool continues to operate. Alternatively, the SNF could be stored 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 for a significantly longer time, up to 14 years after shutdown, assuming the FWMS were to begin receiving SNF on its original schedule. This latter alternative was not evaluated in this study.

There are two principal groups of costs that dominate the cost of decommissioning. These are: undistributed costs (primarily overhead staff), and low-level radioactive waste (LLW) disposal costs. 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 the direct decommissioning activities in parallel and on multiple shifts, to the extent possible, to minimize the duration of the active decommissioning period 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, the LLW disposal rates have always 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).

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 ($480,000/yr for SAFSTOR, $270,000/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 for extended time periods can be rather large.

The range from the least expensive scenario (SAFSTOR1, $93.4 million) to the most expensive scenario (ENTOMB3, $109.8 million) is only about $17 million, or about 18% of the least cost scenario. 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 319 person-rem (SAFSTOR1) to 953 person-rem (DECON), a difference of only about 634 person-rem, which is roughly equivalent to a few years of normal reactor operation. The dose resulting from SAFSTOR is more than a factor of two smaller than the dose from DECON or ENTOMB, with most of the SAFSTOR dose associated with the initial plant layup activities which are common to all alternatives. The radiation doses from DECON and ENTOMB are quite similar, since the majority of the dose in both alternatives is associated with the early plant dismantlement activities.

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 = 3.7×10^{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 $1\ \text{Ci} = 3.7 \times 10^{10}$ 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 the body of radioactive material. [see 10 CFR 32 § 32.2(a)].
Dose Equivalent (H) (radiation protection):	The product of absorbed dose, quality factor, distribution factor, and other modifying factors necessary to obtain at a point of interest in tissue an evaluation of the effects of radiation received by exposed persons, so that the different characteristics of the radiation effects are taken into account. These characteristics may be indicated by modifying adjectives to the term, e.g., dose equivalent, residual.
Dose Equivalent, Maximum Permissible (MPDE) (radiation protection):	The largest dose equivalent received within a specified period permitted by a regulatory committee on the assumption that there is no appreciable probability of somatic or genetic injury. Different levels of MPDE may be set for different groups within a population.
Dose Equivalent, Residual:	The dose equivalent remaining after correction for such physiological recovery as has occurred at a specific time. It is based on the ability of the body to recover to some degree from radiation injury following exposure. It is used only to predict immediate effects.
Dose Meter:	An instrument used for measuring or evaluating the absorbed dose, exposure, or similar radiation quantity (also call "dosimeter").
Dose Rate, Absorbed (D):	The increment in absorbed dose during a suitable small interval of time divided by that interval of time.
Dosimeter:	See dose meter.
Electron Capture (EC):	The capture of an orbital electron by the radioactive nucleus of an atom. This transformation decreases the atomic number of the nucleus by one.
Entombment:	The encasement of radioactive materials in concrete or other structural material sufficiently strong and structurally long-lived to ensure retention of the radioactivity until it has decayed to levels that permit unconditional release of the site.
Environmental Surveillance:	A program to monitor the discharges of radioactivity or chemicals from industrial operations on the surrounding region. As used in this study, it is the program to monitor the extent and consequences of releases of radioactivity or chemicals from the nuclear power plant.
Excess Insurance:	A policy or bond covering the insured against certain hazards, and applying only to loss or damage in excess of a stated amount. The risk of initial loss or damage (excluded from the Excess Policy or bond) may be carried by the insured himself; or may be insured by another policy or bond, providing what is known as "primary insurance."

Exposure:	For x or gamma radiation in air, the sum of the electrical charges of all of the ions of one sign produced in air when all electrons liberated by photons in a suitably small element of volume of air are completely stopped in air, divided by the mass of the air in the volume element. It is commonly expressed in roentgens, but the SI unit of exposure is coulombs per kilogram, where $1 R = 2.58 \times 10^{-4}$ C/kg exactly.
Financial Protection:	The ability to respond in damages for public liability and to meet the costs of investigating and defending claims and settling suits for such damages.[2]
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 non-radioactive 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.

---

[2] Definition found in the Atomic Energy Act of 1954, as amended.

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.[3]
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)].

---

[3] Definition found in the Atomic Energy Act of 1954, as amended.

Radiation:	1) The emission and propagation of radiant energy: for instance, the emission and propagation of electromagnetic waves or protons. 2) The energy propagated through space or through a material medium: for example, energy in the form of alpha, beta, and gamma emissions from radioactive nuclei.
Radiation Area:	Any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive a dose in excess of 5 millirem in any one hour, or a dose in excess of 100 millirem in any 5 consecutive days. (See 10 CFR 20.202.)
Radiation Leakage (Direct):	All radiation coming from a source housing except the useful beam.
Radiation Protection:	All measures concerned with reducing deleterious effects of radiation to persons or materials (also called "radiological protection").
Radiation, Scattered:	Radiation that has deviated in direction during its passage through a substance. It may also be modified by a decrease in energy.
Radiation, Stray:	The sum of leakage and scattered radiation; also called "shine."
Radiation Survey (radiation protection):	An evaluation of the radiation hazard potential associated with a specified set of conditions incident to the production, use, release, storage, or presence of radiation.
Radioactive Material:	Any material or combination of materials that spontaneously emits ionizing radiation and has a specific activity in excess of 0.002 microcuries per gram of material. [See 49 CFR 173.389(e).]
Radioactive Series:	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nonradioactive nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product."
Radioactivity:	The property of certain nuclides of spontaneously emitting particles or gamma radiation or of emitting x radiation following orbital electron capture or of undergoing spontaneous fission.
Radioactivity, Artificial:	Man-made radioactivity produced by particle bombardment or electromagnetic irradiation, as opposed to natural radioactivity.
Radioactivity, Induced:	The radioactivity in a nuclide that has been produced by man-made nuclear reactions.
Radioactivity, Natural:	Radioactivity of naturally occurring nuclides.
Radionuclide:	A radioactive nuclide.

Regulatory Guides:	Documents that describe and make publicly available methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide other guidance to applicants for nuclear operations. Guides are not substitutes for regulations, and compliance with them is not explicitly required. Methods and solutions different from those set out in the guides may be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the NRC. (Government agencies other than the NRC have regulatory guides pertaining to non-nuclear matters.)
Rem:	A former unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors (originally derived from roentgen equivalent man). 1 Rem = 0.01 Sv.
Remote Maintenance:	Maintenance by remote means, i.e., the human is separated by a shielding wall from the item being maintained. Used in the nuclear industry to reduce the occupational radiation doses to maintenance personnel.
Reporting Levels:	Those levels or parameters called out in the environmental technical specifications, the dismantling order, and/or the possession-only license that do not limit decommissioning activities, but that may indicate a measurable impact on the environment.
Repository (Federal):	A site owned and operated by the federal government for long-term storage or disposal of radioactive materials.
Restricted Area:	Any area to which access is controlled for protection of individuals from exposure to ionizing radiation and radioactive materials.
Roentgen (R):	A unit of exposure; 1 R = 2.58×10^{-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

C. T. Raddatz and D. Hagemeyer. *Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities 1988 - Twenty First Annual Report,* NUREG-0713, Vol. 10, July 1991.

C. F. Holoway, et. al. *Monitoring for Compliance With Decommissioning Termination Survey Criteria,* NUREG/CR-2082, June 1981.

Glossary of Terms in Nuclear Science and Technology, Prepared by the American Nuclear Society Standards Subcommittee on Nuclear Terminology and Units, La Grange Park, Illinois, 1986.

Glossary of Nuclear Industry Terms, Standards and Specifications, Atomic Power Equipment Department, General Electric Company, San Jose, California, September 1969.

McGraw-Hill Dictionary of Scientific and Technical Terms, McGraw-Hill, Inc., New York, New York, 1976.

Phase IX Update (1987) Report for the Energy Economic Data Base Program EEDB-IX, DOE/NE-0091, U.S. Department of Energy Report Prepared by United Engineers & Constructors, Inc., Philadelphia, Pennsylvania, July 1988.

Radiological Health Handbook, Public Health Service Publication No. 2106, Revised Edition, U.S. Government Printing Office, Washington, D.C., January 1970.

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-5884
Vol. 1

2. TITLE AND SUBTITLE

Revised Analysis of Decommissioning for the
Reference Pressurized Water Reactor Power Station

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

Main Report

3. DATE REPORT PUBLISHED

MONTH	YEAR
November	1995

4. FIN OR GRANT NUMBER
B2902

5. AUTHOR(S)

G. J. Konzek, R. I. Smith, M. C. Bierschbach, P. N. McDuffie

6. TYPE OF REPORT
Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION – NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Battelle-Pacific Northwest Laboratory
Richland, WA 99352

9. SPONSORING ORGANIZATION – NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Regulatory Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES G.J. Mencinsky, NRC Project Manager

11. ABSTRACT *(200 words or less)*

With the issuance of the final Decommissioning Rule (July 27, 1988), owners and operators of licensed nuclear power plants are required to prepare, and submit to the U.S. Nuclear Regulatory Commission (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 provide some of the needed bases documentation.

This report contains the results of a review and reevaluation of the 1978 PNL decommissioning study of the Trojan nuclear power plant (NUREG/CR-0130), including all identifiable factors and cost assumptions which contribute significantly to the total cost of decommissioning the nuclear power 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 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, and to different depths of contaminated concrete surface removal within the facilities is also examined.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

pressurized water reactor (PWR)
decommissioning
cost/dose/sensitivity

13. AVAILABILITY STATEMENT
Unlimited

14. SECURITY CLASSIFICATION
(This Page)
Unclassified
(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

NUREG/CR-5884
PNL-8742
Vol. 2

Revised Analyses of Decommissioning for the Reference Pressurized 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

Appendices

Final Report

Prepared by
G. J. Konzek, R. I. Smith, M. C. Bierschbach, P. N. McDuffie

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW., Lower Level, Washington, DC 20555-0001
2. The Superintendent of Documents, U.S. Government Printing Office, P. O. Box 37082, Washington, DC 20402-9328
3. The National Technical Information Service, Springfield, VA 22161-0002

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC bulletins, circulars, information notices, inspection and investigation notices; licensee event reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the Government Printing Office: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, international agreement reports, grantee reports, and NRC booklets and brochures. Also available are regulatory guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG-series reports and technical reports prepared by other Federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions. *Federal Register* notices, Federal and State legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Administration, Distribution and Mail Services Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, Two White Flint North, 11545 Rockville Pike, Rockville, MD 20852-2738, for use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018-3308.

DISCLAIMER NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results of such use, of any information, apparatus, product, or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NUREG/CR-5884
PNL-8742
Vol. 2

Revised Analyses of Decommissioning for the Reference Pressurized 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

Appendices

Final Report

Manuscript Completed: June 1995
Date Published: November 1995

Prepared by
G. J. Konzek, R. I. Smith, M. C. Bierschbach, P. N. McDuffie

Pacific Northwest Laboratory
Richland, WA 99352

G. J. Mencinsky, NRC Project Manager

Prepared for
Division of Regulatory Application
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code B2902

DISCLAIMER

NUREG/CR-5884 is not a substitute for NRC regulations, and compliance is not required. The approaches and/or methods described in this NUREG/CR are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

PACIFIC NORTHWEST LABORATORY

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices abailable from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

Abstract

With the issuance of the final Decommissioning Rule (July 27, 1988), owners and operators of licensed nuclear power plants are required to prepare, and submit to the U.S. Nuclear Regulatory Commission (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 provide some of the needed bases documentation.

This report contains the results of a review and reevaluation of the 1978 PNL decommissioning study of the Trojan nuclear power plant (NUREG/CR-0130), including all identifiable factors and cost assumptions which contribute significantly to the total cost of decommissioning the nuclear power 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 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, and to different depths of contaminated concrete surface removal within the facilities is also examined.

Report Contents Outline

Volume 1 (Main Report)

Volume 2 (Appendices)

Contents

Figures

Tables

Acknowledgments

The authors gratefully acknowledge the assistance provided by individuals at the Pacific Northwest Laboratory during the course of this study and preparation of the final report. Denny R. Haffner provided a technical review of the entire study. Dr. Carl Feldman and George J. Mencinsky of the Nuclear Regulatory Commission provided constructive criticism and guidance throughout the study. The editorial review prior to publication was contributed by David R. Payson, Pacific Northwest Laboratory. Marlene Hale, Erica Brown, Jean Cheyney, Laurie Ann Empey, Margie Hutchings, Joan Slavens, Rose Urbina, Margot White, and Pat Young, all of Pacific Northwest Laboratory, prepared the final manuscript. Finally, those many individuals who contributed information that subsequently led to the completeness of this reevaluation study are greatly appreciated and are specially acknowledged in Appendix A. Others who contributed to the completeness of the final report by providing useful comments and additional information are acknowledged in Appendix M.

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.

Special thanks are expressed to the following individuals who gave so willingly of their time and expertise: Chris Alexander of Advanced Engineering Services, for providing information on the removal of the cranes from the reference plant; Daniel S. McGarvey of Johnson & Higgins of Arizona, Inc., for providing nuclear insurance information associated with decommissioning; William N. Lampson, Paul R. Parish, and Russel J. Rutherford of Neil F. Lampson, Inc., for their help concerning the removal of cranes and the steam generators removal and transport estimate presented in this report; and, J. Bradley Mason and Dave Schneidmiller of Pacific Nuclear, for the information on current practices associated with the chemical decontamination of light-water reactor systems.

A full listing of individuals who contributed to this project is provided below.

Advanced Engineering Services:	Chris Alexander
Allied Technology Group, Inc.:	John E. Grochowski Derek Thornton
Bartlett Nuclear:	Art DesRosiers
Brand Scaffold Services, Inc.:	Robert J. Viscomi
Chem-Nuclear Systems, Inc.:	Gary A Benda Mark S. Lewis William S. Mohr David L. Presley Charles Smith
Columbia Concrete Sawing, Inc.:	Jan H. Duncan
Compacting Technologies, International:	Steve Nowak James F. Osborne
Container Products Corporation:	Gregory M. Green
Diversified Scientific Services, Inc.:	Larry Hembree
Electric Power Research Institute:	Ray Lambert
Environmental Protection Agency, Region X:	Dennis A. Faulk

GPU Nuclear Corp.:	Bill Potts
Grating Specialties:	Shawn A. Foster
Interstate Nuclear Services (INS):	Vic Crusselle
Johnson & Higgins of Arizona, Inc.:	Daniel S. McGarvey
Neil F. Lampson, Inc.:	William N. Lampson Paul R. Parish Russell J. Rutherford K. Bruce Tolley
Mirror Insulation:	Kim Gilbert Raget Pagel
Nuclear Assurance Corp.:	James P. Malone James M. Viebrock
Oak Ridge Associated Universities, Oak Ridge Institute of Science and Education:	James D. Berger Rebecca M. Kennard
Oregon Assessor's Office, Columbia County:	Jeff Beman Tom W. Linhares
Oregon Department of Energy:	David Stewart-Smith
Oregon Department of Environmental Quality:	John C. Boik
Oregon Department of Revenue:	Edward Gerhardus
Oregon Public Utility Commission:	Roger Colburn Lee Sparling
Pacific Gas & Electric Company:	Robert T. Nelson
Pacific Nuclear Services:	Mike Hill J. Bradley Mason Peter M. Newton Mark R. Ping Dave Schneidmiller

Pacific Northwest Laboratory:	Lavelle L. Clark
	Dennis R. Haffner
	Jim V. Maestretti
	John K. Rau
	Samuel R. Rod
	Scott A. Vance
PCI Energy Services:	George J. Knetl
Pentek, Inc.:	Bradley P. Fuller
	Sheldon Lefkowitz
Portland General Electric Company:	Steven L. Bumt
	O. Bruce Carpenter
	John L. Frewing
	David W. Heintzman
	Bill Kephart
	Aaron S. McCabe
	Edward P. Miska
	Mike Nolan
	Susan M. Nolan
	Jill Saracione
	Steven P. Sautter
	James S. Willison
Pro-Cut Concrete Cutting, Inc.:	Wilbur D. Pickle
Reese Instruments:	Roy Bennet
Sacramento Municipal Utility District:	Daniel G. Delac
	Kenneth R. Miller
SECO Construction Equipment:	J. Michael Bond
	Barbara A. Bond
Scientific Ecology Group (SEG):	Gary R. Lester
	Pat Walsh
Sonalysts, Inc.:	Karl E. Thonnes
Transnuclear, Inc.:	Charles W. Pennington
Tri-State Motor Transit Co.:	Saundra L. Holdman
	Philip R. Nelson
U.S. Ecology, Inc.:	Arvil Crase
	Dan A. Tallman
	Darwin A. Westlund

U.S. Nuclear Regulatory Commission:	Ramin Assa Roby B. Bevan Frank P. Cardile Ira Dinitz Peter B. Erickson Carl Feldman James C. Holloway James C. Malaro George J. Mencinsky Robert J. Pate Steven R. Ruffin Philip Ting Cheryl A. Trottier Robert Wood
Washington Public Power Supply System:	Joe Bell Charles T. Criscola J. Steve Flood Lowell M. Meeker Vernon E. Shockley Ronald L. Wardlow
Westinghouse Hanford Company:	Henry R. Benzel Robert J. Giroir Joseph J. Hogan Jay F. Woods

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 pressurizer, the reactor pressure vessel, the steam generators, and systems chemical decontamination are contained in Chapter 3, 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 Laboratory (PNL) for the U.S. Nuclear Regulatory Commission (NRC) was utilized in this pressurized water reactor (PWR) 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 Trojan plant (the reference PWR 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 on 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 PWR:

- The cost estimates in this reevaluation study, just as in NUREG/CR-0130,(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 PWR (Trojan) 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 Trojan location are used in this development of a site-specific decommissioning cost estimate. Portland General Electric Company, the majority owner and the operator of the Trojan 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 PWR, 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 PWR 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.

- Steam generator removal, transport, and disposal is handled by an experienced subcontractor (vendor), who is well established in steam generator changeout and associated integrated outage activities, under contract to the DOC. Heavy-lift rigging, barge, and overland transport costs for the steam generators are based on information provided by a qualified vendor of these services, who has handled the barge,overland transport, and installation of NSSS components for several plants. (See Appendix F for additional details.)'

- Steam generators are removed sequentially and barged one at a time to the U.S. Ecology, Inc. commercial disposal site at Hanford. This scenario will consolidate shipping and reduce mobilization costs for the heavy haul vehicles used. (See Appendix F for additional details.)

- 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.

---

[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 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 by approximately 7 years after 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 reevaluation 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.)
- The utility's staffing requirements during decommissioning vary with the level of effort associated with the various phases of onsite 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 PWR, which is the Trojan plant, located at Rainier, Oregon. The utility overhead positions data shown in the table were supplied by the Portland General Electric Company, the majority owner and the operator of the Trojan plant, and include an overhead rate of 42%.

It is acknowledged in this reevaluation 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 reevaluation 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.

Table B.1 Labor costs for decommissioning

Position title	Base pay ($/yr)	Assumed overhead rate (%)	Cost[a] ($/yr)
Utility Overhead Position			
Plant Manager	91,210	42	129,518
Assistant Plant Manager	73,820	42	104,824
Secretary	20,500	42	29,110
Clerk	19,120	42	27,150
Accountant	48,610	42	69,026
Contracts/Procurement Specialist	48,610	42	69,026
Industrial Safety Specialist	47,600	42	67,592
Planning/Scheduling Engineer	52,630	42	74,735
Radioactive Ship. Specialist	55,950	42	79,449
Chemistry Supervisor	52,630	42	74,735
Chemistry Technician	30,290	42	43,012
Quality Assurance Manager	61,140	42	86,819
Quality Assurance Engineer	34,710	42	49,288
Quality Assurance Technician	30,290	42	43,012
Health Physics Manager	55,950	42	79,449
Sr. Health Physics Technician	51,440	42	73,045
Health Physics/ALARA Planner	51,440	42	73,045
Health Physics Technician	31,710	42	45,028
Nuclear Records Specialist[b]	43,260	42	61,429
Building Services Supervisor	61,430	42	87,231
Training Engineer	52,630	42	74,735
Operations Manager	68,620	42	97,440
Administration Manager	61,140	42	86,819
Operations Supervisor	61,140	42	86,819
Control Operator	51,400	42	72,988
Plant Equipment Operator	36,470	42	51,787
Plant Engineer	51,140	42	72,619
Maintenance Manager	67,190	42	95,410
Maintenance Supervisor	61,430	42	87,231
Licensing Engineer	50,890	42	72,264
Craftsman	42,810	42	60,790
Custodian	22,710	42	32,248

Table B.1 (Continued)

Position title	Base pay ($/yr)	Assumed overhead rate (%)	Cost[a] ($/yr)
Utility Overhead Position			
Security Manager	61,140	42	86,819
Security Shift Supervisor	27,070	42	38,439
Security Patrolman	24,560	42	34,875
DOC Overhead Position[c]			
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[b]	62,420	141.5	150,744
Contracts/Accounting Supervisor	62,420	141.5	150,744
Contracts Specialist/Buyer[b]	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[b]	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[b]	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

Table B.1 (Continued)

Position title	Base pay ($/yr)	Assumed overhead rate (%)	Cost[a] ($/yr)
DOC Overhead Position			
Licensing Engineer	50,890	141.5	122,899
Safety Consultant[b]	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 man-year.
(b) Study estimate.
(c) Salary rates include 110% overhead, plus 15% Decommissioning Operations Contractor (DOC) profit on labor.

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 PWR, 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.(4,5) Applying an escalation factor of 2.11, based on the Implicit Price Deflator,(6) brings the mobilization and demobilization costs to $2.64 million, without contingency, in 1993 dollars.

B.4 Radioactive Waste Packaging Costs

The shipping containers assumed to be used for packaging radioactive waste materials for disposal are listed in Table B.2. A brief description, together with the displaced burial volume, the particular application, and the unit cost, is included for each type of container.

B.5 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 more economical to rent such casks than to purchase them, especially the larger ones. The casks assumed in this study for use in shipping highly radioactive materials are listed in Table B.3, together with the application and the estimated rental charges.

Table B.2 Packaging for radioactive materials

Description	Volume (m^3)	Application	Estimated unit cost ($)
Steel cask liner for 8-120B cask; 62 in. OD x 72 in. high; 2,000 lb empty	3.57	Shallow-land burial of activated RPV internals and insulation	4,695
Steel cask liner for 8-120B cask; 62 in. OD x 60 in. high; 1,200 lb empty	0.84	Shallow-land burial of activated RPV	4,695
Canister; 9-in. square by 178-in. high; 300 lb empty	0.24	Deep geologic disposal of GTCC low-level waste (reactor core components)	520
B-25 metal container; 4 ft. x 4 ft. x 6 ft.; 600 lb empty	2.72	Shallow-land burial of LLW	645
Special metal container; U-shaped; 174 in. dia. x 210 in. long x 45 in. high; 1,500 lb empty	13.31	Shallow-land burial of upper core assembly components	1,565
Special metal container, fitted to inner wall shape, welded to wall; 300 lb empty	1.77	Shallow-land burial of RPV nozzle sections	470
Special metal container; 10 ft x 10 ft x 15 ft; 4,600 lb empty	42.48	Shallow-land burial of spent fuel storage racks	4,170
High-Integrity Container (HIC); 75.5 in. dia. x 78 in. high; 900 lb empty	5.72	Dewatered, solids, or solidified water meeting the requirements of LSA material	5,750 - 9,900(a)
Std. Maritime container (Sea-Van); 8 ft x 8.5 ft x 20 ft; 4,180 lb empty	38.51	Shallow-land burial of low-level waste	3,650
Modified Maritime container (Sea-Van);			
8 ft x 4 ft x 20 ft; 3,000 lb empty	18.13	Shallow-land burial of low-level waste	4,965
8 ft x 2 ft x 20 ft; 2,500 lb empty	9.06	Shallow-land burial of low-level waste	4,600
DOT 17-H steel drum; 55-gal	0.21	Shallow-land burial of low-level waste	26.95

(a) Depending on 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.

Table B.3 Shielded casks for shipment of radioactive materials

Casks 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	3,130[c]
TN-8 OWT, 79,200 lb empty; COC No. 9015B	Transport of greater-than-class-C LLW	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 empty; COC No. 9176	Transport of high integrity container or 55-gal drums	1,250
CNS No. 8-120B, 59,320 lb empty; 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 7.

(c) The daily rental rate is predicted on a sliding scale, according to the risk, with spent nuclear fuel being the highest risk cargo and the GTCC material assumed at the same rate in this study.

B.6 Transportation Costs

Most radioactive materials resulting from decommissioning are assumed to be shipped in exclusive-use[2] trucks to a burial site (U.S. Ecology, Inc., at Hanford), or, in the case of highly activated reactor components, to a geologic repository or other such disposal facility as the NRC may approve. The exceptions, all assuming barge transport and overland transport, are the primary pumps and the pressurizer (see Chapter 3 for details), and the steam generators (see Appendix F for details).

Rates for shipping radioactive wastes were provided by Tri-State Motor Transit Co. and from its published tariffs for this cargo.(9) Barge transport and overland transport cost estimates were provided by Neil F. Lampson, Inc.[3], who has handled the barge, overland transport, and installation of NSSS components for several nuclear power plants. Also, see Appendix F, Section F.7 for a detailed description of these costs.

---

[2] Exclusive use, as defined in 49 CFR 173.401(i),(8) 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.

[3] Letter, William N. Lampson, Neil F. Lampson, Inc., to George J. Konzek, Battelle Northwest, transmitting rough-order-of-magnitude data on costs for steam generators removal from the reference PWR, dated January 31, 1992.

Costs of transporting low-level waste to the disposal site are calculated using the CECP. 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 and Hanford.

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, based on data supplied in Reference 9, are given in Appendix C.

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 Hanford), 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.

Table B.4 US ecology shallow-land burial costs at Hanford

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)

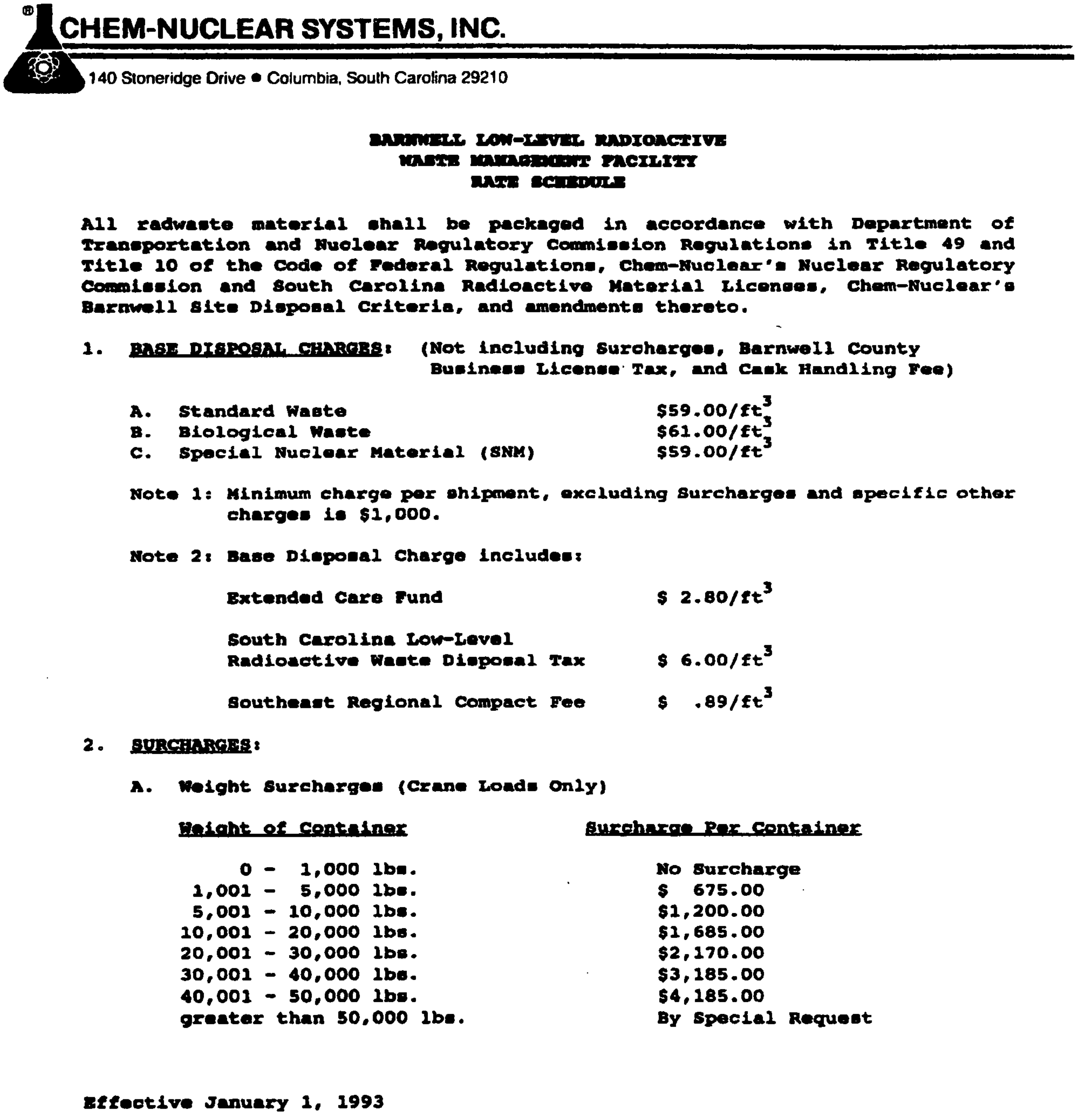
US ECOLOGY
WASHINGTON NUCLEAR CENTER
TAX AND FEE RIDER
SCHEDULE C
EFFECTIVE FEBRUARY 9, 1993

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	$\$59.00/\text{ft}^3$
B.	Biological Waste	$\$61.00/\text{ft}^3$
C.	Special Nuclear Material (SNM)	$\$59.00/\text{ft}^3$

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

Note 2: Base Disposal Charge includes:

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

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 **Page Three**	**Effective January 1, 1993**

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.

B.7.2 Costs for Geologic Disposal

Based on discussion 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.(10,11)

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."(12)

For purposes of this study, the ultimate cost of disposal of mixed wastes (either liquid or solid) expected to be present on the reference PWR site at final shutdown are considered to be operational costs, 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 do not currently exist. Based on the aforementioned projected astronomical disposal costs and on 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 PWR. 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 PWR. 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

Electricity - A principal services cost item is electric power. Discussions with Portland General Electric Company staff, the majority owners and the operator of the reference PWR, indicated that electrical replacement power costs in the range of \$0.025 to \$0.034/kWh are reasonable. For conservatism in this reevaluation study, a unit cost of \$0.034/kWh, or \$34/MWh, is assumed for electricity.

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
Bolt removal tools	2	50.0
Cutting table, plus jigs	1	33.0
Oxyacetylene cutting systems	1	3.3
Plasma-arc equipment	2	33.0
Track-mounted drive unit	4	4.4
Steam generator transport system:		
Upender	1	27.6(a)
Low-profile saddle	1	55.1(a)
Transfer skid	1	198.5(a)
Frame trailer w/shipping cradle	2	248.1(a)
Drum compactor	2	47.4(a)
Closed circuit, high-resolution television	(plant equip.)	55.1(b)
High-pressure water jet	1	176.4(c)
Kelly Decontamination System™	3	186.0(d)
Underwater lights, viewing windows/periscope	As required	11.0
Subsersible 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(e)
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
Total Cost		~ 3.188 million

(a) Previously accounted for in Appendix F, included here for completeness.

(b) Estimated for modifications of existing systems.

(c) System includes floor surface wand, tank interior wand, and compressor unit.

(d) Manufactured by Container Products Corporation. The unit cost shown includes 1 week of training in the use of the equipment.

(e) Assumes the availability of two forklifts from plant operations.

During a recent long-term shutdown (i.e., > 9 months) with about 1,000 people onsite, the reference PWR's average site electricity consumption was reported to be about 5 MW. A significant portion of the electricity was used for heating, air conditioning, lights, etc. A similar inquiry to Rancho Seco concerning their average site consumption for their current possession-only status (i.e., a long-term shutdown mode with less than 200 people onsite and all fuel stored in their fuel pool) revealed an average site consumption of about 3.25 MW. Based on the similarities of Rancho Seco's current shutdown situation to the postulated conditions at the slightly larger reference PWR after final shutdown, an approximate site electricity consumption value (i.e., base load) of about 4 MW is assumed in this study for the reference PWR during active periods of decommissioning. The daily unit cost for electricity is calculated as follows:

(4 MW x $34/MWh) x 24 hrs/day = $3,264/day

In addition, use of the RCS pumps during chemical decontamination would add about 18 MW to the base load while the pumps are running. By making the aforementioned reasonable assumptions about electricity consumption at the site for a specific decommissioning alternative, and by following the appropriate schedule for that decommissioning alternative, the power usage by year after shutdown is estimated.

Oil - The startup boiler would be used to provide steam for the evaporation process, which is anticipated to be used for deboration of the primary water. The estimated fuel consumption would be at a rate of about 100 gallons/hour of #2 diesel fuel, which costs $0.725/gal, in 1993 dollars.

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 on 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 steam generators, 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 on discussions with industry contacts, these services, including labor, equipment, and materials, are estimated to cost about $132,300 per trip, resulting in a total cost of $529,200 for these services for the four steam generators, and $132,300 each for the four primary pumps and for the pressurizer.

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 on the following page.

TABLE B.5. (contd)

Barnwell Rate Schedule		Effective January 1, 1993
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.

B.9.1 Assumptions

For the purpose of this study, the estimated property taxes for the reference PWR are based on the following assumptions:

- a dramatic decrease in property values after final shutdown, when the operating plant is removed from service and from the tax rolls
- only the fair market value associated with the land alone is assessed for tax purposes
- all the land is available for use, except for that small fraction of the site (about 34 acres) inside the exclusion area the land outside the exclusion area is assessed at a value comparable with adjacent similar industrially-zoned property and the property within the exclusion area is assessed at essentially zero value
- property taxes are attributable to plant operations until Period 3, where they are allocated 90% to SNF storage, 10% to safe storage and 100% to decommissioning operations after the SNF inventory is reduced to zero at approximately 7 years after shutdown (see Section B.9.2 for details).

Since the outer area of the site may be unrestricted in use once the reactor has been decommissioned, it may be put to productive use to pay its property taxes.

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

B.9.2 Estimated Property Taxes for the Reference PWR Following Final Shutdown

Based on conversations with real estate personnel, the fair market value of the land outside the exclusion area of the reference PWR is roughly estimated at about $10,000 per acre. The actual value would have to be determined by an industrial appraisal, however. Starting in 1995 and then level thereafter, a tax rate of 1.5% maximum of assessed value goes into effect in the state of Oregon. Therefore, this percentage is used in this study for estimating property taxes at the reference facility.

Assuming that approximately 600 acres of useable land is taxable at 1.5% maximum of assessed value, then the estimated annual property tax can be derived as follows:

$$600 \text{ acres} \times (1.5\% \times \$10{,}000/\text{acre}) = \sim \$90{,}000/\text{yr}$$

B.10 Nuclear Insurance Costs

As delineated in NUREG/CR-0130,(1) the basis for the 1978 nuclear insurance costs given in that study were originally developed in 1975 by American Nuclear Insurers (ANI).[4] 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

---

[4] 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.

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.

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 referenced 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."[5]

A summary of the estimated total post-shutdown insurance costs, by stage, is presented in Table B.7. The bases for the values shown in the table are developed in subsequent sections.

Table B.7. Summary of estimated post-shutdown insurance costs in 1993 dollars

	Cost category	
Stage	Decommissioning cost, $(a)	SNF management cost, $(a,b)
Transition (first 1-1/2 years following shutdown, until receipt of Property Rule waiver)	1,703,754(c)	2,449,146(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) During the first year following shutdown, about 32 weeks of decommissioning activities are postulated (e.g., chemical decontamination of the reactor coolant system, cutting and packaging of the reactor pressure vessel internals, etc.); therefore 32/52 x $2,768,600/year premium, or about $1,703,754 is attributable to decommissioning operations. The remainder, about $1,064,846, is postulated to be attributable to SNF management operations for the first year following shutdown. 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 6-1/2 years or (2) extended safe storage commences.

---

[5] Letter, Daniel S. McGarvey, Johnson & Higgins of Arizona, Inc., to George J. Konzek, Battelle Northwest, transmitting reference plant decommissioning cost projections, dated February 19, 1993.

B.10.1 Assumptions

The estimated property damage insurance and nuclear liability insurance costs presented in this study are based on 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. 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 purposes of this study, it is conservatively estimated to take 18 months, after shutdown, to receive the waiver.

2. 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.

3. 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.

4. Credits of forty percent (40%) and fifty percent (50%) are applied to ANI 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.

5. Nuclear Electric Insurance Limited, NEIL I (business interruption)[6] 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.

6. 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.

7. 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.

8. Facility Form[7] (liability insurance) premium levels stabilize following reductions in 1991 and 1992. The ANI experience modification factor for primary property rating is capped at 35% in 1993. Finally, it is assumed for simplicity that the reference insured is not receiving credits under ANI's individual property credit plan, and that the pre-shutdown Engineering Rating Factor (ERF)[8] is 1.0.

---

[6] 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.

[7] An insurance company evaluation for rating the perceived safety and risk.

[8] The rating factor is a premium multiplier, based upon the insurance company's evaluation for rating the perceived safety and risk.

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

10. A $1 million deductible level is selected. This is consistent with current ANI minimum decommissioning deductible requirements.

11. A $200 million level of Suppliers' and Transporters' (S&T)[9] coverage is maintained in anticipation of a large number of radiological shipments during the 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 coverage, as well as participation in the Secondary Financial Protection (SFP) 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		**Liability**	
Stage	**Percent Reduction**	**Stage**	**Percent Reduction**
Shutdown for Decommissioning	20-40	Shutdown for Decommissioning	40-60
Plant defueled offsite	67	Fuel offsite (if option available)	50-70
Plant defueled onsite	50	D&D 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 PWR 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:

---

[9] 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.

Property			Liability	
Primary Property ($500 million)	$1,750,000		Facility Form	$345,000
Excess Property ($560 million)	$616,000		S&T Policy	$27,000
			Worker Form	$23,100
			SFP	$7,500
Program Total:		$2,768,600/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 ($200 million ANI)	$490,000		Facility Form	$290,000
Excess Property ($300 million ANI)	$270,000		S&T Policy	$27,000
			Worker Form	$23,100
			SFP	$7,500
Program Total:		$1,107,600/yr		

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

Property			Liability	
Primary Property(a)	$350,000		Facility Form	$431,000
Excess Decontamination	$360,000		S&T Policy(b)	$27,000
			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 PWR'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 on the assumption that the reference PWR'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 on 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 PWR'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 on 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 18 months following shutdown of the reference PWR (i.e., the "transition period" pending receipt of a waiver of Property Rule limit requirements) are estimated to be about $4,152,900. 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 $1,107,600. Subsequently, premiums will likely fluctuate according to the level of activity onsite. However, because the SNF inventory must remain in the spent fuel pool for a 7-year period, it is postulated that *all* of the nuclear liability insurance costs, except for a proportionate share of the annual premium covering about 32 weeks during the first year following shutdown when active decommissioning operations occur, are attributable to SNF management operations during the 7-year period. Upon reduction of the SNF inventory to zero and active decommissioning activity commences, subsequent insurance costs are attributable to decommissioning operations.

During periods of active decommissioning and dismantlement, the annual insurance costs could rise again to $1,198,600. The reduction in estimated insurance expenses for the reference PWR 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 the purpose of 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"[10] 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 PWR'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 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(14) requires submittal of a final radiation survey plan as part of the decommissioning plan. Plans for a final termination survey[11] 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 final 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,(15) for conducting radiological surveys in support of license termination. This manual updates information contained in NUREG/CR-2082,(16) and provides guidance for licensees on conducting radiological surveys of their facilities and sites to demonstrate that residual radioactive contamination levels, as derived from NUREG/CR-5512,(17) meet NRC criteria for unrestricted use.[12] 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.

---

[10] 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 or she has sustained a loss 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. The period may also be determined by statute; in certain bonds, it is of indefinite duration because of such statutory requirement.

[11] This survey is known by several titles, including **termination survey**, **post remedial-action survey**, **final status survey** and **final survey**. The term final termination survey is used in this study.

[12] 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.

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 are following 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 of the survey, from training of personnel, to the calculation and interpretation of the results, must be documented in a way that lends itself to audit. 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.(18)

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 radiological contractor, as assumed in this reevaluation study)[13] should be reviewed by the certification inspector prior to initiation of the licensee's final survey plan. 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 radiological contractor should carefully consider the incorporation of comments offered by the certification inspector. This early agreement should minimize the need for a completely independent radiological survey by the certification inspector.(16)

The estimated cost of the termination survey for the reference PWR is based on the information contained in draft NUREG/CR-5849 and in NUREG/CR-2082. Because the latter document used the reference PWR as the model for development of the methodology presented therein, it proved useful in developing the cost estimate for the final termination survey. The total estimated cost of the final termination survey for the reference PWR is about $1.22 million, including about $0.16 million in NRC-related costs for the confirmation survey. The elemental costs of the survey are presented in Table B.8. Brief discussions/derivations of the survey-related costs shown in the table follow.

In NUREG/CR-0130, the termination surveys were conducted intermittently over a period of about 8 months, starting with a survey of the Control Building and ending with a survey of the Turbine Building. For the purpose of this analysis, it is postulated that the surveys are conducted in four survey activity groups, in the order shown in Table B.9. The rationale for the buildings surveys sequences shown in Groups 1 and 2 in the table is based on an estimated diminishing order-of-difficulty of conducting the surveys and on segregation of the site into two classifications of areas - **affected** and **unaffected** areas.[14] This scenario will consolidate survey activities and reduce mobilization costs for the instrumented mobile laboratory postulated to be used by the radiological contractor.

The license termination survey process is labor-intensive, requiring an estimated 13,272 hours of direct labor. This number is increased by 25% in this study to account for lunch, work breaks, and set-up and calibration checks, resulting in total clock time of about 16,590 hours (see Table B.9).

---

[13] 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.(16)

[14] **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.(15)

Table B.8. Summary of estimated costs for the termination survey

Entity	Cost element	Estimated cost, $[a]
Licensee	Labor	
	Radiological survey	958,030[b]
	Report preparation	16,125[c]
	Office materials[d]	2,500
	Services	
	Drilling (auger, coring, restoration)	11,484[e]
	Land surveying	14,138[e]
	Analytical[f]	58,755
	Subtotal, Licensee	1,061,032
NRC	15% of Licensee costs[g]	159,155
Total		1,220,187

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Includes the estimated direct labor costs of $678,040, per diem costs of $262,990 and $17,000 in travel costs.
(c) Based on Table B.11.
(d) Exclusive of instruments and equipment.
(e) Study estimate based on information contained in Reference 16.
(f) Instrumented mobile laboratory (see text for details).
(g) Study estimate based on information contained in Reference 15 and on discussion with the NRC.

Table B.9. Summary of estimated times for the termination surveys of the buildings and site

Site area	Estimated survey time, hours[a]
Group 1 - Buildings	
Reactor/Containment	10,029
Fuel	599
Auxiliary	451
Condensate/Demineralizer	188
Group 2 - Buildings	
Turbine	1,238
Control	395
Shop/Warehouse	252
Administration	130
Chlorine	46
Cooling Tower	17[b]
Group 3 - Site Soil	
• Survey Unit 1[c]	461
• Survey Unit 2[d]	169
• Survey Unit 3[e]	2,449
Group 4 - Sampling	
• Air, Water, etc.	166
Total hours	16,590[f]

(a) Based on the methodology presented in References 15 and 16; includes supervision, QA, and clerical.

(b) With virtually no reason to expect contamination in this area, it is postulated that only spot checks will be required for this termination survey.

(c) An intensive survey in the area 10 m beyond the Group 1 and 2 buildings foundations.

(d) A thorough survey of the plant facilities area (0.1 km^2) outside the intensive survey area.

(e) A cursory survey over the remainder of the site with thorough coverage in any areas found to contain contamination twice above background.

(f) The number of hours shown is for computational accuracy and does not imply precision to that many significant figures.

Two crews, working a single shift, conduct the survey protocol. Each crew is postulated to consist of the staff listed in Table B.10.

The total hours of the two crews equals 136 hours per day and the combined salaries of the crews comes to $5,557.68 per day. Based on the total hours given in Table B.9, the total time to complete the final termination survey protocol is derived as follows:

16,590 hours/136 hrs per day = ~122 work days

or,

~122 work days/5 work days per week = ~24.4 wks (or, ~5.6 months)

Thus, the direct labor cost is: $5,557.68/day x ~122 work days = $678,040. Per diem for 17 full-time equivalent (FTE) staff, calculated using Federal Travel Rates of $91/day, amounts to $262,990.

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

$678,040 + 262,990 + 17,000 = $958,030.

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

Pers-hrs/ crew-hr	Category	Labor rates ($/labor-hr)	Cost (a) ($/crew-hr)	Dose Rate (mrem/crew-hr)
1.0	H.P. Leader/Supvsr.	70.99	70.99	--
5.0	H.P. Survey Technician	36.82	184.10	--
1.0	Laborer (b)	26.37	26.37	--
0.5	Sr. Chem. Tech.(c)	54.40	27.20	--
0.5	Sr. Inst. 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 also assumed that the radiological contractor uses an instrumented mobile laboratory[15] for the duration of the survey. Assuming a 5-year lifetime, straightline 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 24.4 wks = $58,755

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.11 is taken from Reference 16 and the labor costs are based on the DOC costs presented previously in Table B.1.

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 on discussion with NRC and on information contained in Reference 15, it is postulated that this confirmatory/verification survey of selected points will take about one month and is estimated to cost roughly 15% of the licensee's costs shown in Table B.8, or about $159,200. 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.

Table B.11. Estimated labor costs for preparation of termination survey report

Labor category	Person-weeks	Rate, $/wk	Amount, $
Engineer	4	2,363.44	9,454
Graphic Arts	1	1,304.10	1,304
Tech. writer/editor	3	919.79[(a)]	2,759
Clerical	2	1,304.10	2,608
Total	10		16,125

(a) Study estimate.

---

[15] 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.(16)

B.12 Cascading Costs

An extensive literature search revealed that cascading costs[16] have not been given any selective or distinctive consideration in decommissioning cost estimates until recently. This is not surprising, since the history of decommissioning cost estimating has proved to be an evolutionary and iterative process. This highly subjective cost category was not considered as a separate entity in NUREG/CR-0130 in 1978. However, in this reevaluation study of the reference PWR, cascading costs are specifically identified as three activities: asbestos removal and disposal; clean concrete cutting; and selected activities associated with steam generator removal. Thus, full consideration is given in this study to the methods of executing the decontamination processes, which include cascading costs.

B.13 Regulatory Costs

The reference nuclear power plant (Trojan) has been operating since 1975. Trojan is operated by Portland General Electric Company (PGE). Trojan was licensed to operate by the NRC. Federal law gives the NRC sole authority over safety regulation for nuclear power plants. The NRC regulates Trojan's operation and inspects Trojan 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 Trojan'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 from the Department of Energy (DOE) administered Nuclear Waste Fund[17] to the NRC for FYs 1991 through 1995 for purposes of licensing support to the 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 on 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.

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).(19) At the time of this writing, the professional staff-hour rate for FY 1993 was unavailable. For the purpose of this study, the professional staff-hour rate is estimated at $132 per hour (a seven percent 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.

---

[16] 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).

[17] 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.

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.

Oregon also has authority over Trojan operations. Trojan operates under a Site Certificate issued by the Energy Facility Siting Council (EFSC). Oregon law requires PGE to comply with NRC requirements and the terms of its site certificate. The EFSC has directed the Oregon Department of Energy (ODOE) to set up an inspection program at Trojan. There has been an ODOE oversight program at Trojan since 1980. Oregon operates its program in cooperation with the NRC under the terms of a Memorandum of Understanding.(20)

The Administrator, Nuclear Safety and Energy Facilities Division, ODOE, and the Reactor Safety Manager, ODOE, are responsible for implementing the regulation program. Currently, ODOE has authorized a Reactor Safety Manager and two Resident Engineers. The Resident Engineers work full-time at the Trojan Site and are anticipated to continue to do so during periods of active decommissioning. They conduct inspections of PGE activities, identify potential problems, and discuss corrective action with PGE. The Resident Engineers report on their activities to the Reactor Safety Manager, the Administrator, and the EFSC. The reports form the basis for discussions of Trojan status with the EFSC. This program is expected to continue during periods of active decommissioning. The cost of this program, together with a summary of estimated regulatory costs, is given in Table B.12.

B.14 Contingency

Some state utility rate commissions have expressed concerns about the size of the contingency allowances in decommissioning cost estimates. What follows 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 reevaluation study. The discussion is derived from a Northeast Utilities Service Company report on decommissioning of the Millstone Units 1 and 2.(21)

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"

Table B.12. Summary of estimated regulatory costs

Entity	Cost element	Estimated cost, $[a]
Licensee	Services:	
	• Oregon State DEQ (Onsite Inspection)	3,000/yr[b]
	• Oregon State DOE (Onsite Inspection Program)[c]	481,250/yr
	• Oregon State Health Division, Radiation Control Section license:[d]	3,000/yr
	Resolution & Response to NRC Review of the Decom. Plan	103,500[e]
NRC	Environmental Assessment Decommissioning Plan[g]	23,230[f]
	Regional Inspections during periods of safe storage:	
	• Two General Inspections/yr;	
	1-wk/inspection by 1 person	11,652[h]
	• One Security Inspection/yr;	
	3-days by 1 person	3,532[h]
	Resident Inspector (during periods of active decommissioning)[i]	115,300/yr
	Certification Survey[j]	159,155

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

(b) The Oregon State Dept. of Environmental Quality (DEQ) conducts inspections of the Trojan sewage treatment plant 1-day/year, based on the licensee's Water Discharge Permit. These inspections are conducted under the auspices of the Federal Program, National Pollution Discharge Elimination System, delegated by the EPA to Oregon State.

(c) Based on the reported billing cost by the Oregon State Dept. of Energy (ODOE) for the inspection program at Trojan for the period July 1, 1992 to June 30, 1993 (includes the salaries for 3 ODOE on-site inspectors).

(d) This annual fee is for the plant's Radioactive Waste Handling License issued by the State of Oregon for cleanup and/or disposal of materials and equipment.

(e) Study estimate based on engineering judgment and the review of unanticipated costs and variables associated with selected past decommissionings.

(f) Based on discussions with the NRC, this task is estimated to require about 1 man-month (a Period 1 cost).

(g) 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).

(h) Includes Federal Travel Rates of $91/day/person.

(i) Based on 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.

(j) Already included in Table B.8, but included here for completeness.

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 have led them to recognize the propriety of a contingency provision in cost estimates.(13)

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 reevaluation study for the decommissioning of the reference PWR power station.

B.15 References

1. R. I, Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. "Building Construction Cost Data 1993," Robert Snow Means Company, Inc., Kingston, Massachusetts.

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

4. R. I. Smith and L. M. Polentz. 1979. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Addendum 1.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

5. Direct testimony of R. F. Brzezinski, Consumers Power Company before the Michigan Public Service Commission, Case U-6041, March 7, 1979.
6. *National Economic Trends*. February 1993. Federal Reserve Bank of St. Louis, St. Louis, Missouri.
7. NUREG-0383, Vol. 2, Revision 14. *Directory of Certificates of Compliance for Radioactive Materials Packages - Certificates of Compliance*. 1991. U.S. Nuclear Regulatory Commission Report by Office of Nuclear Material Safety and Safeguards, Washington, D.C.
8. Title 49 Code of Federal Regulations, Part 173, *Transportation*.
9. Tri-State Motor Transit Company, published tariffs, Interstate Commerce Commission (ICC) Docket No. MC-109397 and Supplements. 1993.
10. NUREG-1437, Volume 1. 1991. *Generic Environmental Impact Statement for License Renewal of Nuclear Plants - Main Report - Draft Report for Comment*. U.S. Nuclear Regulatory Commission, Washington, D.C.
11. OTA-O-426. 1989. "Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste," Office of Technology Assessment, U.S. Congress, Washington, D.C.
12. *Nuclear Waste News*. August 29, 1991. "States Look to DOE for Mixed Waste Rescue," p. 342.
13. AIF/NESP-036, Volumes 1 and 2. May 1986. *Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates*. Atomic Industrial Forum, Inc. Report by TLG Engineering, Inc., Bethesda, Maryland.
14. Federal Register. "General Requirements for Decommissioning Nuclear Facilities," Vol. 53, No. 123, pp. 24018-24056, June 27, 1988.
15. J. D. Berger. June 1992. *Manual for Conducting Radiological Surveys in Support of License Termination - Draft Report for Comment*. NUREG/CR-5849, ORAU-92/C57, U.S. Nuclear Regulatory Commission Report by Oak Ridge Associated Universities, Oak Ridge, Tennessee.
16. C. F. Holoway, et. al. June 1981. *Monitoring for Compliance With Decommissioning Termination Survey Criteria*. NUREG/CR-2082, ORNL/HASRD-95, U.S. Nuclear Regulatory Commission Report by Oak Ridge National Laboratory, Oak Ridge, Tennessee.
17. W. E. Kennedy, Jr. and R. A. Peloquin. January 1990. *Residual Radioactive Contamination from Decommissioning - Technical Basis for Translating Contamination Levels to Annual Dose*. NUREG/CR-5512, PNL-7212, U.S. Nuclear Regulatory draft report for comment by Pacific Northwest Laboratory, Richland, Washington.
18. E. Y. Shum, J. J. Swift and J. C. Malaro. November 1991. "Decommissioning of Nuclear Facilities Using Current Criteria." Paper presented at the American Nuclear Society 1991 Winter Meeting, San Francisco, California.
19. Federal Register. "Revision of Fee Schedules; 100% Fee Recovery, FY 1992," Vol. 57, No. 142, pp. 32691-32721, July 23, 1992.
20. T. Young, Jr., H. Lieber, and Don Beckham. 1991. *Evaluation of Oregon's Regulatory Program at the Trojan Nuclear Power Plant*. Prepared by Technical Analysis Corporation for Oregon Department of Energy.

21. *Nuclear Power Plant Decommissioning Study for Millstone Units 1 and 2*, Report by Northeast Utilities Service Company, Berlin, Connecticut, May, 1983. (Public Document Room #05000245).

22. Cost Engineers Notebook: American Association of Cost Engineers, AA-4.000, p. 3 of 22, Revision 2, January 1978.

Appendix C

Cost Estimating Computer Program

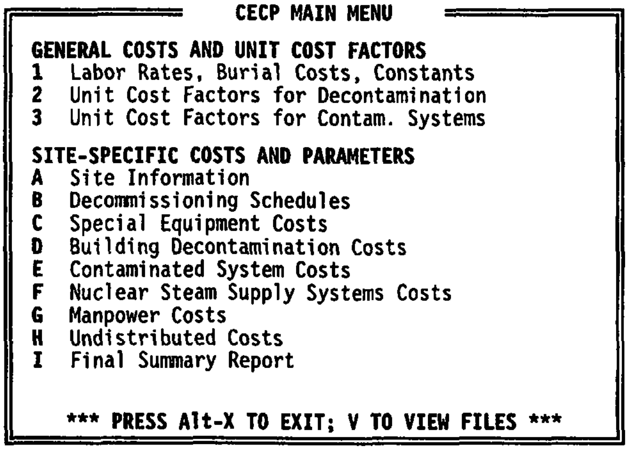
Appendix C

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 PWR 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 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  Manpower Costs
H  Undistributed Costs
I  Final Summary Report

   *** PRESS Alt-X TO EXIT; V TO VIEW 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. The user may save up to 150 different files, but it is unlikely that more than about five will ever be needed. 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. When the user selects items **C**, **D**, **E**, **F**, **G**, or **H**, the CECP requests the user to specify which input files (from **1** through **3** and **A** and **B**) to use. 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.

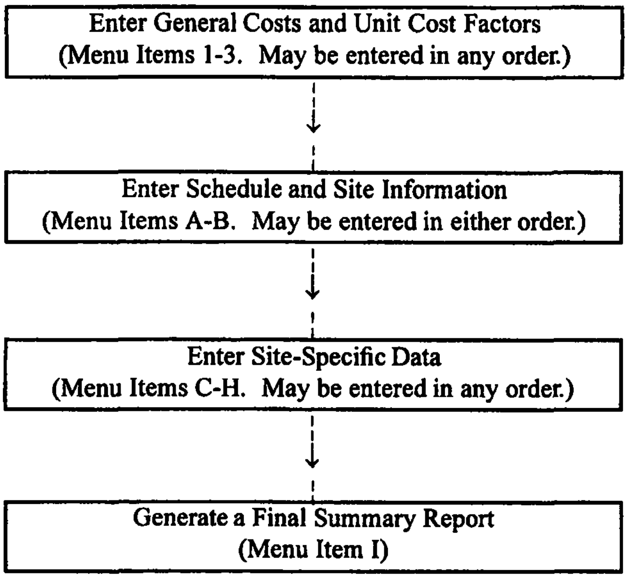
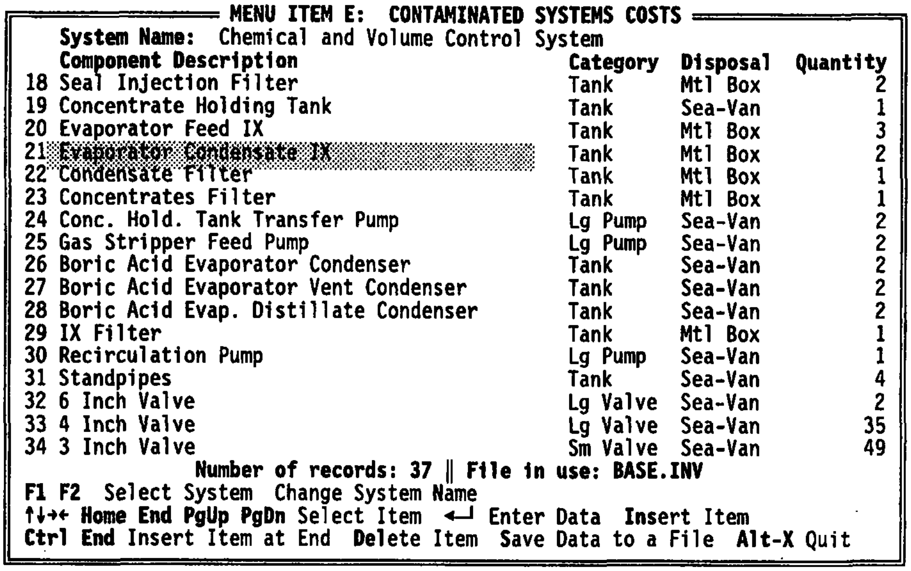
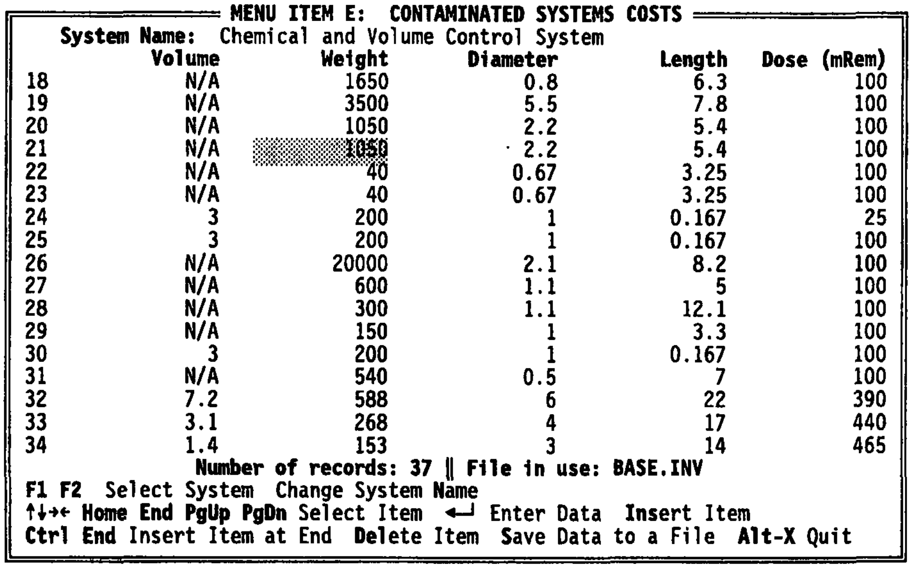


Figure C.2 Flow diagram for entering data into the CECP



```
=============== MENU ITEM E:  CONTAMINATED SYSTEMS COSTS ===============
   System Name:  Chemical and Volume Control System
   Component Description                      Category  Disposal  Quantity
18 Seal Injection Filter                      Tank      Mtl Box          2
19 Concentrate Holding Tank                   Tank      Sea-Van          1
20 Evaporator Feed IX                         Tank      Mtl Box          3
21 Evaporator Condensate IX                   Tank      Mtl Box          2
22 Condensate Filter                          Tank      Mtl Box          1
23 Concentrates Filter                        Tank      Mtl Box          1
24 Conc. Hold. Tank Transfer Pump             Lg Pump   Sea-Van          2
25 Gas Stripper Feed Pump                     Lg Pump   Sea-Van          2
26 Boric Acid Evaporator Condenser            Tank      Sea-Van          2
27 Boric Acid Evaporator Vent Condenser       Tank      Sea-Van          2
28 Boric Acid Evap. Distillate Condenser      Tank      Sea-Van          2
29 IX Filter                                  Tank      Mtl Box          1
30 Recirculation Pump                         Lg Pump   Sea-Van          1
31 Standpipes                                 Tank      Sea-Van          4
32 6 Inch Valve                               Lg Valve  Sea-Van          2
33 4 Inch Valve                               Lg Valve  Sea-Van         35
34 3 Inch Valve                               Sm Valve  Sea-Van         49
              Number of records: 37 || File in use: BASE.INV
F1 F2  Select System  Change System Name
↑↓→← 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:  Chemical and Volume Control System
           Volume       Weight       Diameter         Length   Dose (mRem)
18            N/A         1650            0.8            6.3           100
19            N/A         3500            5.5            7.8           100
20            N/A         1050            2.2            5.4           100
21            N/A         1050            2.2            5.4           100
22            N/A           40           0.67           3.25           100
23            N/A           40           0.67           3.25           100
24              3          200              1          0.167            25
25              3          200              1          0.167           100
26            N/A        20000            2.1            8.2           100
27            N/A          600            1.1              5           100
28            N/A          300            1.1           12.1           100
29            N/A          150              1            3.3           100
30              3          200              1          0.167           100
31            N/A          540            0.5              7           100
32            7.2          588              6             22           390
33            3.1          268              4             17           440
34            1.4          153              3             14           465
              Number of records: 37 || File in use: BASE.INV
F1 F2  Select System  Change System Name
↑↓→← 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)

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, Sm HX, Lg Misc., and Sm Misc. 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.

Examples of typical output reports are illustrated in Figures C.4 through C.6, for the reference PWR. 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 SAFSTOR2 versions of C.1 and C.2.

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 PWR plant inventory, which the CECP uses as the default PWR inventory, is presented below.

C.1.1 Inventories of Process System Components

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 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, presented in Chapter 3 for the piping, Appendix E for the pressure vessel and internals, and Appendix F for the steam generators.

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 separately from their associated piping. No effort is made to identify and quantify the number and characteristics of pipe hangers, under the assumption that most of the pipe hangers are sufficiently small that they can be placed in the piping containers without further consideration.

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. Because the stainless steel piping is primarily associated with the reactor coolant system, and with associated safety and support systems, all of the stainless steel piping is assumed to be removed during decommissioning.

```
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+ INVENTORY OF POTENTIALLY RADIOACTIVE SYSTEMS:  PHYSICAL CHARACTERISTICS +
+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

***  Radioactive Gaseous Waste System
                                                                                           ----- Tanks -----
Component Description                     Category  Disposal    Qty    Wgt(lb)  Vol(ft3)   Dia(ft)  Hgt(ft)
----------------------------------------- --------  --------   ----    -------  --------   -------  -------
Surge Tank                                 Tank     Sea-Van      1        890         8     3.00      6.00
Decay Tank                                 Tank     Sea-Van      4     10,800        43    10.00     16.00
Gas Compressor                             Lg Misc. Sea-Van      2      8,000       200
Moisture Separator                         Sm Misc. Sea-Van      2        100         4
Br. Seal Wtr. HX                           Lg HX    Mtl Box      2      7,700        27
4 Inch Valve                               Lg Valve Sea-Van      1        268         3
3 Inch Valve                               Sm Valve Sea-Van      3        153         1
2 Inch Valve                               Sm Valve Sea-Van     16         90         1
1 1/2 Inch Valve                           Sm Valve Sea-Van     35         62         1
1 Inch Valve                               Sm Valve Sea-Van     12         50         0
3/4 Inch Valve                             Sm Valve Sea-Van     16         30         0

***  Residual Heat Removal System
                                                                                           ----- Tanks -----
Component Description                     Category  Disposal    Qty    Wgt(lb)  Vol(ft3)   Dia(ft)  Hgt(ft)
----------------------------------------- --------  --------   ----    -------  --------   -------  -------
Pump                                       Lg Pump  Sea-Van      2      6,800        28
HX Unit                                    Lg HX    Mtl Box      2     23,100       212
14 Inch Valve                              Lg Valve Sea-Van      7      2,760        31
12 Inch valve                              Lg Valve Sea-Van      3      1,972        24
10 Inch Valve                              Lg Valve Sea-Van      2      1,458        18
 8 Inch Valve                              Lg Valve Sea-Van     18      1,029        15
 2 Inch Valve                              Sm Valve Sea-Van      2         90         1
 3/4 Inch Valve                            Sm Valve Sea-Van     10         30         0

***  Safety Injection System
                                                                                           ----- Tanks -----
Component Description                     Category  Disposal    Qty    Wgt(lb)  Vol(ft3)   Dia(ft)  Hgt(ft)
----------------------------------------- --------  --------   ----    -------  --------   -------  -------
Accuml. Tank                               Tank     Sea-Van      4     76,500        56    11.00     21.00
Boron Injection Tank                       Tank     Sea-Van      1     28,500        37     5.50     12.50
Safety Injection Pump                      Lg Pump  Sea-Van      2      8,600       165
Refueling Water Storage Tank               Tank     Sea-Van      1    177,800       362    44.00     39.60
Primary Makeup Water Storage Tank          Tank     Sea-Van      1     99,200       206    30.00     35.40
10 Inch Valve                              Lg Valve Sea-Van      8      1,458        18
 8 Inch Valve                              Lg Valve Sea-Van      8      1,029        15
 6 Inch Valve                              Lg Valve Sea-Van      2        588         7
 4 Inch Valve                              Lg Valve Sea-Van      9        268         3
 3 Inch Valve                              Sm Valve Sea-Van      4        153         1
 2 Inch Valve                              Sm Valve Sea-Van      1         90         1
 1 1/2 Inch Valve                          Sm Valve Sea-Van      4         62         1
 1 Inch Valve                              Sm Valve Sea-Van     33         50         0
 3/4 Inch Valve                            Sm Valve Sea-Van     20         30         0
```

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

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

***  Radioactive Gaseous Waste System
Component Description                      Category  Disposal    Qty  Crew-Hrs  Pers-Hrs   Exp Hrs  Pers-Rem    Curies
------------------------------------------ --------  --------    ---  --------  --------   -------  --------    ------
Surge Tank                                  Tank     Sea-Van       1      11.7      64.3      40.9       0.0     0.016
Decay Tank                                  Tank     Sea-Van       4     101.3     556.9     353.9       0.3     0.595
Gas Compressor                              Lg Misc. Sea-Van       2       0.0       0.0       0.0       0.0     0.000
Moisture Separator                          Sm Misc. Sea-Van       2       0.0       0.0       0.0       0.0     0.000
Br. Seal Wtr. HX                            Lg HX    Mtl Box       2       4.1      16.4      10.4       0.0     0.176
4 Inch Valve                                Lg Valve Sea-Van       1       3.0      16.3      10.4       0.2     0.000
3 Inch Valve                                Sm Valve Sea-Van       3       0.0       0.0       0.0       0.0     0.000
2 Inch Valve                                Sm Valve Sea-Van      16       0.0       0.0       0.0       0.0     0.000
1 1/2 Inch Valve                            Sm Valve Sea-Van      35       0.0       0.0       0.0       0.0     0.003
1 Inch Valve                                Sm Valve Sea-Van      12       0.0       0.0       0.0       0.0     0.000
3/4 Inch Valve                              Sm Valve Sea-Van      16       0.0       0.0       0.0       0.0     0.000

                                                                           120       654       416         1     0.790


***  Residual Heat Removal System
Component Description                      Category  Disposal    Qty  Crew-Hrs  Pers-Hrs   Exp Hrs  Pers-Rem    Curies
------------------------------------------ --------  --------    ---  --------  --------   -------  --------    ------
Pump                                        Lg Pump  Sea-Van       2       4.1      16.4      10.4       0.0     0.003
HX Unit                                     Lg HX    Mtl Box       2       4.1      16.4      10.4       0.2     1.405
14 Inch Valve                               Lg Valve Sea-Van       7      20.8     114.2      72.6       0.6     0.027
12 Inch valve                               Lg Valve Sea-Van       3       8.9      48.9      31.1       0.3     0.008
10 Inch Valve                               Lg Valve Sea-Van       2       5.9      32.6      20.7       0.3     0.004
 8 Inch Valve                               Lg Valve Sea-Van      18      53.4     293.7     186.6       2.7     0.024
 2 Inch Valve                               Sm Valve Sea-Van       2       0.0       0.0       0.0       0.0     0.000
 3/4 Inch Valve                             Sm Valve Sea-Van      10       0.0       0.0       0.0       0.0     0.000

                                                                            97       522       332         4     1.472


***  Safety Injection System
Component Description                      Category  Disposal    Qty  Crew-Hrs  Pers-Hrs   Exp Hrs  Pers-Rem    Curies
------------------------------------------ --------  --------    ---  --------  --------   -------  --------    ------
Accuml. Tank                                Tank     Sea-Van       4     113.5     624.3     396.7       3.2     0.826
Boron Injection Tank                        Tank     Sea-Van       1      15.5      85.5      54.3       0.2     0.059
Safety Injection Pump                       Lg Pump  Sea-Van       2       4.1      16.4      10.4       0.0     0.003
Refueling Water Storage Tank                Tank     Sea-Van       1      85.7     471.3     299.5       0.1     1.919
Primary Makeup Water Storage Tank           Tank     Sea-Van       1      61.1     336.2     213.6       0.1     1.071
10 Inch Valve                               Lg Valve Sea-Van       8      23.7     130.5      82.9       1.1     0.016
 8 Inch Valve                               Lg Valve Sea-Van       8      23.7     130.5      82.9       1.2     0.010
 6 Inch Valve                               Lg Valve Sea-Van       2       5.9      32.6      20.7       0.3     0.002
 4 Inch Valve                               Lg Valve Sea-Van       9      26.7     146.8      93.3       1.7     0.004
 3 Inch Valve                               Sm Valve Sea-Van       4       0.0       0.0       0.0       0.0     0.001
 2 Inch Valve                               Sm Valve Sea-Van       1       0.0       0.0       0.0       0.0     0.000
 1 1/2 Inch Valve                           Sm Valve Sea-Van       4       0.0       0.0       0.0       0.0     0.000
 1 Inch Valve                               Sm Valve Sea-Van      33       0.0       0.0       0.0       0.0     0.001
 3/4 Inch Valve                             Sm Valve Sea-Van      20       0.0       0.0       0.0       0.0     0.000

                                                                           360     1,974     1,254         8     3.912
```

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

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
+ POTENTIALLY RADIOACTIVE SYSTEMS:  REMOVAL, TRANSPORTATION, DISPOSAL COSTS. +
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

***  Radioactive Gaseous Waste System
Component Description                      Category Disposal   Qty  Removal Container Transport  Disposal Tot. Costs
------------------------------------------ -------- --------   ---  ------- --------- ---------  -------- ----------
Surge Tank                                 Tank     Sea-Van      1    2,233       123        33     1,031      3,420
Decay Tank                                 Tank     Sea-Van      4   19,561     5,958     1,598    50,024     77,141
Gas Compressor                             Lg Misc. Sea-Van      2       85     2,207       592    18,527     21,411
Moisture Separator                         Sm Misc. Sea-Van      2        6        28         7       232        273
Br. Seal Wtr. HX                           Lg HX    Mtl Box      2      581     1,057       273     8,499     10,409
4 Inch Valve                               Lg Valve Sea-Van      1      572        37        10       310        929
3 Inch Valve                               Sm Valve Sea-Van      3        0        63        17       532        612
2 Inch Valve                               Sm Valve Sea-Van     16        0       199        53     1,667      1,919
1 1/2 Inch Valve                           Sm Valve Sea-Van     35        0       299        80     2,513      2,892
1 Inch Valve                               Sm Valve Sea-Van     12        0        83        22       695        800
3/4 Inch Valve                             Sm Valve Sea-Van     16        0        66        18       556        640

                                                                     23,037    10,119     2,704    84,586    120,445


***  Residual Heat Removal System
Component Description                      Category Disposal   Qty  Removal Container Transport  Disposal Tot. Costs
------------------------------------------ -------- --------   ---  ------- --------- ---------  -------- ----------
Pump                                       Lg Pump  Sea-Van      2      581     1,876       503    15,748     18,708
HX Unit                                    Lg HX    Mtl Box      2      646         0     1,538    31,212     33,397
14 Inch Valve                              Lg Valve Sea-Van      7    4,001     2,665       715    22,372     29,752
12 Inch valve                              Lg Valve Sea-Van      3    1,715       816       219     6,851      9,600
10 Inch Valve                              Lg Valve Sea-Van      2    1,143       402       108     3,377      5,030
 8 Inch Valve                              Lg Valve Sea-Van     18   10,288     2,554       685    21,448     34,975
 2 Inch Valve                              Sm Valve Sea-Van      2        0        25         7       208        240
 3/4 Inch Valve                            Sm Valve Sea-Van     10        0        41        11       347        400

                                                                     18,374     8,379     3,786   101,563    132,101


***  Safety Injection System
Component Description                      Category Disposal   Qty  Removal Container Transport  Disposal Tot. Costs
------------------------------------------ -------- --------   ---  ------- --------- ---------  -------- ----------
Accuml. Tank                               Tank     Sea-Van      4   22,022    42,202    11,320   354,337    429,882
Boron Injection Tank                       Tank     Sea-Van      1    2,987     3,931     1,054    33,002     40,974
Safety Injection Pump                      Lg Pump  Sea-Van      2      633     2,372       636    19,917     23,558
Refueling Water Storage Tank               Tank     Sea-Van      1   17,114    24,522     6,578   205,886    254,099
Primary Makeup Water Storage Tank          Tank     Sea-Van      1   12,122    13,681     3,670   114,870    144,343
10 Inch Valve                              Lg Valve Sea-Van      8    4,572     1,609       432    13,506     20,119
 8 Inch Valve                              Lg Valve Sea-Van      8    4,572     1,135       305     9,532     15,545
 6 Inch Valve                              Lg Valve Sea-Van      2    1,143       162        44     1,362      2,711
 4 Inch Valve                              Lg Valve Sea-Van      9    5,144       333        89     2,793      8,359
 3 Inch Valve                              Sm Valve Sea-Van      4        0        84        23       709        816
 2 Inch Valve                              Sm Valve Sea-Van      1        0        12         3       104        120
 1 1/2 Inch Valve                          Sm Valve Sea-Van      4        0        34         9       287        331
 1 Inch Valve                              Sm Valve Sea-Van     33        0       228        61     1,911      2,199
 3/4 Inch Valve                            Sm Valve Sea-Van     20        0        83        22       695        800

                                                                     70,309    90,388    24,246   758,910    943,854
```

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

```
++++++++++++++++++++++++++++++++++++++++++++
+ BUILDING COMPONENTS TO BE DECONTAMINATED +
++++++++++++++++++++++++++++++++++++++++++++

***  Fuel Bldg
                                                         Length      Width    Depth
Component description            Activity     (ft)       (ft)        (in)  orientation
------------------------------   --------    ------      -----       -----  -----------
Fuel Pool (Two Walls)           Mtl  Wash    58.000     40.500        N/A      Wall
Fuel Pool (Two Walls)           Mtl  Wash    80.000     40.500        N/A      Wall
Fuel Pool (Floor)               Mtl  Wash    29.000     40.000        N/A      Floor
Cask Loading Pit (Two walls)    Mtl  Wash    24.000     40.500        N/A      Wall
Cask Loading Pit (Two walls)    Mtl  Wash    16.000     40.500        N/A      Wall
Cask Loading Pit (Floor)        Mtl  Wash     8.000     12.000        N/A      Floor
Wash Pit (Two Walls)            Mtl  Wash    32.000     21.000        N/A      Wall
Wash Pit (Two Walls)            Mtl  Wash    34.000     21.000        N/A      Wall
Wash Pit (Floor)                Mtl  Wash    16.000     17.000        N/A      Floor
Load Pit Gate (Two Walls)       Mtl  Wash     3.000     25.000        N/A      Wall
Load Pit Gate (Two Walls)       Mtl  Wash     2.000     25.000        N/A      Wall
Load Pit Gate (Two Walls)       Mtl  Wash     7.000     25.000        N/A      Wall
Load Pit Gate (Floor)           Mtl  Wash     1.500      3.000        N/A      Floor
Load Pit Gate (Floor)           Mtl  Wash     3.500      5.000        N/A      Floor
Transfer Canal (Two walls)      Mtl  Wash    89.000     40.500        N/A      Wall
Transfer Canal (Two walls)      Mtl  Wash     8.000     40.500        N/A      Wall
Transfer Canal (Two walls)      Mtl  Wash     8.000     40.500        N/A      Wall
Transfer Canal (Two walls)      Mtl  Wash     7.000     40.500        N/A      Wall
Transfer Canal (Floor)          Mtl  Wash     4.000     44.500        N/A      Floor
Canal Gate (Two walls)          Mtl  Wash     4.500     25.000        N/A      Wall
Canal Gate (Two walls)          Mtl  Wash     3.000     25.000        N/A      Wall
Canal Gate (Two walls)          Mtl  Wash     2.500     25.000        N/A      Wall
Canal Gate (Floor)              Mtl  Wash     2.250      6.500        N/A      Floor
Canal Gate (Floor)              Mtl  Wash     1.250      3.500        N/A      Floor
Fuel Pool (Two walls)           Mtl  Rmvl    58.000     40.500      0.125      Wall
Fuel Pool (Two walls)           Mtl  Rmvl    80.000     40.500      0.125      Wall
Fuel Pool (Floor)               Mtl  Rmvl    29.000     40.000      0.125      Floor
Cask Loading Pit (Two walls)    Mtl  Rmvl    24.000     40.500      0.125      Wall
Cask Loading Pit (Two walls)    Mtl  Rmvl    16.000     40.500      0.125      Wall
Cask Loading Pit (Floor)        Mtl  Rmvl     8.000     12.000      0.125      Floor
Wash Pit (Two walls)            Mtl  Rmvl    32.000     21.000      0.125      Wall
Wash Pit (Two walls)            Mtl  Rmvl    34.000     21.000      0.125      Wall
Wash Pit (Floor)                Mtl  Rmvl    16.000     17.000      0.125      Floor
Load Pit Gate (Two walls)       Mtl  Rmvl     3.000     25.000      0.125      Wall
Load Pit Gate (Two walls)       Mtl  Rmvl     2.000     25.000      0.125      Wall
Load Pit Gate (Two walls)       Mtl  Rmvl     7.000     25.000      0.125      Wall
Load Pit Gate (Floor)           Mtl  Rmvl     1.500      3.000      0.125      Floor
Load Pit Gate (Floor)           Mtl  Rmvl     3.500      5.000      0.125      Floor
```

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

```
+++++++++++++++++++++++++++++++++++++++++++++++++
+ BUILDING DECONTAMINATION: TIMES AND EXPOSURES +
+++++++++++++++++++++++++++++++++++++++++++++++++

***  Fuel Bldg
                                               Time               Exposure
Component description            Activity      (hours) pers-hours pers-hours    Man rem
------------------------------   --------      ------- ---------- ----------    -------
Fuel Pool (Two Walls)            Mtl  Wash      11.745     46.980     11.745      0.014
Fuel Pool (Two Walls)            Mtl  Wash      16.200     64.800     16.200      0.020
Fuel Pool (Floor)                Mtl  Wash       4.833     19.333      4.833      0.006
Cask Loading Pit (Two walls)     Mtl  Wash       4.860     19.440      4.860      0.006
Cask Loading Pit (Two walls)     Mtl  Wash       3.240     12.960      3.240      0.004
Cask Loading Pit (Floor)         Mtl  Wash       0.400      1.600      0.400      0.000
Wash Pit (Two Walls)             Mtl  Wash       3.360     13.440      3.360      0.004
Wash Pit (Two Walls)             Mtl  Wash       3.570     14.280      3.570      0.004
Wash Pit (Floor)                 Mtl  Wash       1.133      4.533      1.133      0.001
Load Pit Gate (Two Walls)        Mtl  Wash       0.375      1.500      0.375      0.000
Load Pit Gate (Two Walls)        Mtl  Wash       0.250      1.000      0.250      0.000
Load Pit Gate (Two Walls)        Mtl  Wash       0.875      3.500      0.875      0.001
Load Pit Gate (Floor)            Mtl  Wash       0.019      0.075      0.019      0.000
Load Pit Gate (Floor)            Mtl  Wash       0.073      0.292      0.073      0.000
Transfer Canal (Two walls)       Mtl  Wash      18.023     72.090     18.023      0.022
Transfer Canal (Two walls)       Mtl  Wash       1.620      6.480      1.620      0.002
Transfer Canal (Two walls)       Mtl  Wash       1.620      6.480      1.620      0.002
Transfer Canal (Two walls)       Mtl  Wash       1.418      5.670      1.418      0.002
Transfer Canal (Floor)           Mtl  Wash       0.742      2.967      0.742      0.001
Canal Gate (Two walls)           Mtl  Wash       0.563      2.250      0.563      0.001
Canal Gate (Two walls)           Mtl  Wash       0.375      1.500      0.375      0.000
Canal Gate (Two walls)           Mtl  Wash       0.313      1.250      0.313      0.000
Canal Gate (Floor)               Mtl  Wash       0.061      0.244      0.061      0.000
Canal Gate (Floor)               Mtl  Wash       0.018      0.073      0.018      0.000
Fuel Pool (Two walls)            Mtl  Rmvl      13.737     75.556     48.009      0.058
Fuel Pool (Two walls)            Mtl  Rmvl      16.043     88.238     56.068      0.068
Fuel Pool (Floor)                Mtl  Rmvl       8.678     47.729     30.328      0.037
Cask Loading Pit (Two walls)     Mtl  Rmvl       8.606     47.331     30.075      0.036
Cask Loading Pit (Two walls)     Mtl  Rmvl       7.101     39.055     24.816      0.030
Cask Loading Pit (Floor)         Mtl  Rmvl       3.137     17.254     10.963      0.013
Wash Pit (Two walls)             Mtl  Rmvl       5.839     32.116     20.407      0.025
Wash Pit (Two walls)             Mtl  Rmvl       5.873     32.304     20.526      0.025
Wash Pit (Floor)                 Mtl  Rmvl       4.365     24.005     15.253      0.018
Load Pit Gate (Two walls)        Mtl  Rmvl       3.094     17.019     10.814      0.013
Load Pit Gate (Two walls)        Mtl  Rmvl       3.086     16.972     10.785      0.013
Load Pit Gate (Two walls)        Mtl  Rmvl       3.129     17.207     10.934      0.013
Load Pit Gate (Floor)            Mtl  Rmvl       0.000      0.000      0.000      0.000
Load Pit Gate (Floor)            Mtl  Rmvl       0.000      0.000      0.000      0.000
```

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

```
+++++++++++++++++++++++++++++++++++
+ BUILDING DECONTAMINATION: COSTS +
+++++++++++++++++++++++++++++++++++

***  Fuel Bldg

Component Description            Activity    Removal  Container  Transport   Disposal
------------------------------   --------    -------  ---------  ---------   --------
Fuel Pool (Two Walls)            Mtl  Wash  1,617.84       0.00       0.00   2,936.25
Fuel Pool (Two Walls)            Mtl  Wash  2,231.51       0.00       0.00   4,050.00
Fuel Pool (Floor)                Mtl  Wash    667.13       0.00       0.00   1,450.00
Cask Loading Pit (Two walls)     Mtl  Wash    669.45       0.00       0.00   1,215.00
Cask Loading Pit (Two walls)     Mtl  Wash    446.30       0.00       0.00     810.00
Cask Loading Pit (Floor)         Mtl  Wash     55.21       0.00       0.00     120.00
Wash Pit (Two Walls)             Mtl  Wash    462.83       0.00       0.00     840.00
Wash Pit (Two Walls)             Mtl  Wash    491.76       0.00       0.00     892.50
Wash Pit (Floor)                 Mtl  Wash    156.43       0.00       0.00     340.00
Load Pit Gate (Two Walls)        Mtl  Wash     51.66       0.00       0.00      93.75
Load Pit Gate (Two Walls)        Mtl  Wash     34.44       0.00       0.00      62.50
Load Pit Gate (Two Walls)        Mtl  Wash    120.53       0.00       0.00     218.75
Load Pit Gate (Floor)            Mtl  Wash      2.59       0.00       0.00       5.63
Load Pit Gate (Floor)            Mtl  Wash     10.06       0.00       0.00      21.88
Transfer Canal (Two walls)       Mtl  Wash  2,482.55       0.00       0.00   4,505.62
Transfer Canal (Two walls)       Mtl  Wash    223.15       0.00       0.00     405.00
Transfer Canal (Two walls)       Mtl  Wash    223.15       0.00       0.00     405.00
Transfer Canal (Two walls)       Mtl  Wash    195.26       0.00       0.00     354.38
Transfer Canal (Floor)           Mtl  Wash    102.37       0.00       0.00     222.50
Canal Gate (Two walls)           Mtl  Wash     77.48       0.00       0.00     140.63
Canal Gate (Two walls)           Mtl  Wash     51.66       0.00       0.00      93.75
Canal Gate (Two walls)           Mtl  Wash     43.05       0.00       0.00      78.13
Canal Gate (Floor)               Mtl  Wash      8.41       0.00       0.00      18.28
Canal Gate (Floor)               Mtl  Wash      2.52       0.00       0.00       5.47
Fuel Pool (Two walls)            Mtl  Rmvl  2,625.25   1,687.32     452.61  14,166.95
Fuel Pool (Two walls)            Mtl  Rmvl  3,068.55   2,327.34     624.29  19,540.63
Fuel Pool (Floor)                Mtl  Rmvl  1,655.75     833.25     223.51   6,996.03
Cask Loading Pit (Two walls)     Mtl  Rmvl  1,641.69     698.20     187.29   5,862.19
Cask Loading Pit (Two walls)     Mtl  Rmvl  1,353.79     465.47     124.86   3,908.13
Cask Loading Pit (Floor)         Mtl  Rmvl    596.72      68.96      18.50     578.98
Wash Pit (Two walls)             Mtl  Rmvl  1,113.01     482.71     129.48   4,052.87
Wash Pit (Two walls)             Mtl  Rmvl  1,119.62     512.88     137.58   4,306.18
Wash Pit (Floor)                 Mtl  Rmvl    830.89     195.38      52.41   1,640.45
Load Pit Gate (Two walls)        Mtl  Rmvl    588.45      53.87      14.45     452.33
Load Pit Gate (Two walls)        Mtl  Rmvl    586.80      35.92       9.63     301.55
Load Pit Gate (Two walls)        Mtl  Rmvl    595.07     125.71      33.72   1,055.44
Load Pit Gate (Floor)            Mtl  Rmvl      0.00       3.23       0.87      27.14
Load Pit Gate (Floor)            Mtl  Rmvl      0.00      12.57       3.37     105.54
```

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

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

                *** Fuel Bldg

                Concrete Washing--
                  Surface Area:        22,864 ft2
                  Decon Costs:        $13,150
                  Crew Hours:              95
                  Pers-Hours:             381
                  Pers-Rem:              0.12

                Metal Washing--
                  Surface Area:        15,428 ft2
                  Decon Costs:        $10,427
                  Crew Hours:              76
                  Pers-Hours:             303
                  Pers-Rem:              0.09

                Concrete Removal--
                  Surface Area:         6,570 ft2
                  Weight Removed:      78,846 lb
                  Removal Costs:      $86,357
                  Container Costs:     $3,541
                  Shipping Costs:      $2,844
                  Burial Costs:       $47,158
                  Burial Volume:          972 ft3
                  Number of Drums:     131.41
                  Crew Hours:             788
                  Pers-Hours:           2,760
                  Pers-Rem:              1.90

                Metal Removal--
                  Surface Area:        15,428 ft2
                  Weight Removed:      80,354 lb
                  Removal Costs:      $24,410
                  Container Costs:    $11,082
                  Shipping Costs:      $2,973
                  Burial Costs:       $93,047
                  Burial Volume:        1,429 ft3
                  Number of Vans:        2.23
                  Crew Hours:             128
                  Pers-Hours:             704
                  Pers-Rem:              0.54

                Concrete Cutting--
                  Inch-feet:            8,664
                  Cutting Costs:      $33,069
                  Crew Hours:             269
                  Pers-Hours:             673
                  Pers-Rem:              0.52
```

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

```
COSTS (IN DOLLARS) FOR REACTOR PRESSURE VESSEL AND INTERNALS
============================================================

COMPONENTS                    CUTTING  CONTAINERS   TRANSPORT    DISPOSAL       TOTAL

Insulation                     50,439       1,290       1,332       9,311     108,600
                                            4,695      33,189       8,345

Setup/Teardown                 77,974

Top Plate                       3,409       1,565       1,332      34,508      40,813

Upper Portion                               1,290       1,332      11,441
CRD Guides

Upper Portion                  79,304       2,580       1,332      18,622     212,155
Post and Columns

Lower Portion,                              9,390      39,852      47,013
Posts, Columns,
CRD Guides

Upper Core Barrel              12,305       1,290       1,332      13,780     127,028
                                           14,085      47,396      36,840

Thermal Shields                17,667       3,120     124,864     327,600     473,252

Shroud Plates                  50,551       4,160     159,111     436,800     650,621
and Formers

Upper/Lower Grid Plates        25,219       4,160     125,970     436,800     592,149

Upper Portion of Support       22,930       1,040      61,446     109,200     194,616
Posts and Inst. Guides

Lower Core Barrel              67,720      11,440     401,358   1,201,200   1,681,718

Support Forging                42,712      28,170      68,537      84,170     223,589
and Tie Plates

Lower Posts and                22,930       4,695      33,449      11,643      72,717
Instrument Guides

Setup/Teardown                 51,983

Upper/Lower RPV Heads          28,224       4,515       4,661     107,139     144,539

Upper/Lower RPV Flanges        11,238       4,515       4,661      69,864      90,278

Nozzle Sections                 4,346       3,760       5,327      66,847      80,281

Lower Wall                     28,480     103,290     184,231     257,783     573,784

Studs & Nuts                        0       1,290       1,332      14,636      17,258

CRD & Instrument               37,468         645       1,332       4,656      44,101
Penetrations

TOTALS                        634,899     210,985   1,303,375   3,308,196   5,457,456
```

Figure C.6 CECP output file for RPV internals

Table C.1 DECON case for reference PWR, Hanford burial site (final summary report for DECON)

	Costs (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	600,077	600,077	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	3,322,575	3,322,575	0	0	0	0.00
Totals	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 0.6200)											
Removal of NSSS											
Removal of RPV Internals	0	473,160	92,970	1,101,830	2,787,273	0	4,455,233	3,454	1,456	13,107	63.99
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Solution	1,074,600	0	1,725	0	23,278	0	1,099,602	480	3,936	11,808	12.00
Totals	14,324,600	473,160	94,695	1,101,830	3,276,852	0	19,271,137	8,534	6,800	33,363	121.69
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	11,454	7,448	154,586	0	173,488	3,188	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	316,134	316,134	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	9,463	9,463	0	0	0	0.00
Chemical Decon/Deboration Energy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,493,178	9,493,178	0	0	87,069	87.07
Totals for Period 2	14,324,600	473,160	106,149	1,109,278	3,431,437	9,493,178	28,937,802	11,722	6,800	120,432	208.76
Period 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,905,743	1,905,743	0	0	22,277	20.53
DOC Staff	0	0	0	0	0	965,545	965,545	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00

Table C.1 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,842	42,842	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	6,862,503	6,862,503	0	0	22,277	20.53
Totals for Period 3	0	0	0	0	0	6,862,503	6,862,503	0	0	22,277	20.53
Period 4: Deferred Dismantlement (Year 6.9200 to Year 8.6200)											
Removal of NSSS											
Removal of Reactor Pressure Vessel	0	161,739	118,015	201,545	520,924	0	1,002,223	2,924	498	4,480	17.68
Steam Generator--Direct Removal Costs	1,070,711	5,165,032	437,363	1,575,067	3,349,743	0	11,597,916	64,524	1,443	86,557	60.00
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	30,336	8,137	254,706	0	315,323	3,910	115	634	4.87
Large Miscellaneous RCS Piping	0	22,862	3,794	1,018	33,638	0	61,311	489	119	653	5.01
Small Miscellaneous RCS Piping	0	42,714	421	113	3,786	0	47,034	54	222	1,220	9.36
RCS Insulation	0	0	39,720	5,327	248,293	0	293,341	5,120	0	0	0.00
Pressurizer	0	8,112	0	172,294	118,327	0	298,733	2,440	16	90	0.69
Pressurizer Relief Tank	0	5,868	3,650	979	30,645	0	41,142	470	30	166	1.27
Primary Pumps	0	32,448	0	689,175	203,678	0	925,301	4,200	65	360	2.76
Spent Fuel Racks	0	661,500	63,680	16,601	1,006,162	0	1,747,944	18,113	267	2,400	1.20
Biological Shield	0	173,519	86,917	44,867	699,105	0	1,004,407	12,936	518	3,365	31.22
Totals	1,070,711	6,437,673	783,896	2,715,124	6,469,007	0	17,476,411	115,181	3,293	99,926	134.06
Removal of Contaminated Plant Systems											
Component Cooling Water System	0	63,324	63,800	17,114	535,670	0	679,908	8,224	338	1,802	10.59
Clean Radioactive Waste Treatment System	0	49,471	16,765	4,504	140,751	0	211,492	2,162	266	1,405	5.46
Containment Spray System	0	17,489	8,656	2,322	72,679	0	101,146	1,116	98	500	1.98
Chemical and Volume Control System	0	137,558	44,844	12,076	378,432	0	572,909	5,871	725	3,919	22.00
Dirty Radioactive Waste Treatment System	0	19,994	3,706	994	31,112	0	55,806	478	113	574	1.44
Main Steam System (Within Containment)	0	53,567	26,440	7,092	221,994	0	309,094	3,408	281	1,529	7.70
Radioactive Gaseous Waste System	0	26,785	11,316	3,025	94,641	0	135,767	1,480	147	762	0.57
Residual Heat Removal System	0	23,984	8,505	3,820	102,619	0	138,927	1,568	138	685	4.63
Safety Injection System	0	75,098	88,257	23,674	741,019	0	928,049	11,377	395	2,113	8.00
Spent Fuel Cooling System	0	30,872	5,834	1,571	48,669	0	86,947	770	166	884	6.39
Stainless Steel Piping (3 - 24 Inches)	0	799,941	64,028	17,175	568,652	0	1,449,796	8,253	4,153	22,842	230.67
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,634	2,584	88,658	0	738,778	1,242	3,313	18,224	228.36
Retrofit Materials	0	17,741	1,059	284	8,921	0	28,006	137	95	508	4.01

Table C.1 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Electrical Components and Annunciators	0	14,365	55,366	14,852	464,863	0	549,446	7,137	94	378	0.03
Control Rod Drive	0	2,156	141	38	1,183	0	3,517	18	16	63	0.00
Small Hangers (4" pipe or less)	0	1,281,639	181,259	52,479	891,795	0	2,407,172	12,609	6,678	36,728	0.94
Large Hangers (> 4" pipe)	0	800,070	139,190	40,299	684,816	0	1,664,375	9,683	4,162	22,893	0.59
Totals	0	4,051,957	728,800	203,903	5,076,474	0	10,061,134	75,531	21,179	115,807	533.36
Decontamination of Site Buildings											
Fuel Bldg	23,577	110,767	14,324	5,736	137,690	0	292,095	2,362	905	3,510	2.21
Containment Bldg	125,020	106,706	19,888	6,875	181,299	0	439,787	2,988	1,846	6,789	3.39
Auxiliary Bldg	64,318	135,203	8,156	5,062	95,065	0	307,804	1,839	1,583	5,458	3.23
Waste Water Solidification Costs	293,300	0	54,775	55,592	86,524	0	490,192	1,414	875	2,624	0.71
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	67,590	0	887,176	1,010	720	4,320	2.00
Cascading Costs—Concrete Cutting	0	48,168	0	0	0	0	48,168	0	392	980	0.75
Cascading Costs—Asbestos Removal	0	165,000	0	0	0	0	165,000	0	0	0	0.00
Removal of HVAC Ducts	0	107,355	24,662	6,615	167,390	0	306,023	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	92,957	2,166,263	0	2,643,469	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	76,623	20,554	643,336	0	774,267	9,877	179	895	0.46
Bridge Crane	7,542	75,780	3,650	1,315	76,603	0	164,889	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	1,522	76,603	0	326,336	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	2,664	67,398	0	84,301	1,280	23	125	0.31
Floor Drains	0	248,660	7,925	4,091	63,746	0	324,423	1,180	1,715	5,145	1.09
Totals	1,275,509	1,310,430	635,500	202,982	3,829,507	0	7,253,928	72,518	10,234	37,952	16.28
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	58,456	38,011	788,913	0	885,380	16,268	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	3,390,649	3,390,649	0	0	29,744	11.97
DOC Staff	0	0	0	0	0	11,935,886	11,935,886	0	0	69,888	28.13
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	1,024,335	1,024,335	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	927,457	927,457	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	261,975	261,975	0	0	0	0.00

Table C.1 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Steam Generator--Undistributed Costs	0	0	0	0	0	208,885	208,885	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	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	24,808,844	24,808,844	0	0	99,632	40.10
Totals for Period 4	2,346,220	11,800,060	2,206,652	3,160,019	16,163,902	26,029,031	61,705,884	279,498	34,705	353,317	723.80
Grand Totals	16,670,820	12,273,220	2,312,801	4,269,297	19,595,339	51,492,427	106,613,904	291,220	41,505	496,026	953.09
Grand Totals with 25% contingency	20,838,525	15,341,525	2,891,001	5,336,622	24,494,174	64,365,534	133,267,380	291,220	41,505	496,026	953.09

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) without contingency	Costs (dollars) with 25% contingency
A (labor and materials):	0.727	71,895,719	89,869,649
B (energy and transportation):	0.075	7,378,994	9,223,743
C (waste burial):	0.198	19,595,339	24,494,174
	A + B + C ($)	98,870,052	123,587,565
	Taxes and Insurance ($)	7,743,852	9,679,815
	Grand Totals ($)	106,613,904	133,267,380

Table C.2. DECON case for reference PWR, Barnwell burial site (final summary report for DECON)

	Costs (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	600,077	600,077	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	3,322,575	3,322,575	0	0	0	0.00
Totals	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 0.6200)											
Removal of NSSS											
Removal of RPV Internals	0	473,160	92,970	1,353,942	4,329,456	0	6,249,529	3,454	1,456	13,107	63.99
Chemical Decontamination	13,250,000	0	0	0	2,105,580	0	15,355,580	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Solution	1,074,600	0	1,725	0	134,600	0	1,210,924	480	3,936	11,808	12.00
Totals	14,324,600	473,160	94,695	1,353,942	6,569,636	0	22,816,033	8,534	6,800	33,363	121.69
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	11,454	24,168	893,874	0	929,496	3,188	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	316,134	316,134	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	9,463	9,463	0	0	0	0.00
Chemical Decon/DeborationEnergy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,493,178	9,493,178	0	0	87,069	87.07
Totals for Period 2	14,324,600	473,160	106,149	1,378,110	7,463,510	9,493,178	33,238,707	11,722	6,800	120,432	208.76
Period 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,905,743	1,905,743	0	0	22,277	20.53
DOC Staff	0	0	0	0	0	965,545	965,545	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00

Table C.2 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,842	42,842	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	6,862,503	6,862,503	0	0	22,277	20.53
Totals for Period 3	0	0	0	0	0	6,862,503	6,862,503	0	0	22,277	20.53
Period 4: Deferred Dismantlement (Year 6.9200 to Year 8.6200)											
Removal of NSSS											
Removal of Reactor Pressure Vessel	0	161,739	118,015	849,295	2,767,791	0	3,896,841	2,924	498	4,480	17.68
Steam Generator--Direct Removal Costs	1,070,711	5,555,033	437,363	5,675,010	18,168,082	0	30,906,199	64,524	1,443	86,557	60.00
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	30,336	26,404	1,115,999	0	1,194,883	3,910	115	634	4.87
Large Miscellaneous RCS Piping	0	22,862	3,794	3,302	139,555	0	169,513	489	119	653	5.01
Small Miscellaneous RCS Piping	0	42,714	421	367	15,501	0	59,002	54	222	1,220	9.36
RCS Insulation	0	0	39,720	17,286	1,441,130	0	1,498,136	5,120	0	0	0.00
Pressurizer	0	8,112	0	237,750	684,215	0	930,077	2,440	16	90	0.69
Pressurizer Relief Tank	0	5,868	3,650	3,177	134,273	0	146,968	470	30	166	1.27
Primary Pumps	0	32,448	0	951,000	1,177,747	0	2,161,195	4,200	65	360	2.76
Spent Fuel Racks	0	661,500	63,680	86,021	5,117,255	0	5,928,456	18,113	267	2,400	1.20
Biological Shield	0	173,519	86,917	145,585	3,789,282	0	4,195,301	12,936	518	3,365	31.22
Totals	1,070,711	6,827,674	783,896	7,995,197	34,550,830	0	51,228,308	115,181	3,293	99,926	134.06
Removal of Contaminated Plant Systems											
Component Cooling Water System	0	63,324	63,800	55,531	2,347,054	0	2,529,708	8,224	338	1,802	10.59
Clean Radioactive Waste Treatment System	0	49,471	16,765	14,615	616,945	0	697,796	2,162	266	1,405	5.46
Containment Spray System	0	17,489	8,656	7,534	318,445	0	352,125	1,116	98	500	1.98
Chemical and Volume Control System	0	137,558	44,844	39,184	1,678,189	0	1,899,774	5,871	725	3,919	22.00
Dirty Radioactive Waste Treatment System	0	19,994	3,706	3,225	136,317	0	163,242	478	113	574	1.44
Main Steam System (Within Containment)	0	53,567	26,440	23,013	972,674	0	1,075,695	3,408	281	1,529	7.70
Radioactive Gaseous Waste System	0	26,785	11,316	9,815	423,500	0	471,417	1,480	147	762	0.57
Residual Heat Removal System	0	23,984	8,505	12,394	436,108	0	480,991	1,568	138	685	4.63
Safety Injection System	0	75,098	88,257	76,818	3,246,794	0	3,486,967	11,377	395	2,113	8.00
Spent Fuel Cooling System	0	30,872	5,834	5,099	220,738	0	262,543	770	166	884	6.39
Stainless Steel Piping (3 - 24 Inches)	0	799,941	64,028	55,729	2,355,435	0	3,275,133	8,253	4,153	22,842	230.67
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,634	8,385	354,408	0	1,010,329	1,242	3,313	18,224	228.36
Retrofit Materials	0	17,741	1,059	922	38,966	0	58,688	137	95	508	4.01

Table C.2 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Electrical Components and Annunciators	0	14,365	55,366	48,190	2,036,808	0	2,154,730	7,137	94	378	0.03
Control Rod Drive	0	2,156	141	123	5,183	0	7,602	18	16	63	0.00
Small Hangers (4" pipe or less)	0	1,281,639	181,259	170,284	3,166,572	0	4,799,754	12,609	6,678	36,728	0.94
Large Hangers (> 4" pipe)	0	800,070	139,190	130,762	2,431,634	0	3,501,656	9,683	4,162	22,893	0.59
Totals	0	4,051,957	728,800	661,624	20,785,771	0	26,228,152	75,531	21,179	115,807	533.36
Decontamination of Site Buildings											
Fuel Bldg	23,577	110,767	14,324	18,613	669,354	0	836,636	2,362	905	3,510	2.21
Containment Bldg	125,020	106,706	19,888	22,307	848,656	0	1,122,577	2,988	1,846	6,789	3.39
Auxiliary Bldg	64,318	135,203	8,156	16,424	517,346	0	741,448	1,839	1,583	5,458	3.23
Waste Water Solidification Costs	293,300	0	54,775	117,564	513,275	0	978,914	1,414	875	2,624	0.71
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	373,800	0	1,193,386	1,010	720	4,320	2.00
Cascading Costs--Concrete Cutting	0	48,168	0	0	0	0	48,168	0	392	980	0.75
Cascading Costs--Asbestos Removal	0	165,000	0	0	0	0	165,000	0	0	0	0.00
Removal of HVAC Ducts	0	107,355	24,662	21,466	899,812	0	1,053,295	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	301,626	12,573,296	0	13,259,171	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	76,623	66,692	2,818,792	0	2,995,862	9,877	179	895	0.46
Bridge Crane	7,542	75,780	3,650	7,199	384,551	0	478,721	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	8,490	385,551	0	642,252	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	8,643	362,302	0	385,184	1,280	23	125	0.31
Floor Drains	0	248,660	7,925	13,275	345,516	0	615,377	1,180	1,715	5,145	1.09
Totals	1,275,509	1,310,430	635,500	602,298	20,692,252	0	24,515,989	72,518	10,234	37,952	16.28
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	58,456	123,337	4,561,805	0	4,743,598	16,268	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	3,390,649	3,390,649	0	0	29,744	11.97
DOC Staff	0	0	0	0	0	11,935,886	11,935,886	0	0	69,888	28.13
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	1,024,335	1,024,335	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	927,457	927,457	0	0	0	0.00

Table C.2 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Small Tools and Minor Equipment	0	0	0	0	0	269,775	269,775	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	208,885	208,885	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	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	24,816,644	24,816,644	0	0	99,632	40.10
Totals for Period 4	2,346,220	12,190,061	2,206,652	9,382,457	80,590,659	26,036,831	132,752,878	279,498	34,705	353,317	723.80
Grand Totals	16,670,820	12,663,221	2,312,801	10,760,566	88,054,169	51,500,227	181,961,804	291,220	41,505	496,026	953.09
Grand Totals with 25% contingency	20,838,525	15,829,026	2,891,001	13,450,708	110,067,711	64,375,284	227,452,255	291,220	41,505	496,026	953.09

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):	0.415	72,293,520	90,366,900
B (energy and transportation):	0.080	13,870,263	17,337,829
C (waste burial):	0.505	88,054,169	110,067,711
	A + B + C ($)	174,217,952	217,772,440
	Taxes and Insurance ($)	7,743,852	9,679,815
	Grand Totals ($)	181,961,804	227,452,255

Table C.3. SAFSTOR case for reference PWR, Hanford burial site (final summary report for SAFSTOR2)

	Costs (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	600,077	600,077	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	3,322,575	3,322,575	0	0	0	0.00
Totals	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 0.6200)											
Removal of NSSS											
Removal of RPV Internals	0	473,160	92,970	1,101,830	2,787,273	0	4,455,233	3,454	1,456	13,107	63.99
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Solution	1,074,600	0	1,725	0	23,278	0	1,099,602	480	3,936	11,808	12.00
Totals	14,324,600	473,160	94,695	1,101,830	3,276,852	0	19,271,137	8,534	6,800	33,363	121.69
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	11,454	7,448	154,586	0	173,488	3,188	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	316,134	316,134	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	9,463	9,463	0	0	0	0.00
Chemical Decon/Deboration Energy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,493,178	9,493,178	0	0	87,069	87.07
Totals for Period 2	14,324,600	473,160	106,149	1,109,278	3,431,437	9,493,178	28,937,802	11,722	6,800	120,432	208.76
Period 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,905,743	1,905,743	0	0	22,277	20.53
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,842	42,842	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53
Totals for Period 3	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53

Table C.3. (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Period 4: Extended Safe Storage (Year 6.9200 to Year 58.3000)											
Layup Spent Fuel Pool											
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	67,590	0	887,176	1,010	720	4,320	2.00
Totals	754,211	0	65,375	0	67,590	0	887,176	1,010	720	4,320	2.00
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	1,213	789	16,367	0	18,368	338	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	41,529,842	41,529,842	0	0	213,741	86.02
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	1,533,385	1,533,385	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	2,497,222	2,497,222	0	0	0	0.00
Laundry Services	0	0	0	0	0	572,410	572,410	0	0	0	0.00
Maintenance Allowance	0	0	0	0	0	892,933	892,933	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	576,483	576,483	0	0	0	0.00
Property Taxes	0	0	0	0	0	4,624,200	4,624,200	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	30,828,000	30,828,000	0	0	0	0.00
Totals	0	0	0	0	0	84,985,567	84,985,567	0	0	213,741	86.02
Totals for Period 4	754,211	0	66,588	789	83,957	84,985,567	85,891,111	1,347	720	218,061	88.02
Period 5: Deferred Dismantlement (Year 58.3000 to Year 60.0000)											
Removal of NSSS											
Removal of Reactor Pressure Vessel	0	161,739	118,015	201,545	383,554	0	864,853	2,924	498	4,480	1.46
Steam Generator--Direct Removal Costs	1,070,711	5,165,032	437,363	1,575,067	3,230,253	0	11,478,427	64,524	1,443	86,557	0.07
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	30,336	8,137	254,706	0	315,323	3,910	115	634	0.01
Large Miscellaneous RCS Piping	0	22,862	3,794	1,018	33,638	0	61,311	489	119	653	0.01
Small Miscellaneous RCS Piping	0	42,714	421	113	3,786	0	47,034	54	222	1,220	0.01
RCS Insulation	0	0	39,720	5,327	248,293	0	293,341	5,120	0	0	0.00
Pressurizer	0	8,112	0	172,294	118,327	0	298,733	2,440	16	90	0.00
Pressurizer Relief Tank	0	5,868	3,650	979	30,645	0	41,142	470	30	166	0.00
Primary Pumps	0	32,448	0	689,175	203,678	0	925,301	4,200	65	360	0.00
Spent Fuel Racks	0	661,500	63,680	16,601	1,006,162	0	1,747,944	18,113	267	2,400	1.20
Biological Shield	0	173,519	86,917	44,867	699,105	0	1,004,407	12,936	518	3,365	0.04
Totals	1,070,711	6,437,673	783,896	2,715,124	6,212,148	0	17,219,551	115,181	3,293	99,926	2.79
Removal of Contaminated Plant Systems											
Component Cooling Water System	0	63,324	63,800	17,114	535,670	0	679,908	8,224	338	1,802	0.01
Clean Radioactive Waste Treatment System	0	49,471	16,765	4,504	140,751	0	211,492	2,162	266	1,405	0.01
Containment Spray System	0	17,489	8,656	2,322	72,679	0	101,146	1,116	98	500	0.00

Table C.3. (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Chemical and Volume Control System	0	137,558	44,844	12,076	378,432	0	572,909	5,871	725	3,919	0.03
Dirty Radioactive Waste Treatment System	0	19,994	3,706	994	31,112	0	55,806	478	113	574	0.00
Main Steam System (Within Containment)	0	53,567	26,440	7,092	221,994	0	309,094	3,408	281	1,529	0.01
Radioactive Gaseous Waste System	0	26,785	11,316	3,025	94,641	0	135,767	1,480	147	762	0.00
Residual Heat Removal System	0	23,984	8,505	3,820	102,619	0	138,927	1,568	138	685	0.01
Safety Injection System	0	75,098	88,257	23,674	741,019	0	928,049	11,377	395	2,113	0.01
Spent Fuel Cooling System	0	30,872	5,834	1,571	48,669	0	86,947	770	166	884	0.01
Stainless Steel Piping (3 - 24 Inches)	0	799,941	64,028	17,175	537,583	0	1,418,727	8,253	4,153	22,842	0.27
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,634	2,584	80,887	0	731,007	1,242	3,313	18,224	0.27
Retrofit Materials	0	17,741	1,059	284	8,893	0	27,978	137	95	508	0.00
Electrical Components and Annunciators	0	14,365	55,366	14,852	464,863	0	549,446	7,137	94	378	0.00
Control Rod Drive	0	2,156	141	38	1,183	0	3,517	18	16	63	0.00
Small Hangers (4" pipe or less)	0	1,281,639	181,259	52,479	891,795	0	2,407,172	12,609	6,678	36,728	0.00
Large Hangers (> 4" pipe)	0	800,070	139,190	40,299	684,816	0	1,664,375	9,683	4,162	22,893	0.00
Totals	0	4,051,957	728,800	203,903	5,037,607	0	10,022,267	75,531	21,179	115,807	0.62
Decontamination of Site Buildings											
Fuel Bldg	23,577	110,767	14,324	5,736	137,690	0	292,095	2,362	905	3,510	0.00
Containment Bldg	125,020	106,706	19,888	6,875	181,299	0	439,787	2,988	1,846	6,789	0.00
Auxiliary Bldg	64,318	135,203	8,156	5,062	95,065	0	307,804	1,839	1,583	5,458	0.00
Waste Water Solidification Costs	293,300	0	54,775	55,592	86,524	0	490,192	1,414	875	2,624	0.71
Cascading Costs--Concrete Cutting	0	48,168	0	0	0	0	48,168	0	392	80	0.00
Cascading Costs--Asbestos Removal	0	165,000	0	0	0	0	165,000	0	0	0	0.00
Removal of HVAC Ducts	0	107,355	24,662	6,615	167,390	0	306,023	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	92,957	2,166,263	0	2,643,469	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	76,623	20,554	643,336	0	774,267	9,877	179	895	0.46
Bridge Crane	7,542	75,780	3,650	1,315	76,603	0	164,889	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	1,522	76,603	0	326,336	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	2,664	67,398	0	84,301	1,280	23	125	0.00
Floor Drains	0	248,660	7,925	4,091	63,746	0	324,423	1,180	1,715	5,145	1.09
Totals	521,298	1,310,430	570,125	202,982	3,761,917	0	6,366,752	71,508	9,514	33,632	4.39
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	57,244	37,222	772,546	0	867,012	15,930	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	3,390,650	3,390,650	0	0	29,744	0.01
DOC Staff	0	0	0	0	0	11,935,888	11,935,888	0	0	69,888	0.03

Table C.3. (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
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	1,024,335	1,024,335	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	916,117	916,117	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	261,975	261,975	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	208,885	208,885	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	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	24,797,507	24,797,507	0	0	99,632	0.05
Totals for Period 5	1,592,009	11,800,060	2,140,064	3,159,231	15,784,218	26,017,694	60,493,276	278,151	33,985	348,997	7.85
Grand Totals	16,670,820	12,273,220	2,312,801	4,269,297	19,299,612	135,501,112	190,326,862	291,220	41,505	709,767	325.17
Grand Totals with 25% Contingency	20,838,525	15,341,525	2,891,001	5,336,622	24,124,515	169,376,390	237,908,578	291,220	41,505	709,767	325.17

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) without contingency	Costs (dollars) with 25% contingency
A (labor and materials):	0.815	119,875,721	149,844,651
B (energy and transportation):	0.054	7,955,477	9,944,347
C (waste burial):	0.131	19,299,612	24,124,515
	A + B + C ($)	147,130,810	183,913,513
	Taxes and Insurance ($)	43,196,052	53,995,065
	Grand Totals ($)	190,326,862	237,908,578

Table C.4 SAFSTOR case for reference PWR, Barnwell burial site (final summary report for SAFSTOR2)

	Costs (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	600,077	600,077	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	3,322,575	3,322,575	0	0	0	0.00
Totals	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Totals for Period 1	0	0	0	0	0	9,107,715	9,107,715	0	0	0	0.00
Period 2: Defuel and Layup (Year 0.0000 to Year 0.6200)											
Removal of NSSS											
Removal of RPV Internals	0	473,160	92,970	1,353,942	4,324,201	0	6,244,274	3,454	1,456	13,107	63.99
Chemical Decontamination	13,250,000	0	0	0	2,105,580	0	15,355,580	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Solution	1,074,600	0	1,725	0	134,600	0	1,210,924	480	3,936	11,808	12.00
Totals	14,324,600	473,160	94,695	1,353,942	6,564,381	0	22,810,778	8,534	6,800	33,363	121.69
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	11,454	24,168	893,874	0	929,496	3,188	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	316,134	316,134	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	9,463	9,463	0	0	0	0.00
Chemical Decon/DeborationEnergy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,493,178	9,493,178	0	0	87,069	87.07
Totals for Period 2	14,324,600	473,160	106,149	1,378,110	7,458,255	9,493,178	33,233,452	11,722	6,800	120,432	208.76
Period 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)											
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,905,743	1,905,743	0	0	22,277	20.53
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00

Table C.4 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Plant Power Usage	0	0	0	0	0	42,842	42,842	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53
Totals for Period 3	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53
Period 4: Extended Safe Storage (Year 6.9200 to Year 58.3000)											
Layup Spent Fuel Pool											
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	373,800	0	1,193,386	1,010	720	4,320	2.00
Totals	754,211	0	65,375	0	373,800	0	1,193,386	1,010	720	4,320	2.00
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	1,213	2,559	94,640	0	98,412	338	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	41,529,842	41,529,842	0	0	213,741	86.02
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	1,533,385	1,533,385	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	2,497,222	2,497,222	0	0	0	0.00
Laundry Services	0	0	0	0	0	572,410	572,410	0	0	0	0.00
Maintenance Allowance	0	0	0	0	0	892,933	892,933	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	576,483	576,483	0	0	0	0.00
Property Taxes	0	0	0	0	0	4,624,200	4,624,200	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	30,828,000	30,828,000	0	0	0	0.00
Totals	0	0	0	0	0	84,985,567	84,985,567	0	0	213,741	86.02
Totals for Period 4	754,211	0	66,588	2,559	468,440	84,985,567	86,277,365	1,347	720	218,061	88.02
Period 5: Deferred Dismantlement (Year 58.3000 to Year 60.0000)											
Removal of NSSS											
Removal of Reactor Pressure Vessel	0	161,739	118,015	849,295	1,289,611	0	2,418,661	2,924	498	4,480	1.46
Steam Generator--Direct Removal Costs	1,070,711	5,555,033	437,363	5,675,010	18,110,162	0	30,848,279	64,524	1,443	86,557	0.07
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	30,336	26,404	1,115,999	0	1,194,883	3,910	115	634	0.01
Large Miscellaneous RCS Piping	0	22,862	3,794	3,302	139,555	0	169,513	489	119	653	0.01
Small Miscellaneous RCS Piping	0	42,714	421	367	15,501	0	59,002	54	222	1,220	0.01
RCS Insulation	0	0	39,720	17,286	1,441,130	0	1,498,136	5,120	0	0	0.00
Pressurizer	0	8,112	0	237,750	684,215	0	930,077	2,440	16	90	0.00

Table C.4 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Pressurizer Relief Tank	0	5,868	3,650	3,177	134,273	0	146,968	470	30	166	0.00
Primary Pumps	0	32,448	0	951,000	1,177,747	0	2,161,195	4,200	65	360	0.00
Spent Fuel Racks	0	661,500	63,680	86,021	5,117,255	0	5,928,456	18,113	267	2,400	1.20
Biological Shield	0	173,519	86,917	145,585	3,789,282	0	4,195,301	12,936	518	3,365	0.04
Totals	1,070,711	6,827,674	783,896	7,995,197	33,014,730	0	49,692,208	115,181	3,293	99,926	2.79
Removal of Contaminated Plant Systems											
Component Cooling Water System	0	63,324	63,800	55,531	2,347,054	0	2,529,708	8,224	338	1,802	0.01
Clean Radioactive Waste Treatment System	0	49,471	16,765	14,615	616,945	0	697,796	2,162	266	1,405	0.01
Containment Spray System	0	17,489	8,656	7,534	318,445	0	352,125	1,116	98	500	0.00
Chemical and Volume Control System	0	137,558	44,844	39,184	1,678,189	0	1,899,774	5,871	725	3,919	0.03
Dirty Radioactive Waste Treatment System	0	19,994	3,706	3,225	136,317	0	163,242	478	113	574	0.00
Main Steam System (Within Containment)	0	53,567	26,440	23,013	972,674	0	1,075,695	3,408	281	1,529	0.01
Radioactive Gaseous Waste System	0	26,785	11,316	9,815	423,500	0	471,417	1,480	147	762	0.00
Residual Heat Removal System	0	23,984	8,505	12,394	436,108	0	480,991	1,568	138	685	0.01
Safety Injection System	0	75,098	88,257	76,818	3,246,794	0	3,486,967	11,377	395	2,113	0.01
Spent Fuel Cooling System	0	30,872	5,834	5,099	220,738	0	262,543	770	166	884	0.01
Stainless Steel Piping (3 - 24 Inches)	0	799,941	64,028	55,729	2,355,435	0	3,275,133	8,253	4,153	22,842	0.27
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,634	8,385	354,408	0	1,010,329	1,242	3,313	18,224	0.27
Retrofit Materials	0	17,741	1,059	922	38,966	0	58,688	137	95	508	0.00
Electrical Components and Annunciators	0	14,365	55,366	48,190	2,036,808	0	2,154,730	7,137	94	378	0.00
Control Rod Drive	0	2,156	141	123	5,183	0	7,602	18	16	63	0.00
Small Hangers (4" pipe or less)	0	1,281,639	181,259	170,284	3,166,572	0	4,799,754	12,609	6,678	36,728	0.00
Large Hangers (> 4" pipe)	0	800,070	139,190	130,762	2,431,634	0	3,501,656	9,683	4,162	22,893	0.00
Totals	0	4,051,957	728,800	661,624	20,785,771	0	26,228,152	75,531	21,179	115,807	0.62
Decontamination of Site Buildings											
Fuel Bldg	23,577	110,767	14,324	18,613	669,354	0	836,636	2,362	905	3,510	0.00
Containment Bldg	125,020	106,706	19,888	22,307	848,656	0	1,122,577	2,988	1,846	6,789	0.00
Auxiliary Bldg	64,318	135,203	8,156	16,424	517,346	0	741,448	1,839	1,583	5,458	0.00
Waste Water Solidification Costs	293,300	0	54,775	117,564	513,275	0	978,914	1,414	875	2,624	0.71
Cascading Costs--Concrete Cutting	0	48,168	0	0	0	0	48,168	0	392	980	0.00
Cascading Costs--Asbestos Removal	0	165,000	0	0	0	0	165,000	0	0	0	0.00
Removal of HVAC Ducts	0	107,355	24,662	21,466	899,812	0	1,053,295	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	301,626	12,573,296	0	13,259,171	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	76,623	66,692	2,818,792	0	2,995,862	9,877	179	895	0.46
Bridge Crane	7,542	75,780	3,650	7,199	384,551	0	478,721	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	8,490	385,551	0	642,252	1,360	304	2,104	0.00

Table C.4 (Continued)

	Costs (dollars)										
	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Refueling Cranes	0	4,309	9,930	8,643	362,302	0	385,184	1,280	23	125	0.00
Floor Drains	0	248,660	7,925	13,275	345,516	0	615,377	1,180	1,715	5,145	1.09
Totals	521,298	1,310,430	570,125	602,298	20,318,452	0	23,322,604	71,508	9,514	33,632	4.39
Dry Active Waste Costs for this Period											
Dry Active Waste	0	0	57,244	120,778	4,467,164	0	4,645,186	15,930	0	0	0.00
Site Termination Survey											
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00
Undistributed Costs											
Utility Staff	0	0	0	0	0	3,390,650	3,390,650	0	0	29,744	0.01
DOC Staff	0	0	0	0	0	11,935,888	11,935,888	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	1,024,335	1,024,335	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	916,117	916,117	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	269,775	269,775	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	208,885	208,885	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	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	24,805,307	24,805,307	0	0	99,632	0.05
Totals for Period 5	1,592,009	12,190,061	2,140,064	9,379,898	78,586,118	26,025,494	129,913,644	278,151	33,985	348,997	7.85
Grand Totals	16,670,820	12,663,221	2,312,801	10,760,566	86,512,814	135,508,912	264,429,134	291,220	41,505	709,767	325.17
Grand Totals with 25% contingency	20,838,525	15,829,026	2,891,001	13,450,708	108,141,017	169,386,140	330,536,417	291,220	41,505	709,767	325.17

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):	0.544	120,273,522	150,341,902
B (energy and transportation):	0.065	14,446,746	18,058,433
C (waste burial):	0.391	86,512,814	108,141,017
	A + B + C ($)	221,233,082	276,541,352
	Taxes and Insurance ($)	43,196,052	53,995,065
	Grand Totals ($)	264,429,134	330,536,417

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. Thus, only those portions of the carbon steel piping associated with the main steam system that are within the reactor containment building are assumed to be removed, to facilitate the final cleanup and decontamination of the containment building. Because the remaining carbon steel systems which serve the turbine, service cooling water, potable water, sanitary sewer, etc., are assumed to be uncontaminated, they 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.

Inventory Listings

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

- Component Cooling Water
- Chemical and Volume Control
- Containment Spray
- Clean Radioactive Waste Treatment
- Dirty Radioactive Waste Treatment
- Main Steam (within containment)
- Radioactive Gaseous Waste
- Residual Heat Removal
- Safety Injection
- Spent Fuel Cooling
- Electrical Components and Annunciators
- Stainless Steel Piping

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.

Table C.5 Reference PWR system components and piping inventories

COMPONENT COOLING WATER SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
Probably clean				
2 ea.	CCW Hx	70,000 lb.	5 ft dia. x 32 ft	volume = 603 ft^3
2 ea.	CCW pump	15,000 lb.	10.3 ft x 4.7 ft x 5.3 ft	volume = 257 ft^3
2 ea.	CCW surge tank		7 ft dia. x 8 ft	area = 253 ft^2
1 ea.	Chem. addn tk.		2 ft dia. x 5 ft	area = 16 ft^2
Potentially contaminated				
9 ea.	Sample HX	7,000 lb.	1 ft dia. x 10 ft	

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
24	18	7,100	88.6
18	4	4,900	60.5
14	10	2,760	31.1
8	45	1,029	14.6
6	4	588	7.2
4	6	268	3.1
3	10	153	1.4
2	2	90	1.0
1½	31	62	0.6
1	29	50	0.3
¾	10	30	0.2

CLEAN RADIOACTIVE WASTE TREATMENT SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
1 ea.	Rx Cool. Drain Tk.	1,670 lb	3 ft dia. x 8 ft long	area = 90 ft^2
2 ea.	Rx Cool. Drain Pump	500 lb	4 ft x 1 ft x 2 ft	volume = 8 ft^3
1 ea.	Rx Cool. Drain Filter	350 lb	1.3 ft dia. x 4.7 ft long	volume = 6.3 ft^3
1 ea.	Spent Resin Storage Tk.	6,800 lb	9 ft dia. x 11 ft long	area = 438 ft^2
2 ea.	Clean Waste Recv. Tk.	10,958 lb	10 ft dia. x 30 ft high	area = 1100 ft^2
2 ea.	Clean Waste Recv. Pump	500 lb	4 ft x 1 ft x 2 ft long	volume = 8 ft^3
2 ea.	Treated Waste Mon. Tk.	11,200 lb	10 ft dia. x 26 ft long	area = 974 ft^2
2 ea.	Treated Waste Mon. Pump	230 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
1 ea.	Aux Bldg. Drain Tk.	2,090 lb	6 ft dia. x 9 ft high	area = 226 ft^2
2 ea.	Aux Bldg. Drain Pump	1,300 lb	15 ft high	volume = 12 ft^3
1 ea.	Chem. Waste. Drain Tk.	5,400 lb	10 ft dia. x 15 ft high	area = 628 ft^2
2 ea.	Chem. Waste Drain Pump	200 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
1 ea.	Waste. Conc. Hold. Tk.	2,090 lb	6 ft dia. x 10 ft high	area = 245 ft^2
1 ea.	Waste. Conc. Hold. Pump	230 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
1 ea.	Clean Waste Filter	67 lb	0.6 ft dia. x 2.2 ft long	volume = 1 ft^3
1 ea.	Cln. Radwst. Evaporator	40,000 lb	19 ft x 9 ft x 12 ft	volume = 2,052 ft^3

Table C.5 (Continued)

CLEAN RADIOACTIVE WASTE TREATMENT SYSTEM (continued)

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
1 ea.	Cln. Radwst. Evaporator	40,000 lb	19 ft x 9 ft x 12 ft	volume = 2,052 ft^3
1 ea.	Cln. Radwst. Evap Condens			

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
3	19	153	1.4
2	64	90	1.0

CONTAINMENT SPRAY SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
2 ea.	Pump	6,800 lb	4 ft dia. x 9 ft long	volume = 113 ft^3
2 ea.	Pump	100 lb	1 ft dia. x 2 ft long	volume = 2 ft^3
1 ea.	Tank		9 ft dia. x 10 ft high	area = 410 ft^2
6 ea.	Small Elect Equip	75 lb		
6 ea.	Large Elect Equip	150 lb		

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
18	4	4,900	60.5
14	6	2,760	31.1
10	6	1,458	18.2
3	6	153	1.4
1½	6	62	0.6
1	6	50	0.3
¾	12	30	0.2

CHEMICAL AND VOLUME CONTROL SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
3 ea.	Regenerative HX	6,000 lb	1.2 ft dia. x 18' long	volume = 21 ft^3
1 ea.	Seal Water HX	1,700 lb	1.2 ft dia. x 14' long	volume = 17 ft^3
1 ea.	Letdown HX	1,900 lb	1.5 ft dia. x 18' long	volume = 32 ft^3
1 ea.	Excess Letdown HX	1,600 lb	0.9 ft dia. x 11' long	volume = 7 ft^3
2 ea.	Centrif. Chrg Pump	17,090 lb	17.8 ft x 4.2 ft x 4.6 ft	volume = 344 ft^3
1 ea.	Vol. Control Tank	4,850 lb	7.5 ft dia. x 10.4 ft long	area = 333 ft^2
1 ea.	Chem. Mix Tank	77 lb	0.75 ft dia. x 2.5 ft long	volume = 1 ft^3
3 ea.	Holdup Tank	30,000 lb	18 ft dia. x 34 ft long	area = 2,432 ft^2
2 ea.	Monitor Tank	20,000 lb	20 ft dia. x 10 ft high	area = 1,257 ft^2
2 ea.	Boric Acid Tank	20,000 lb	12 ft dia. x 34 ft high	area = 1,508 ft^2
1 ea.	Batch Tank	1,450 lb	4 ft dia. x 5.8 ft high	area = 98 ft^2
1 ea.	Resin Fill Tank	260 lb	5.3 ft dia. x 6.2 ft high	area = 148 ft^2
1 ea.	Reciprocal Charg. Pump	17,700 lb	14 ft x 5.7 ft x 4.3 ft	volume = 343 ft^3
2 ea.	Boric Acid Pump	618 lb	4.3 ft x 1.25 ft x 1.75 ft	volume = 10 ft^3

Table C.5 (Continued)

CHEMICAL AND VOLUME CONTROL SYSTEM (continued)

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
1 ea.	Reactor Coolant Filter	200 lb	1.25 ft dia. x 4.25 ft long	volume = 6 ft^3
2 ea.	Mixed Bed Demineralizer	1,050 lb	2.2 ft dia. x 5.4 ft long	volume = 21 ft^3
1 ea.	Cation IX	1,050 lb	2.2 ft dia. x 5.4 ft long	volume = 21 ft^3
2 ea.	Seal Injection Filter	1,650 lb	0.8 ft dia. x 6.3 ft long	volume = 3 ft^3
1 ea.	Concentrate Hold. Tank	3,500 lb	5.5 ft dia. x 7.8 ft long	area = 183 ft^2
3 ea.	Evaporator Feed IX	1,050 lb	2.2 ft dia. x 5.4 ft long	volume = 21 ft^3
2 ea.	Evaporator Condensate IX	1,050 lb	2.2 ft dia. x 5.4 ft long	volume = 21 ft^3
1 ea.	Condensate Filter	40 lb	0.67 ft dia. x 3.25 ft long	
1 ea.	Concentrates Filter	40 lb	0.67 ft dia. x 3.25 ft long	
2 ea.	Conc. Hold. Tk Trnsfer Pmp			
2 ea.	Gas Stripper Feed Pump			
2 ea.	Boric Acid Evap. Skid Assm	20,900 lb	15.2 ft x 11.4 ft x 11.0 ft	
	BA Evap. Condenser		2.1 ft dia. x 8.2 ft long	
	BA Evap. Vent Condenser		1.1 ft dia. x 5.0 ft long	
	BA Evap. Distillate Condenser		1.1 ft dia. x 12.1 ft long	
1 ea.	IX Filter		1 ft dia. x 3.3 ft long	volume = 3 ft^3
1 ea.	Recirculation Pump			
4 ea.	Standpipes		0.5 ft dia. x 7 ft long	volume = 1.5 ft^3

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
6	2	588	7.2
4	35	268	3.1
3	49	153	1.4
2	184	90	1.0
1	28	50	0.3
¾	80	30	0.2

DIRTY RADIOACTIVE WASTE TREATMENT SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
1 ea.	Rx Cavity Drain Pump	800 lb	2 ft dia. x 15 ft long	volume = 47 ft^3
2 ea.	Rx Cont. Sump Pump	1,500 lb	2 ft dia. x 6 ft high	volume = 19 ft^3
1 ea.	Laundry Drain Tank		6 ft dia. x 9 ft high	
1 ea.	Laundry Strainer			
1 ea.	Laundry Drain Tk. Pump			
1 ea.	Laundry Waste Filter			
1 ea.	Dirty Waste Monitor Tk.	5,800 lb	10 ft dia. x 12 ft high	area = 534 ft^2
2 ea.	Dirty Waste Mon. Tk. Pump	200 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
2 ea.	Dirty Waste Mon. Tk. Filter	76 lb	0.6 ft dia. x 3 ft high	volume = 1 ft^3
1 ea.	Dirty Waste Drain Tank	6,540 lb	10 ft dia. x 13 ft high	area = 565 ft^2
2 ea.	Dirty Waste Dr. Tk. Pump	400 lb	4 ft x 1 ft x 2 ft	volume = 8 ft^3
2 ea.	Aux. Bldg. Sump Pump	1,300 lb	2 ft dia. x 15 ft high	volume = 27 ft^3

Table C.5 (Continued)

DIRTY RADIOACTIVE WASTE TREATMENT SYSTEM (continued)

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
3	14	153	1.4
2	32	90	1.0

RADIOACTIVE GASEOUS WASTE SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
1 ea.	Surge tank	890 lb	3 ft dia. x 6 ft high	area = 71 ft^2
4 ea.	Decay tank	10,800 lb	10 ft dia. x 16 ft high	area = 660 ft^2
2 ea.	Gas compressor	8,000 lb	10 ft x 4 ft x 5 ft	volume = 200 ft^3
2 ea.	Moist. separator	100 lb	1 ft x 1 ft x 1 ft	
2 ea.	HEPA/pre filter	200 lb	1.5 ft dia. x 3 ft high	
1 ea.	Exhaust fan	100 lb	1.5 ft x 1.5 x 2 ft	
2 ea.	Br. seal wtr. HX	7,700 lb	1.5 ft dia. x 15 ft long	volume = 27 ft^3
4 ea.	Large Elect. Equip	150 lb		
2 ea.	Large Mech. Equip	5000 lb		
1 ea.	HVAC Equip	150 lb		

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
4	1	268	3.1
3	3	153	1.4
2	16	90	1.0
1½	35	62	0.6
1	12	50	0.3
¾	16	30	0.2

MAIN STEAM SYSTEM (WITHIN CONTAINMENT)

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
4 ea.	Flow orifices	250 lb./ft	28 in. dia. x 10 ft	volume = 43 ft^3

Pipe size	Thickness (in.)	Weight (lb./ft)	Volume (ft^3/ft)	Linear ft
28 in.	0.855	247.88	4.28	590
14 in.	0.593	84.91	1.07	420
3 in.	0.300	10.25	0.05	500

RESIDUAL HEAT REMOVAL SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
2 ea.	Pump	6,800 lb	2 ft dia. x 9 ft long	volume = 28 ft^3
2 ea.	HX Unit	23,100 lb	3 ft dia. x 30 ft long	volume = 212 ft^3
12 ea.	Small Elect. Equip	75 lb		
11 ea.	Large Elect. Equip	150 lb		
1 ea.	Small Mech. Equip	75 lb		

Table C.5 (Continued)

RESIDUAL HEAT REMOVAL SYSTEM

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
14	7	2,760	31.1
12	3	1,972	24.2
10	2	1,458	18.2
8	18	1,029	14.6
2	2	1,029	1.0
¾	10	30	0.2

SAFETY INJECTION SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
4 ea.	Accumul. tank	76,500 lb	11 ft dia. x 21 ft high	area = 916 ft^2
1 ea.	B. Inj. tank	28,500 lb	5.5 ft dia. x 12.5 ft high	area = 264 ft^2
2 ea.	Safety Inj. pump	8,600 lb	14.3 ft x 3.3 ft x 3.5 ft	volume = 165 ft^3
1 ea.	Refueling water tank	177,800 lb	44 ft dia. x 39.6 ft high	volume = 60,200 ft^3
1 ea.	Primary water stor. tank	99,200 lb	30 ft dia. x 35.4 ft high	volume = 25,000 ft^3
10 ea.	Small Elect. Equip	75 lb		
10 ea.	Large Elect. Equip	150 lb		
1 ea.	Small Mech. Equip	75 lb		

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
10	8	1,458	18.2
8	8	1,029	14.6
6	2	588	7.2
4	9	268	3.1
3	4	153	1.4
2	1	90	1.0
1½	4	62	0.6
1	33	50	0.3
¾	20	30	0.2

SPENT FUEL COOLING SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
1 ea.	Pump	1,000 lb	5 ft x 1.5 ft x 2 ft	volume = 15 ft^3
2 ea.	Pump	900 lb	5 ft x 1.5 ft x 2 ft	volume = 15 ft^3
1 ea.	Pump	700 lb	4 ft x 1.5 ft x 2 ft	volume = 12 ft^3
1 ea.	Filter	360 lb	0.9 ft dia. x 3.8 ft	volume = 2.5 ft^3
1 ea.	Filter	360 lb	0.9 ft dia. x 3.8 ft	volume = 2.5 ft^3
1 ea.	Filter	150 lb	0.75 ft dia. x 3.8 ft	volume = 1.7 ft^3
1 ea.	Demineralizer	2,200 lb	4 ft dia. x 10 ft long	volume = 151 ft^3
2 ea.	Heat Exchanger	6,100 lb	1.7 ft dia. x 19 ft long	volume = 151 ft^3

Table C.5 (Continued)

SPENT FUEL COOLING SYSTEM

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
10	8	1,458	18.2
8	12	1,029	14.6
6	1	588	7.2
4	16	268	3.1
3	9	153	1.4
2	2	90	1.0
1	10	50	0.3
¾	5	30	0.2

CONTROL ROD DRIVE SYSTEM

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
4 ea.	Small Elect. Equip	75 lb		
4 ea.	Large Elect. Equip	150 lb		
1 ea.	Large Mech. Equip	150 lb		

ELECTRICAL COMPONENTS AND ANNUNCIATORS

Number	Component	Weight (each)	Physical dimensions	Volume/area (each)
2 ea.	125 VDC Power (Small)	150 lb		
2 ea.	125 VDC Power (Medium)	500 lb		
1 ea.	125 VDC Power (Large)	5000 lb		
1 ea.	4.16 KV AC & Aux (Small)	500 lb		
1 ea.	4.16 KV AC & Aux (Large)	20000 lb		
7 ea.	480 KV AC Ld Cntr (Small)	500 lb		
7 ea.	480 KV AC Ld Cntr (Large)	2000 lb		
1 ea.	480 KV AC MCC	500 lb		
12 ea.	480 KV AC MCC	20000 lb		
2 ea.	Annunciators (elec port.)	75 lb		
22 ea.	Annunciators (mech port.)	75 lb		

STAINLESS STEEL PIPING[a]

Pipe size	Nuclear class	Thickness (in.)	Weight (lb./ft)	Volume (ft^3/ft)	Linear ft
24 in.	I	0.375	94.62	3.14	170
18 in.	III	0.375	70.59	1.77	30
16 in.	II	0.375	62.58	1.40	300
14 in.	I	1.250	170.22	1.07	170
	II	0.250	36.71	1.07	200
	II	0.375	54.57	1.07	270
	III	0.375	54.57	1.07	610
12 in.	I	1.125	139.68	0.89	150
	II	0.375	49.56	0.89	400
	III	0.406	53.53	0.89	270
10 in.	I	1.000	104.13	0.63	330
	II	0.165	18.70	0.63	320
	II	0.365	40.48	0.63	360

Table C.5 (Continued)

STAINLESS STEEL PIPING(a) (continued)

Pipe size	Nuclear class	Thickness (in.)	Weight (lb./ft)	Volume (ft^3/ft)	Linear ft
	III	0.365	40.48	0.63	60
	(b)	0.165	18.70	0.63	1,000
8 in.	I	0.906	74.69	0.41	250
	II	0.322	28.55	0.41	530
	II	0.500	43.39	0.41	50
	II	0.906	74.69	0.41	20
	III	0.322	28.55	0.41	620
	(b)	0.148	13.40	0.41	400
	(b)	0.322	28.55	0.41	130
6 in.	I	0.718	45.30	0.24	550
	II	0.134	9.29	0.24	100
	II	0.280	18.97	0.24	500
	III	0.280	18.97	0.24	90
	(b)	0.134	9.29	0.24	1,400
4 in.	I	0.531	22.51	0.11	280
	II	0.120	5.61	0.11	250
	II	0.237	10.79	0.11	500
	II	0.337	14.98	0.11	70
	II	0.531	22.51	0.11	180
	III	0.237	10.79	0.11	1,340
	(b)	0.120	5.61	0.11	2,200
3 in.	I	0.437	14.32	0.07	40
	II	0.120	4.33	0.07	220
	II	0.216	7.58	0.07	2,000
	II	0.437	14.32	0.07	1,100
	III	0.216	7.58	0.07	1,460
	(b)	0.120	4.33	0.07	5,000
	(b)	0.216	7.58	0.07	20
2 in.	I	0.343	7.44	0.03	550
	II	0.154	3.65	0.03	200
	II	0.218	5.02	0.03	800
	II	0.343	7.44	0.03	1,450
	III	0.154	3.65	0.03	4,100
	(b)	0.154	3.65	0.03	1,400
1½ in.	I	0.281	4.86	0.02	700
	II	0.145	2.72	0.02	200
	II	0.200	3.63	0.02	800
	II	0.281	4.86	0.02	200
	III	0.145	2.72	0.02	1,700
	(b)	0.145	2.72	0.02	1,500

Table C.5 (Continued)

STAINLESS STEEL PIPING[a] (continued)

Pipe size	Nuclear class	Thickness (in.)	Weight (lb./ft)	Volume (ft^3/ft)	Linear ft
1 in.	I	0.250	2.84	0.01	100
	II	0.133	1.68	0.01	100
	II	0.179	2.17	0.01	300
	II	0.250	2.84	0.01	600
	III	0.133	1.68	0.01	1,500
	(b)	0.133	1.68	0.01	2,000
3/4 in.	I	0.218	1.94	0.006	290
	II	0.113	1.13	0.006	200
	II	0.154	1.47	0.006	300
	II	0.218	1.94	0.006	700
	III	0.113	1.13	0.006	900
	(b)	0.113	1.13	0.006	1,000
1/2 in.	I	0.187	1.30	0.004	105
	II	0.147	1.09	0.004	200
	II	0.187	1.30	0.004	200
	III	0.109	0.85	0.004	800
	(b)	0.109	0.85	0.004	1,000

Small Hangers (4" pipe or less)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
1	4,920	82	1
2	2,962	123	1
3	1,554	164	2
4	1,172	205	2

Large Hangers (>4" pipe)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
6	452	288	3
8	1,002	370	4
10	246	453	5
12	134	535	5
14	236	618	6
18	19	783	8
20	3	865	9
24	80	1,030	10
28	32	1,195	12

(a) Inventory excludes RCS piping, which is accounted for in Chapter 3.
(b) Indicates piping that is not nuclear grade.

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.

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.2.20, the assumptions of C.2.1 and C.2.2 are applied to specific system components to arrive at the reference PWR 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 PWR 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	10ft^2	\$3.20	15ft^2	\$4.80	20 ft^2	\$6.40	length x dia. x \$0.32
Plastic	@\$0.04/ft^2	25ft^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

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.

(a) Nominal time for cutting rate of 30 in./min.

• Transfer the piping section to a maritime container	5 min.(a)
• 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.

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.(b)
• 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.(c)
• 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.

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

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	= 2.97 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.

C.2.5 Removal and Packaging of Contaminated RCS Piping, 32 in. Dia. to 37 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 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) Nominal time for 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:

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

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	1.3 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

(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.

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: - Pressurizer Relief Tank
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 per tank = 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
Person-hours per tank = 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 PWR 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. @ $\$0.32/\text{ft}^2 = 3 \times \text{vol}^{2/3} \times \$0.32 \times 1.15$
Plastic @ $\$0.04/\text{ft}^2 = 3 \times \text{vol}^{2/3} \times \$0.04 \times 1.15$

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)		= $418.95
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)	= $171.80
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 thepreceding 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 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 Pressurizer

The pressurizer is mounted on the floor of the reactor building. All piping has previously been severed from the pressurizer. The insulation is removed and the pipe openings are welded closed. The vessel is rigged for lifting and raised to the operating deck where it is placed on a horizontal transport cradle. The basic operations are listed below, together with the estimated clock times required for each operation.

• Install scaffolding around pressurizer	15 min.
• Remove insulation from pressurizer vessel	30 min.
• Cap open piping ports	150 min.
• Attach lifting devices to pressurizer vessel	120 min.
• Lift the pressurizer vessel to the operating deck	120 min.
• Secure the pressurizer vessel to the shipping cradle	30 min.
• Remove scaffolding and move to next location	15 min.
Crew-minutes for removing pressurizer (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	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	1.574 x adjusted duration = 982 min.
Crew-Hours per cut	16.37 hrs.
Total labor cost (16.37 x $190.13/crew-hr)	$3,112.43
Crew Exposure Hours (adjusted duration)	10.4 hrs.
Exposure Person-hours @ 5.5 pers-hours/crew-hour	57.2 hrs.
Radiation Dose Rate (mrem/hr)	4.6
Transport cradle (modified steam generator cradle)	$5,000
Total estimated cost for removal and packaging pressurizer	$8,112

C.2.13 Removal and Packaging of Primary Pumps

Each primary pump is supported on 3 hinged support posts and stabilized horizontally with tie rods and seismic snubbers. Lubrication and seal coolant lines are attached. 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		120 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.2.14 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)	Dose Rate (mrme/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 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.

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:

$$\$0.575/ft^2\ X\ 1.05 = \$0.604/ft^2$$

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

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

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.2.15 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 PWR 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			103.49
Average labor cost, 2-shift operations $108.66[b]			$108.66[b]

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

Concrete walls are cut with 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)	$60 \text{ min.} + \frac{N^{(b)}}{1 \text{ in-ft/min.}} \text{ min.}$

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

(a) This activity is in parallel with scaffold removal/next installation.
(b) N=[thickness of cut (in) x length of cut (ft)].

Non-productive Time Adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in protective clothing	39.4% of adjusted duration(a)
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

Cutting Concrete Floors

• Install floor slab holding device	30 min.(b)
• 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)	$60 \text{ min.} + \frac{N^{(c)}}{1 \text{ in-ft/min.}} \text{ min.}$

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(d)
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

C.2.16 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

---

(a) 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.

(b) Building crane is used for this operation.

(c) N = [thickness of cut (in) x length of cut (ft)].

(d) 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.

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 rate, 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 these analyses, 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 rates ($/hr) ($/labor-hr)	Cost[(a)] ($/crew-hr)	Dose rate (mrem/crew-hr)
3.00	Laborer	26.37	79.11	3
0.25	H. P. Tech.	36.82	--[(b)]	0
0.25	Crew Leader	54.84	13.71	0
3.50			92.82	3
Average for 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:

$$[\$13/\text{hr. (bits)} + \$2.50/\text{hr. (filters)} + \$43.12/\text{hr. (system)} + \$8.76/\text{hr. (compressor)}] \,/\, 16.25\ \text{ft}^2/\text{hour} + \$0.539/\text{ft}^2\ \text{(drums)} = \$4.69/\text{ft}^2$$

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

$$4 \times [\$9.00\ \text{(labor)} + \$4.69\ \text{(material)}] + \$0.539\ \text{(drums)} = \$56.92/\text{ft}^2$$

Summary for Removing 1 Inch of Concrete Surface

Unit cost factor (horizontal surfaces) = $\$13.69/\text{ft}^2$
Unit cost factor (vertical/overhead) = $\$56.92/\text{ft}^2$
Waste volume generated (1 in. removed) = $0.083\ \text{ft}^3/\text{ft}^2$
Radiation Exposure = $0.24\ \text{mrem}/\text{ft}^2$

C.2.17 Removal of Activated/Contaminated Concrete by Controlled Blasting

The activated portion of the reactor biological is removed from the containment building by controlled drilling and blasting. The volume of concrete to be removed (6335 ft^3) is a hollow cylinder with an inner radius of 10 feet, an outer radius of 14 feet, and a height of about 21 feet, based on a calculated residual radioactivity on the remaining portion of the shield of 10 mrem/yr, as given in Section 3.4.6. In this analysis, the shield will be removed in 4 layers. Each layer consists of 5 concentric rings 0.8 foot thick and about 5 feet high. After one set of rings has been removed, the next set in the layer beneath is removed, and so on, until all 4 sets have been removed. Because the rings are large, only half a ring will be removed at a time.

Using a track drill, holes 5 feet deep will be drilled into the concrete on two-foot centers parallel to the inner cylindrical surface of the concrete. Explosives will be inserted into the holes and the holes back-filled with sand. Blasting mats and two fog spray systems (one in the work area and one in the pit below the bio shield) will be used to contain the scattering of debris and dust. Four B-25 containers (4 ft x 4 ft x 6 ft) will be placed in the pit to catch falling rubble. To minimize the amount of debris falling onto the pit floor, wooden chutes will be rigged to direct the rubble into the boxes. Following the removal of each semi-circular ring of concrete, the boxes will be removed and replaced with empty ones.

In this analysis, it is assumed that while holes are being drilled in one half-ring, rubble and re-bar are being removed from the previous half-ring. The time required for drilling holes significantly exceeds the time required to cut re-bar and remove the boxes of rubble. Thus, drilling time is the limiting factor.

It is postulated that a crew consisting of 1 crew leader, 2 craftsmen, 2 laborers, 1 explosive demolition engineer, and 0.5 health physics technician will be required for the blasting operation. Normally, there will be one crew working per shift, with two-shift operations. The crew labor costs are:

Pers-hrs/crew-hr	Category	Labor rate ($/pers-hr)	Cost(a) ($/crew-hr)
2.0	Laborer	26.37	52.74
2.0	Crafts	49.70	99.40
0.5	H. P. Tech.	36.82	--(b)
1.0	Crew Leader	54.84	54.84
1.0	Engineer	59.09	59.09
6.5			266.07
Average lab or cost, 2-shift operations			$279.37(c)

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

The time required to remove the activated portion of the biological shield and the associated labor and material costs are determined below. In the equation for Net Time that follows, the terms marked with asterisks are tasks performed at the same time the holes are drilled. Because these tasks do not take as long as the drilling operation, they are not time-limiting and do not contribute to net time.

$$\text{Net Time} = ST0 + NL \times [ST + (10 \times MT) + TPH \times NH + RCT^{*} + DRL^{*}] + CT,$$

where ST0 = equipment set-up time for the job as a whole: the time required to set up scaffolding, fog spray systems, and erect barriers to contain dust and debris in work areas and pit.
= 120 minutes
NL = number of layers = 4
ST = set-up time, the time required to set up all the equipment for each layer equals 60 minutes/layer
MT = time to perform tasks required for each half-ring, namely
- install blasting mats and start fog spray = 30 minutes
- evacuate area and detonate charges = 15 minutes
- remove blasting mats and stop fog spray = 30 minutes

NH = number of holes in one layer = 181 (calculated below)
TPC = time per cut, the time required to cut through a piece of re-bar
= 2 minutes
TPH = time required for preparing each hole, namely,
- drill hole 5 feet deep = 10 minutes
- place charge in hole = 5 minutes
- verify charge has detonated = 1 minute

DR = debris removal = 120 minutes: removal of four boxes of rubble from one half-ring and replacing them with empty ones. Done in parallel with drilling holes in one half-ring and cutting rebar in the previous half-ring
NC = number of cuts of #18 re-bar in one layer
= 365 (calculated below)
*RCT = re-bar cutting time per layer: TPC x NC = 730 minutes, done in parallel with drilling holes and debris removal. Not time limiting.
*DRL = debris removal per layer: 10 x DR = 10 x 120 = 1200 minutes, done in parallel with drilling holes and rebar cutting. Not time limiting.
and
CT = clean-up time, the time required to sample area for radioactivity and remove equipment and any remaining debris
= 240 minutes.

The number of holes in the 5 rings, NHR1, NHR2, NHR3, NHR4, and NHR5, assuming 2-foot centers, are:

$$NHR1 = 2 \times \pi \times R1/2 = \pi \times 10.0 = 31.42 = 31$$
$$NHR2 = 2 \times \pi \times R2/2 = \pi \times 10.8 = 33.93 = 34$$
$$NHR3 = 2 \times \pi \times R3/2 = \pi \times 11.6 = 36.44 = 36$$
$$NHR4 = 2 \times \pi \times R4/2 = \pi \times 12.4 = 38.96 = 39$$
$$NHR5 = 2 \times \pi \times R5/2 = \pi \times 13.2 = 41.47 = 41$$

Thus NH = 31 + 34 + 36 + 39 + 41 = 181.

Re-bar is assumed to be spaced uniformly throughout, on 1 foot centers. The number of cuts for the 5 rings, NCR1, NCR2, NCR3, NCR4, NCR5, are:

$$NCR1 = 2 \times \pi \times R1 = \pi \times 20.0 = 62.83 = 63$$
$$NCR2 = 2 \times \pi \times R2 = \pi \times 21.6 = 67.86 = 68$$
$$NCR3 = 2 \times \pi \times R3 = \pi \times 23.2 = 72.88 = 73$$
$$NCR4 = 2 \times \pi \times R4 = \pi \times 24.8 = 77.91 = 78$$
$$NCR5 = 2 \times \pi \times R5 = \pi \times 26.4 = 82.94 = 83$$

Thus, NC = 63 + 68 + 73 + 78 + 83 = 365.

Using the values above gives:

Net Time = 15184 minutes = 253.0 hours.

Factoring in a work difficulty adjustment of 1.3 and a non-productive time adjustment of 1.574 (Section C.2.1), the total work duration is:

Work Duration = 1.3 x 1.574 x (Net Time) = 517.7 hrs.

Assuming 2 8-hour shifts are worked 5 days per week this is:

Work Duration = 517.7/16 = 32.4 work days = 7/5 x 32.4 = 45.4 calendar days

Material costs are:

Air compressor (750 CFM)	$2575/month/(30 days/month) x 45.4 days	= $3,896.83
Drill Bits	$165.60/bit/(10 holes/bit) x 181 holes x 4 layers	= $11,989.44
Fog Spray System	5 nozzles @ $139.09	= $695.45
Blasting Mats	5 x $22/day x 45.4 days	= $4,994.00
Gas torch consumables	$6.75/hr x (2/60) hrs/cut x 365 cuts x 4 layers	= $328.50
Explosives	$1.33/lb x 2 lbs/hole x 181 holes x 4 layers	= $1,925.84
Blasting Caps	$1.79/hole x 181 holes x 4 layers	= $1,295.96
Total materials cost		= $25,126.02
Total, including 15% DOC overhead		= $28,894.93
Total Labor costs = $279.37/hr x 517.7 hrs		= $144,630
Total material costs		= $ 28,895
Total cost for removal of shield		= $173,525
Total removal costs per ft^3 = $173,525/6300 ft^3		= $ 27

Radiation exposures times are assumed to be:

Engineer (setting charges)	= 6 minutes/hole x 181 holes x (work difficulty adjustment) x 4 layers
	= 6 x 181 x 1.3 x 4 layers = 5647 minutes = 94.12 hours
Laborers and crafts (100%)	= 1.3 x 15184 = 19739 minutes = 329.0 hours
Crew Leader and H. P. Technician (assume exposure comparable with engineer)	= 94.12 hours

Assuming a radiation field of 20 mrem/hour, the total radiation exposure at shutdown is
Total radiation exposure = (94.12 x 1 + 329.0 x 4 + 94.12 x 1.5) x 20/1000 = 31 pers-rem

The weight of the removed concrete is about 1,267,000 lb, assuming a concrete density of 200 lb/ft^3, which includes the associated reinforcing steel. It is assumed that the volume expansion factor for the rubble is 1.56, resulting in about 9,875 cubic feet of rubble volume for packaging. For an allowable payload of 9,400 lb, the boxes of shield rubble are weight-limited, not volume-limited. Thus about 135 B-25 containers will be required, each weighing about 10000 pounds, fully loaded. The costs for removing, packaging, transporting, and disposing of the activated concrete is summarized below:

- Removal: $173,500
- Container: $86,900
- Transport: $44,900
- Disposal: $699,000

C.2.18 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	10 min.
• Attach lifting devices to surface section	10 min.
• Make major cut in metal surface(a)	A min.
• Remove track-mounted torch system	10 min.
• Place the section in the disposal container	10 min.(b)
• Remove contamination control system	15 min.
• Remove scaffolding and move to next location	15 min.

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.

(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.

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.2.1.

C.2.19 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 1992 for duct removal. The average rate of removal in linear feet per 8-hour day for the inventory of ductwork in the reference PWR 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)	Dose 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 operations			$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 8 ft section	2.23	
Total Labor Cost per section	2.22 x $84.17/crew-hr	= $187.70
Operations: 2 crews per shift, 2 shifts per day		
Crew Exposure Hours per section	(Adjusted Duration)	= 1.50 hrs.
Radiation Dose per section		= 3.0 mrem
Radiation Dose per ft removed		= 0.38 mrem

C.2.20 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, 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)	Dose 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 operations			$111.86(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.

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

Assuming two crews per shift, two shifts per day, the duration of the grating removal effort in the Containment, Fuel, and Auxiliary buildings would be about 9.7 days, based on an estimated 11,265 ft^2 of grating to be removed.

Principal material costs are gases for torches at $7.76/hr, including 15% DOC profit (see Section C.2.2). Costs of materials used in the removal operations is determined as follows:

[5.083 hrs/crew x 2 crews/shift] x 2 shifts/day x 9.7 days = 197.22 hrs 197.22 hrs x $7.76/hr / 11,265 ft^2 = $0.14/$ft^2$

It is estimated that about 3.31 maritime containers at $4,965/each will be required, resulting in a total container cost of $16,500. The unit cost for packaging is:

$16,500 / 11,265 ft^2 = $1.46/$ft^2$

Thus, the total removal cost per ft^2 is estimated to be:

$3.08 (labor) + $0.14 (torch gases) + $1.46 (maritime containers) = $4.68/$ft^2$

Summary

Unit cost factor = $4.68/$ft^2$
Radiation exposure = 0.11 mrem/ft^2

C.2.21 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)	Dose 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 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.

The decontamination operations and associated time durations are listed below.

- Manually decontaminate 1 LF of handrail — 2 min.[a]
- Radiation survey — 1 min.

(a) Assumed to be washed twice, rinsed once, and dried.

• Move to next location	1 min.[a]

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.

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.

Costs of materials used in the decontamination operations:

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 (about 26 gallons) 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. Ten used wipes are estimated to occupy about 0.0324 ft^3, or a total space of about 60.62 ft^3. The estimated total space required, including space for the 26 gallon containers (about 3.5 ft^3), is about 64.12 ft^3. About nine 55-gallon drums are needed for this waste, resulting in an estimated equivalent cost of 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 = 0.0054 ft^3/LF
Radiation exposure = 0.067 mrem/LF

---

[a] The move is made in parallel with the survey.

C.2.22 Removal of Contaminated Floor Drains

Discussions between the authors and senior staff of Pacific Nuclear Services (PNS)(a) 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 PWR are 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.

Based upon information provided by the Trojan staff, it is estimated that there are approximately 210 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.(b)
• Below Drain: install scaffolding; drill bolt holes and affix steel strapping; rig plastic trough/bucket	35 min.
• Core drill the drain plug	206 min.(a)
• Collect and dispose of waste water	30 min.(b)
• 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.
Crew minutes for removing one drain (actual duration)	291 min.
Work Difficulty Adjustments:	
Height/Access adjustment	7% of actual duration
Adjusted Work Duration	1.07 x actual duration = 311 min.

(a) 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.

(b) These values include 110% overhead and 15% DOC profit.

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

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 ($/crew-hr)	Cost[a] ($/crew-hr	Dose 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 operations			$108.66[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.

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

Assuming four crews per shift, two shifts per day, the duration of the drains removal effort in the Reactor/Containment, Radwaste & Control, and Turbine Generator buildings would be about 26 days (~1.2 months), based on an estimated total of 210 drains to be removed.

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
  (26.25 days x $938.40/day) / 210 drains = $117.30/drain

On a weight-basis, it is estimated that a B-25 container will hold 17 drain plugs, situated in two layers. At that rate, it is further estimated that 12.4 B-25 containers will be required, resulting in a total cost/drain of (12.4 containers x $618.50/container) / 210 drains = $36.52.

Thus, the total removal cost per drain is estimated as determined below.

$869.28 (labor) + $110.40 (core bits) + $5.80 (materials) + $117.30 (equipment rentals) + $36.52 (containers) = $1,139.30/drain

Summary[a]

Unit cost factor = $1,139.30/drain
Waste volume generated, water = 5 gal/drain
Waste volume generated, solids = 2.80 ft^3/drain
Radiation exposure = 5.2 mrem/drain

C.2.23 Removal of Pipe Hangers

It is estimated that 12,800 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 28-inch main steam lines. A typical 1-inch pipe hanger weighs about 60 pounds; a 28-inch hanger weighs about 1,200 pounds. Based on data from a sample of 1-, 4-, 14-, and 28-inch hangers, it was found that the hanger weight can be approximated by

$$Wgt = 41.25*D + 40.34,$$

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 limit 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 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.

(a) Specific specialized equipment purchases for this drain removal task are included separately in Appendix B, Table B.6.

• 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 operations	1.2 x 10 min = 12 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 (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 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-hours 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. Moreover, additional bolts and concrete fasteners will need to be cut. 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 operations	1.2 x 35 min = 42 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 (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 (1.89 x $190.13/crew-hr)	= $359.35	
Material Costs (Gases) @$6.75/hr x 42 min/(60 min/hr)	= 4.72	
Total Cost, large hanger	= $364.07	

Crew exposure-hours per hanger (adjusted duration) = 1.2 hrs
Exposure person-hours 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, he or she may add his or her own site name and distances. 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, based on data supplied in Reference 1, are given below.

$$\begin{aligned}\text{Round-Trip CNS 8-120B Cost for the Hanford Burial Site} = {} & R1 \times d1/d10 \\ & + R2 \times d2/d20 \\ & + n \times (R3 \times w/w0 \times d/d0 + OW1 + P) \\ & + (n - 1) \times (R4 \times d/d0 + OW2)\end{aligned}$$

where R1 = cost of transporting empty cask from cask supplier (Barnwell) to reactor site = $11,855.99,
d1 = distance in miles between reactor site and the cask supplier,
d10 = reference distance between reactor site and the cask supplier = 2,799 miles,
R2 = cost of transporting empty cask from the burial site (Hanford) back to supplier = $10,122.75,
d2 = distance in miles between burial site and supplier,
d20 = reference distance between burial site and supplier = 2,674 miles,
n = number of casks to be shipped to the burial site,
R3 = cost of transporting fully loaded cask from site to burial site = $2,456.80,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask = 74,000 pounds,
d = distance between reactor site and burial site, in miles,
d0 = reference distance between reactor site and burial site = 297 miles,
R4 = cost of transporting empty cask from burial site back to reactor site = $1,216.06,
OW1 = overweight charges = $219.05,
OW2 = overweight charges = $69.37, and
P = permit cost = $120.00.

$$\begin{aligned}\text{Round-Trip CNS 8-120B Cost for the Barnwell Burial Site} = {} & n \times (R1 \times d/d0) \\ & + n \times (R2 \times d/d0 \times w/w0 + OW + P)\end{aligned}$$

where R1 = cost of transporting empty cask from Barnwell to reactor site = $11,855.99,
d = distance in miles between Barnwell and reactor site,
d0 = reference distance between Barnwell and reactor site = 2,799 miles,
R2 = cost of transporting fully loaded cask from reactor site to Barnwell = $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.

$$\begin{aligned}\text{Round-Trip 14/210H Cost for the Hanford Burial Site} = {} & R1 \times d1/d10 \\ & + R2 \times d2/d20 \\ & + n \times (R3 \times d/d0 + OW + P) \\ & + (n-1) \times (R4 \times d/d0) \\ & + n \times R5 \times d1/d10\end{aligned}$$

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

$$\begin{aligned}\text{Round-Trip 14/210H Cost for the Barnwell Burial Site} = {} & n \times (R1 \times d/d0) \\ & + n \times (R2 \times d/d0 + OW + P) \\ & + n \times (R3 \times d/d0)\end{aligned}$$

where R1 = cost of transporting empty cask from Barnwell to reactor site = $5,150.16,
d = distance in miles between Barnwell and reactor site,
d0 = reference distance between Barnwell and reactor site = 2,799 miles,
R2 = cost of transporting fully loaded cask from reactor site to Barnwell = $5,235.45,
n = number of casks to be shipped to the burial site,
OW = overweight and other charges = $1,849.91,
P = permit cost = $125.00, and
R3 = cost of transporting HIC from supplier to the reactor site = $4,210.50.

$$\begin{aligned}\text{Round-Trip NAC-LWT Cost to the Geologic Repository} = {} & R1 \times d1/d10 \\ & + R2 \times d2/d20 \\ & + n \times (R3 \times w/w0 \times d/d0 + OW + P) \\ & + (n-1) \times (R4 \times d/d0 + OW)\end{aligned}$$

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

$$\begin{aligned}\text{Round-Trip TN-8 Cost to the Geologic Repository} = {} & R1 \times d1/d10 \\ & + R2 \times d2/d20 \\ & + n \times (R3 \times w/w0 \times d/d0 + OW + P) \\ & + (n-1) \times (R4 \times d/d0 + OW + P)\end{aligned}$$

where R1 = cost of transporting empty cask from cask supplier to reactor site = $18,790.61,
d1 = distance in miles between reactor site and the cask supplier,
d10 = reference distance between reactor site and the cask supplier = 2,799 miles,
R2 = cost of transporting empty cask from the repository back to supplier = $13,551.44,
d2 = distance in miles between repository and supplier,
d20 = reference distance between repository and supplier = 2,070 miles,
n = number of casks to be shipped to the repository,
R3 = cost of transporting fully loaded cask from site to repository = $5,286.12,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask = 84,040 pounds,
d = distance between reactor site and repository, in miles,
d0 = reference distance between reactor site and repository = 907 miles,
R4 = cost of transporting empty cask from repository back to reactor site = $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, 96-ft^3 metal boxes, or maritime containers, the round-trip truck transportation charges are

Round-Trip Low Level Waste Cost (in dollars) for Hanford Burial Site = R x D/D0 + PC

where R = the round-trip distance rate = $1,211.82,
D = distance in miles between site and Hanford,
D0 = the reference distance, from Rainier, Oregon, to Hanford, Washington = 297 miles,
PC = permit cost = $120,

assuming that the cargo does not exceed 40,000 pounds.

Round-Trip Low Level Waste Cost (in dollars) for Barnwell Burial Site = R x D/D0 + PC

where R = the round-trip distance rate = $4,226.49,
D = distance in miles between site and Barnwell,
D0 = the reference distance, from Rainier, Oregon, to Barnwell, SC = 2,799 miles,
PC = permit cost = $95, assuming that the cargo does not exceed 40,000 pounds.

Each of the spent fuel racks is shipped in specially constructed oversize metal containers. Transportation costs for each rack are calculated from the following formulas:

Fuel Rack Shipment Cost to Hanford (in dollars) = R x d/d0 + P + DF + OW + OD + T

where R = cost of transporting rack to Hanford = $966.54,
d = distance from reactor site to Hanford, in miles,
d0 = reference distance between reactor site and Hanford = 297,
P = permit cost = $95.00,
DF = drop frame charge = $100.00,
OW = over-width charge = $100.00,
OD = over-dimension charge = $65.00, and
T = tarpaulin charge = $35.00.

Fuel Rack Shipment Cost to Barnwell (in dollars) = R x d/d0 + P + DF + OW + OD + T

where R = cost of transporting rack to Barnewell = $5,712.36,
d = distance from reactor site to Barnwell, in miles,
d0 = reference distance between reactor site and Barnwell = 2,799,
P = permit cost = $125.00,
DF = drop frame charge = $100.00,
OW = over-width charge = $582.00,
OD = over-dimension charge = $543.00, and
T = tarpaulin charge = $35.00.

The Reactor Building and Fuel Building cranes will be shipped in specially modified maritime containers. The transportation formulas for these cranes are calculated as follows:

Crane Shipment Cost to Hanford (in dollars) = R x d/d0 x w/w0 + P + OW + T,

where R = cost of transporting crane to Hanford = $1,100,
d = distance from reactor site to Hanford, in miles,
d0 = reference distance between reactor site and Hanford = 297 miles,
w = weight of loaded truck, in pounds,
w0 = weight of fully loaded truck = 40,000 pounds
P = permit cost = $95.00,
T = twist lock trailer cost = $120.00, and
OW = overweight charge = $69, if load exceeds 40,000 pounds; no charge, otherwise.

Crane Shipment Cost to Barnwell (in dollars) = R x d/d0 x w/w0 + P + OW + 0.4 x d,

where R = cost of transporting crane to Barnwell = $5,984,
d = distance from reactor site to Barnwell, in miles,
d0 = reference distance between reactor site and Barnwell = 2,799 miles,
w = weight of loaded truck, in pounds,
w0 = weight of fully loaded truck = 40,000 pounds
P = permit cost = $95.00, and
OW = overweight charge = $543, if load exceeds 40,000 pounds; no charge, otherwise.

For the specific case of the reference PWR, barges and trucks are used to transport equipment and material to the disposal sites. Rail transportation is not used. Because barge costs are complex and strongly site-specific, no attempt has been made to include barge cost algorithms in the CECP.

C.4 References

1. *Tri-State Motor Transit Company*, published tariffs, Interstate Commerce Commission (ICC), Docket No. MC-109397 and Supplements, 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 pressurized water reactor (PWR), the Trojan plant near Rainier, Oregon, if the plant operated until expiration of its operating license, and therefore are representative of other large PWRs that do operate until their licenses expire. These analyses do not necessarily reflect the actual situation at the Trojan reactor, which was prematurely closed late in 1992.

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 on 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 PWR is estimated to be 7 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 14 years. This 14-year estimate presumes the utility maintains its spent fuel pool under a modified Part 50 license after shutdown, and is based on existing schedules for the DOE's acceptance of the SNF under the 10 CFR Part 961 contract.

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 PWR
- 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 PWR.

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 anticipates 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. Until waste acceptance begins, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel.

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)(5) 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

---

[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 PWR is assumed to fall into the standard fuel category. One of the General Specifications for standard fuel is a minimum cooling time of five (5) 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."

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),(7) 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,(5) 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.(5)

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 on 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. Under current conditions, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel until acceptance by DOE.(5)

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

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[a]	900
2003	900
2004	900
2005	900
2006	900
2007	900
Total	8,200

(a) According to information contained in Reference 5, the reference PWR's first fuel acceptance allocation appears in CY 2002.

The quantities of SNF from the reference PWR eligible for acceptance in each of the first 10 years of projected FWMS operation are presented in Table D.2, together with projections done for this study of the additional transfers of SNF necessary to deplete the SNF inventory at the reference PWR. The data shown in the table are based on the projected acceptance rates, shown previously in Table D.1, but continue 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 PWR are projected to occur in the year 2029, assuming Portland General Electric (PGE) has, through the exchange process available under the 10 CFR 961 contract, obtained sufficient acceptance rights to be able to deliver the final 193 assemblies during that year. Otherwise, it is likely that several more years would pass before the last assemblies could be removed from the spent fuel pool.

Based on a pool capacity of 1408 spent fuel assemblies, it can also be seen from Table D.2 that the reference PWR has adequate pool capacity to accommodate its remaining inventory without additional storage capability.

It should be noted that Trojan's current operating license expires in CY-2011, based on 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 Trojan plant is CY-2015 (the date shown in Table D.2).(8)

This license end-date used by the EIA assumes that the 40-year licensing period began at the start of commercial operation of the Trojan plant, not at the start of construction. The EIA's shutdown date of CY-2015 is used throughout this study for the purpose of developing decommissioning schedules.

Table D.2 Postulated SNF disposition schedule for the reference PWR(a)

Calendar year of fuel pick-up	Year/month of discharge	SNF inventory (assemblies)	SNF assemblies accepted each year
2002	1978/03	1156	1
2005	1980/04	1253	53
2006	1981/05	1267	35
2007	1982/03	1274	38
2008	1983/01	1280	39
2010	1984/04	1272	52
	1985/05	1232	40
2011	1986/04	1215	61
	1987/04	1158	57
2012	1988/04	1152	49
	1989/03	1095	57
2013	1990/03	1086	53
2014	1991/03	1099	53
2015(b)	1992/04	1219	73
	1993/06	1150	69
2016	1994/08	1081	69
2017	1995/09	1041	40
	1996/10	986	55
2018	1998/01	931	55
2019	1999/02	877	54
2020	2000/03	825	52
	2001/03	774	51
2021	2002/04	723	51
2022	2003/06	673	50
	2004/08	623	50
2023	2005/09	573	50
2024	2006/09	524	49
	2007/10	479	45
2025	2008/11	434	45
2026	2010/01	390	44
	2011/02	346	44
2027	2012/02	303	43
2028	2013/03	259	44
	2014/03	215	44
2029(c)	2014/10	193	22
	2015/12	0	193

(a) Based on Reference 5 and on the postulated acceptance projections done for this study (see text for details). Does not represent the actual situation at the prematurely shutdown Trojan reactor, but is reasonably representative of large PWRs that operate for their licensed lifetime.

(b) CY 2015 is the EIA projected year of final shutdown for the reference PWR (see text for details).

(c) CY 2029 is the year in which the reference PWR'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

OCRWM submitted the "Final Version Dry Cask Storage Study" to the 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,"(9) 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 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.(10)

In a generic environmental impact statement on spent fuel storage,(11) 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 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 Long Island Light Company; 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. 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.(12) 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,(13) 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. 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, while dry storage facilities are considered independent of the plant, and are subject to regulation under 10 CFR Part 72. It should be noted that a general license under Subpart K, Part 72 can be granted to Part 50 licensees, if approved storage casks are used.

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

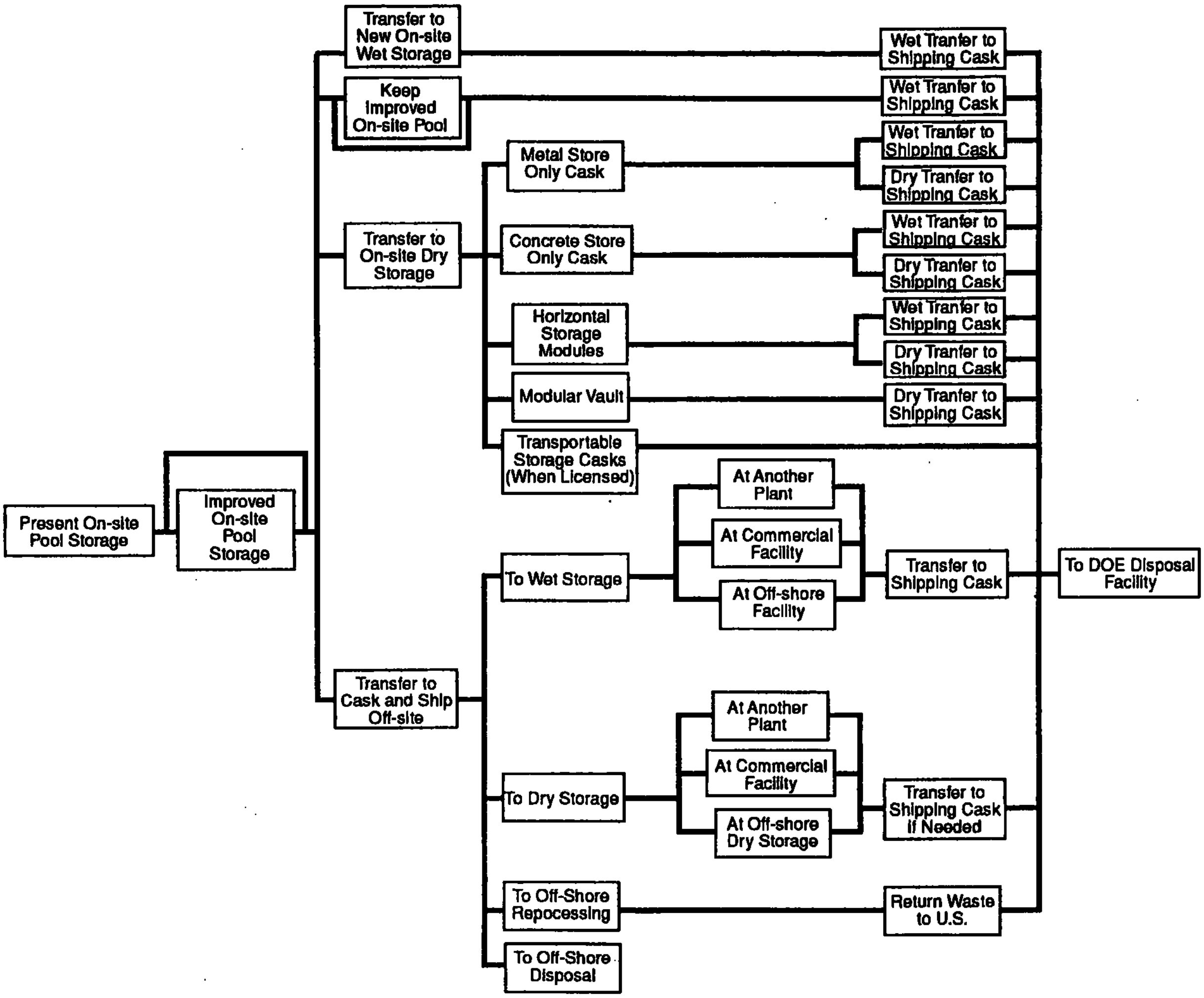
An important consideration when selecting the decommissioning mode to employ on a retired power reactor facility is what to do with the SNF stored onsite. The range of storage/disposition alternatives of SNF is discussed in Section D.4.1. A methodology for evaluating the present value of the total storage 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 on information extracted from a study on such alternatives for Rancho Seco Nuclear Generating Station(14) and other sources. Based on those sources, an overview of post-shutspent 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.

In the case of dry storage, five alternatives are shown in Figure D.1: metal storage casks, concrete casks, vault storage, horizontal storage modules, and transportable or dual-purpose casks. These five methods of dry storage have been studied previously and officially evaluated by DOE.(9) 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



(a) Based on information contained in References 9 and 14.

S9304067.25

Figure D.1 Storage/disposition alternatives for spent nuclear fuel[(a)] in case of emergencies as long as fuel is onsite.[5] Under the offsite group of alternatives, wet and dry storage possibilities are included for storing SNF at another plant, a commercial storage facility, and off-shore. The possibilities of foreign reprocessing and disposal are included 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 United States should be in a form acceptable to the DOE for final disposal, as shown in Figure D.1.

In the Rancho Seco study(14) 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 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(14) 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 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; and
- 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.

---

[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, they include dual-purpose cask design and shipment of sealed canistered spent fuel.(15) In addition, dry transfer facilities are also under consideration.

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 PWR 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 some may have already been forced to install external dry storage facilities on their sites to contain SNF that exceeded their pool capacities. 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 in the reactor pool 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, as seen in Table D.3.

Table D.3 Distribution of sites storing SNF for a given number of years following shutdown[a]

Years until SNF inventory reaches zero	Number of sites
5	7
6	3
7	10
8	5
9	12
10	7
11	5
12	4
13	2
14[b]	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 16.

(b) The reference PWR's (Trojan's) inventory is reduced to zero in the year 2029, or 14 years after final shutdown, assuming the plant operates until 2015.

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 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 modified Part 50 license)
- transfer all SNF to an on-site 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 cooling time before the last discharge of SNF could be accepted by DOE as standard fuel 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 operating nuclear power reactors, the licensee shall, within 2 years following permanent cessation of operation of the 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 upon expiration of the reactor operating license until title to the irradiated fuel and possession of the fuel is transferred to the Secretary of

> Energy for its ultimate disposal. Licensees of nuclear power reactors that have permanently ceased operation by April 4, 1994 are required 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 of the total storage system life-cycle cost can be estimated for each system, for purposes of comparison. The following expression yields the present value 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; 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 on-site 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.

$$\begin{aligned} PV = D_{p0} &+ \sum_{i=1}^{n} D_{pi}/(1+k)^{i} + D_{d0}/(1+k)^{n} \\ &+ DD_{p}/(1+k)^{n+1} + \sum_{i=n}^{N} D_{di}/(1+k)^{i} + DD_{d}/(1+k)^{N} \end{aligned}$$

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 \$4.2 million (1993 \$) 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 14 years (i.e., SNF inventory has reached zero; see Table D.3). With these assumptions, the cost of the SNF pool operations until the inventory has reached zero is evaluated to be about \$50 million (present value), without contingency.

Table D.4 Estimated annual SNF storage costs at the reference PWR(a,b)

Cost category	Estimated annual cost (1993 $)(c)		
Non-personnel costs	**Pool**	**Safe storage**	**ISFSI(d)**
Instr. & Elect. Maint. (materials. & 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 (materials. & supplies)	43,743	4,860	43,743
Protective Clothing Laundry	83,539	9,282	27,300
Electric Power (@ $0.034/kWh)	61,200	6,800	30,000
Licensing & Inspection(e)	32,258	3,584	32,258
Property Taxes	81,000	9,000	81,000
Nuclear Liability & Property Ins.(f)	507,600	600,000	507,600
Subtotal, Non-Personnel Costs	1,498,838	633,526	761,901
Personnel Costs			
Utility Staff Labor(g)	2,722,491	302,499	1,264,681
Total Annual Operating Cost	4,221,329	936,025	2,026,582

(a) Based on information found in Reference 17, 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) Study estimate. As of this writing, the materials licenses annual fees for FY 1993 have not been published.
(f) 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.7).
(g) Derived from Table 3.2.

Similarly, the initial cost of establishing a dry ISFSI (D_{d0}) during Year 6 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 573 assemblies, storage capacity for about 263 metric tonnes of uranium (MTU) would be required to accommodate the inventory of SNF remaining in the pool at 7 years after reactor shutdown. Based on data from Reference 9, the estimated cost of storage capacity is about $65,000/MTU for about 24 concrete casks, for a total cost of about $17 million (1993 $) expended during Year 6. Equipment and storage pads/ fences/etc. would cost about an additional $5 million (1993 $) during Year 6. The labor costs for removing the SNF from the pool and placing it in the ISFSI during Year 6 are estimated to be about $0.3 million (1993 $). Thus, the total initial cost of establishing and loading the ISFSI (D_{d0}) would be about $22.3 million (1993 $) in Year 6, without contingency. Labor and non-personnel costs associated with ISFSI operation (D_{di}) are estimated to be about $2 million (1993 $) per year. Decommissioning costs for the ISFSI (DD_d) is estimated to be about 10% of the capital cost, or about $2.2 million (1993 $) during Year 15. The first 7 years of pool storage results in an initial cumulative expenditure of about $26 million (present value). Added to those initial pool costs are the large initial capital cost of the ISFSI ($19 million, present value), the cumulative present value of the ISFSI operating costs ($12.3 million) and the present value of ISFSI decommissioning costs ($1.4 million). The resulting present value of SNF storage operations utilizing 7 years of pool storage and 7 years of dry cask storage is about $52 million, without contingency. Thus, for the relatively short storage time considered in this analysis, it is slightly more cost-effective to store the SNF in the fuel storage pool than to build a dry ISFSI. However, if the storage period were to be extended to 20 years, the present value cost of the pool-ISFSI combination would be about $5 million less than that of the spent fuel pool, as shown in Figure D.2.

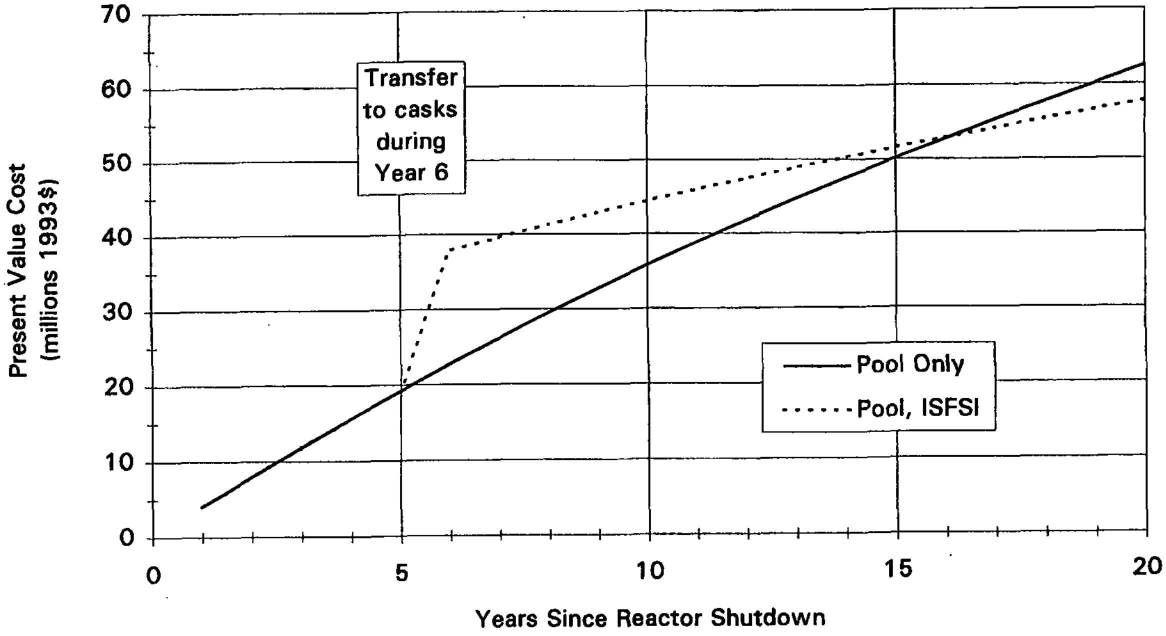


Figure D.2 Present value costs for SNF storage operations

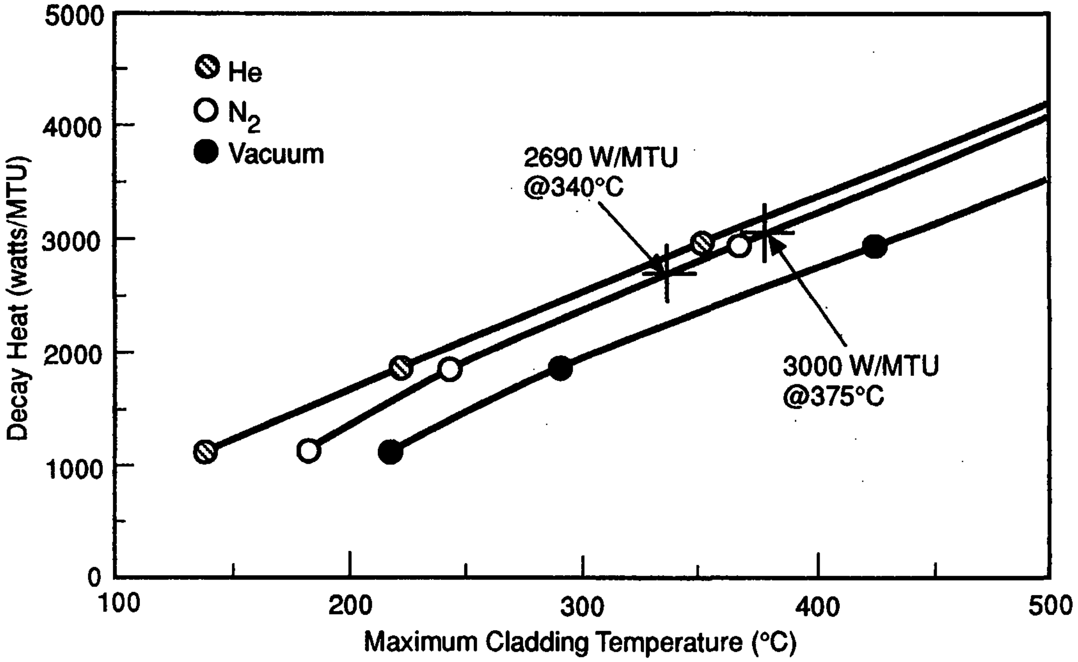
D.5 Required SNF Cooling Time Following Discharge Before Dry Storage

To determine the cooling time required before fuel from Trojan 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 three experimental programs at INEL were examined, wherein fuel rod cladding temperatures were inferred from measurements. These data sets included:

- An average value of 0.4582 MTU/assembly, derived from data contained in DOE/RL-90-44, *Spent Fuel Storage Requirements 1990-2040*(16) for the fuel used in the cask tests, based on fuel from Surry Reactor.
- Castor-V/21: 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 352, 368, and 424°C for cask atmospheres of helium, nitrogen, or vacuum, respectively, extracted from EPRI NP-4887, *The Castor-V/21 PWR Spent-Fuel Storage Cask: Testing and Analyses.*(18)

- 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 139, 181, and 217°C for cask atmospheres of helium, nitrogen, or vacuum, respectively, extracted from EPRI NP-5268, *The MC-10 PWR Spent-Fuel Storage Cask: Testing and Analysis.*(19)
- 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 221, 241, and 290°C for cask atmospheres of helium, nitrogen, or vacuum, respectively, extracted from EPRI NP-5128, *The TN-24P PWR Spent-Fuel Storage Cask: Testing and Analyses.*(20)

These average heat loadings are plotted versus the maximum cladding temperature inferred from the loaded cask measurements in Figure D.3, to obtain a curve of maximum cladding temperature versus fuel decay heat rate.



S9304067.12

Figure D.3 Decay heat emission rate as a function of maximum cladding temperature for PWR fuel stored in metal casks

The second step was to calculate the allowable maximum temperatures for two levels of internal fuel rod pressurization, for cooling times of 2 to 5 years. Assuming the use of standard 17x17 Westinghouse fuel assemblies, with rod internal gas pressure of 1293 psi while operating with the gas temperature at 382°C, hot cladding hoop stresses in the range from about 100 to 120 MPa for cladding temperatures ranging from about 300 to 420°C 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.*(21) 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 2 to 5 years, for assumed cladding hoop stresses ranging from 50 to 120 MPa. The results of these calculations are shown in Table D.5, for hoop stresses of 100 and 120 MPa.

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 371 to 333°C.

Nominal values of 340 and 375°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 340 and 375°C were read from the curve of Decay Heat versus Cladding Temperature (Figure D.3) to be about 2690 and 3000 watts/MTU, respectively.

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,*(22) for cooling times of 1, 2, 5, and 10 years, at burnups of 18, 28, 33, 40, 46, 50, and 55 GWD/MTU, and for initial enrichments of 2.5, 3.3, 4.0, and 4.5 % ^{235}U in the fuel. Those data were plotted on a log-log scale and smooth curves were drawn through the points. The cooling times required for decay heat emission rates of 2690 and 3000 watts/MTU, as read from the curves for each level of burnup and initial enrichment, are tabulated in Table D.6. These values of required cooling time were plotted and the (eyeball-fit) curve of cooling time in years as a function of fuel burnup is shown in Figure D.4.

Information on the projected numbers of fuel assemblies having various levels of burnup that will be discharged from the Trojan reactor during its last 7 years of operation was obtained from the Spent Fuel Storage Requirements Report,(16) which contains the spent fuel inventories and inventory projections for all U.S. commercial nuclear power plants made by the Energy Information Administration (EIA). These projections are based on a certain set of assumptions EIA has developed for estimating future inventories of SNF.

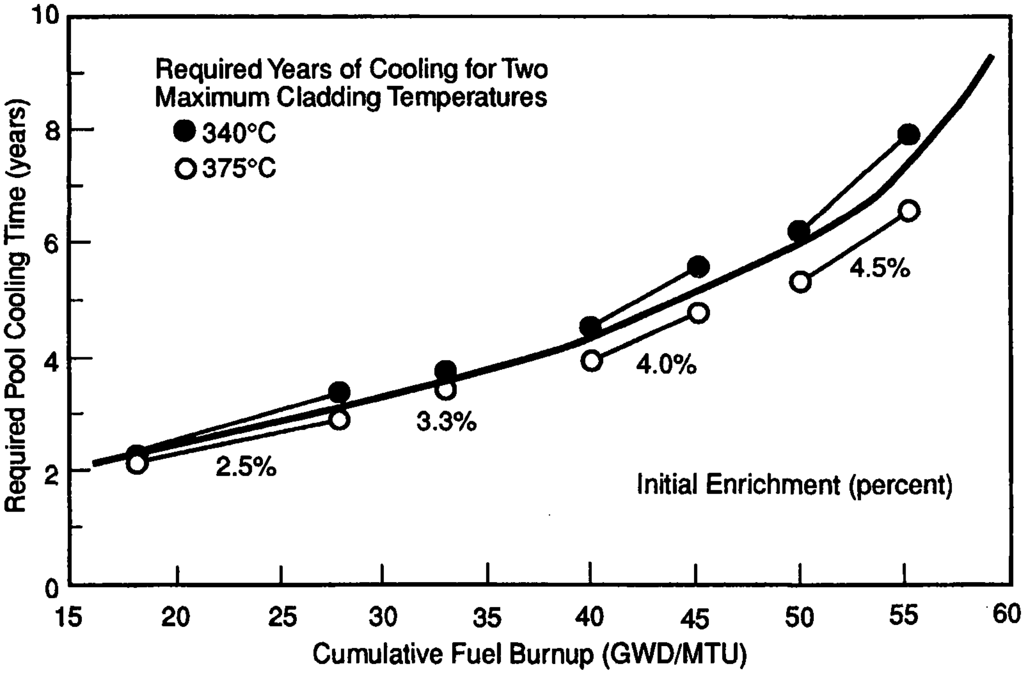
These estimates may *not* reflect the current expectations of any given utility. For purposes of this study, given the burnups as projected by EIA of the fuel in the last seven discharges from Trojan (including the fuel in the core at final shutdown), the required cooling times in the reactor pool, before the fuel could be safely placed in dry storage in a metal cask, were read from the curve. The actual cooling times of the assemblies at the time of final shutdown were subtracted from the required cooling times read from the curve in Figure D.4. The resulting additional cooling times following reactor shutdown for the fuel assemblies from the last seven discharges from Trojan are tabulated in Table D.7.

Table D.5 Calculated allowable cladding temperatures in dry storage

Cooling time (years)	2	3	4	5
Max. Temp. (°C @ 100 MPa)	401	392	385	371
Max. Temp. (°C @ 120 MPa)	388	380	374	363

Table D.6 Required cooling times as functions of initial enrichment and cumulative burnup, for two maximum cladding temperatures

Initial enrichment (%)	Cumulative burnup (GWD/MTU)	Cooling time (years)	
		(340°C)	(375°C)
2.5	18	2.30	2.15
2.5	28	3.20	2.90
3.3	33	3.70	3.35
4.0	40	4.40	3.90
4.0	46	5.40	4.70
4.5	50	6.05	5.20
4.5	55	7.50	6.30



S9304067.13

Figure D.4 Required cooling time as a function of fuel burnup for maximum cladding temperatures of 340°C and 375°C, for various initial enrichments

Table D.7 Required cooling times following final shutdown, for last seven discharges from Trojan reactor

Discharge date	No. of assemblies	Burnup (MWD/MTU)	Cooling time after final shutdown (years)
January 2010	32	48,533	0
	3	56,000	1.28
	9	56,000	1.28
February 2011	32	48,688	0.62
	3	56,178	2.40
	9	56,178	2.40
March 2012	31	48,912	1.66
	3	56,437	3.49
	9	56,437	3.49
March 2013	32	48,571	2.68
	3	56,043	4.43
	9	56,043	4.43
March 2014	32	48,163	3.60
	3	55,573	5.30
	9	55,573	5.30
October 2014	16	48,163	4.21
	2	55,573	5.88
	4	55,573	5.88
December 2015	48	16,222	2.08
	48	32,443	3.98
	48	45,962	5.00
	48	54,072	6.82
	1	60,058	>8.5

Based on this analysis, the fuel pool could not be finally emptied until at least 7 years following reactor shutdown, if the SNF is destined for dry storage onsite. (However, it should be recognized that the Contract allows a utility to deliver to DOE 5-year old SNF without restrictions.) The one assembly requiring more than 8 years cooling may be an anomaly resulting from the EIA's projection of SNF discharges. In any event, some means might be found to accommodate that assembly (if it exists), perhaps by shipping to some other pool for a few years.

D.6 Rationale for the Spent Fuel Storage Option Postulated for the Reference PWR

When the reference PWR 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 PWR 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 the contemplated federal repository, the costs may extend over a long period of time, especially if the federal repository construction is delayed.

The following general information concerning spent fuel storage is extracted from Klepfer and Bowser,(14) and adapted, where appropriate, to this study in support of the rationale for the spent fuel storage option postulated for the reference PWR.

The costs of spent fuel storage at a shutdown nuclear plant vary depending on 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 PWR, Trojan, 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 PWR'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 PWR is exclusively a nuclear generating site.]

- When the shutdown plant is large in size, as is the case of the reference PWR, 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.(23) [This means that the reference plant (Trojan) cannot be decontaminated and released from regulatory controls until its fuel is shipped. In the OFF option, this cannot occur until at least 2029,(16) some 14 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).

---

[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.(14)

- 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 6, Trojan's licensed/ maximum fuel pool capacity of 1408 assemblies (including full core reserve) will occur in 2004, with a total additional capacity needed for 472 assemblies through 2014. The end of plant life is projected by EIA to be 2015.(16) However, as previously shown in Table D.2, the reference PWR will have adequate pool capacity to accommodate its remaining inventory without the need for additional storage capability, assuming DOE receives SNF beginning in 1998 and at the rates given in Table D.1.

To determine the minimum SAFSTOR period for the reference PWR, it is assumed that the SNF remains stored in the reference PWR's fuel pool, under the 10 CFR Part 50 possession-only license, after final reactor shutdown in CY 2015.[7] Then, the minimum SAFSTOR period for the reference PWR, without use of the DCS exchange process, can be defined as the time between the year of reactor shutdown, in CY 2015, and the year in which the last shipments occur in CY 2029, or 14 years.

It is further concluded that immediate dismantlement (DECON) in the exact same manner as defined in the original PWR study(24) does not appear to be viable because decommissioning cannot start immediately after final reactor shutdown without removal of the stored SNF. Based on the estimated SNF cooling-time analysis presented in Section D.5, the fuel pool could not be finally emptied until at least 7 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 seven years after shutdown.

For purposes of 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 on-site 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.

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.

---

[7] CY 2015 is the Energy Information Administration's projected year of final shutdown for the Trojan plant, as defined in References 8 and 16.

The results of the analyses presented in this appendix realistically reflect the available decommissioning alternatives for the reference PWR. 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 PWR. Therefore, the conclusions reached herein concerning decommissioning alternatives for the reference PWR may not be the same for other PWR power stations.

D.7 References

1. *Code of Federal Regulations*, Title 10, Part 50, "Domestic Licensing of Production and Utilization Facilities," Superintendent of Documents, GPO, Washington, D.C., January 1, 1990.
2. *Code of Federal Regulations*, Title 10, Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," Superintendent of Documents, GPO, Washington, D.C., January 1, 1990.
3. "Nuclear Waste Policy Act of 1982," Public Law 97-425 (January 7, 1983).
4. U.S. Department of Energy. "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste," Code of Federal Regulations, Title 10, Part 961 (1990).
5. U.S. Department of Energy. "Annual Capacity Report," DOE/RW-0294P, Office of Civilian Radioactive Waste Management, Washington, D.C. (December 1991).
6. U.S. Department of Energy. "Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program," DOE/RW-0247, Washington, D.C. (November 1989).
7. "Nuclear Waste Policy Amendments Act of 1987," Title V, Subtitle A, Public Law 100-203 (December 22, 1987).
8. U.S. Department of Energy. 1990. *Commercial Nuclear Power 1990 - Prospects for the United States and the World.* DOE/EIA-0438(90), U.S. Department of Energy Report by Energy Information Administration, Washington, D.C.
9. U.S. Department of Energy, Office of Civilian Radioactive Waste Management, *Final Version Dry Cask Storage Study*, February 1989 (DOE/RW-0220).
10. U.S. Department of Energy. *OCRWM Mission Plan Amendment*, DOE/RW-0128, Washington, D.C., 1987, pp. 111 and 112.
11. U.S. Nuclear Regulatory Commission. *Final Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel*, NUREG-0575, Washington, D.C., 1979.
12. *Code of Federal Regulations*, Title 10, Part 71, "Packaging and Transportation of Radioactive Materials," Superintendent of Documents, GPO, Washington, D.C., January 1, 1990.

13. U.S. Nuclear Regulatory Commission. "Review and Final Revision of Waste Confidence Decision," Federal Register, Vol. 55, No. 181, September 18, 1990.

14. H. H. Klepfer and R. W. Bowser. "Rancho Seco Spent Fuel Disposition Strategy." Proceedings of the Second Annual International Conference on *High Level Radioactive Waste Management*, Las Vegas, Nevada, April 28 - May 3, 1991.

15. F. Sturz. "Dry Spent Fuel Storage Licensing at Reactor Sites." In Proceedings of the Institute of Nuclear Materials Management Spent Fuel Management Seminar VIII, January 16-18, 1991, Washington, D.C.

16. DOE/RL-90-44. *Spent Fuel Storage Requirements 1990-2040*, U.S. Department of Energy, Richland Operations Office, Richland, Washington (November 1990).

17. S. R. Rod. 1991. *Cost Estimates of Operating Onsite Spent Fuel Pools After Final Reactor Shutdown.* PNL-7778, U.S. Department of Energy Report by Pacific Northwest Laboratory, Richland, Washington.

18. J. M. Creer, et al. *The Castor-V/21 PWR Spent-Fuel Storage Cask: Testing and Analyses*, NP-4887, Electric Power Research Institute, Palo Alto, California, November 1986.

19. M. A. McKinnon, et al. *The MC-10 PWR Spent-Fuel Storage Cask: Testing and Analysis*, NP-5268, Electric Power Research Institute, Palo Alto, California, July 1987.

20. J. M. Creer, et al. *The TN-24P PWR Spent-Fuel Storage Cask: Testing and Analyses*, NP-5128, Electric Power Research Institute, Palo Alto, California, April 1987.

21. E. P. Simonen and E. R. Gilbert. *DATING - A Computer Code for Determining Allowable Temperatures for Dry Storage of Spent Fuel in Inert and Nitrogen Gases*, PNL-6639, Pacific Northwest Laboratory, Richland, Washington, December 1980.

22. Regulatory Guide 3.54, *Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation*, U.S. Nuclear Regulatory Commission, Washington, D.C., September 1984.

23. U.S. Nuclear Regulatory Commission. *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities*, NUREG-0586, Washington, D.C., 1988.

24. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

Appendix E

Reactor Pressure Vessel and Internals Dismantlement and Disposal Activities, Manpower, and Costs

Appendix E

Reactor Pressure Vessel and Internals Dismantlement and Disposal Activities, Manpower, and Costs

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 may approve. 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 PWR, originally presented in NUREG/CR-0130,(2) are used to define the classification of the various components and segments of those components, as described in Addendum 3 to NUREG/CR-0130,(3) and the various segments are segregated for packaging according to their activity levels.

The RPV head and the upper core support assembly are removed and placed in their normal storage locations within the reactor containment area, prior to defueling. Following defueling, the lower core assembly is removed from the RPV to the refueling cavity for disassembly. Disassembly, sectioning, and packaging of the RPV internal structures are carried on in the refueling cavity. Following the sectioning and packaging of the RPV internals, the RPV head is reinstalled and the reactor-coolant system (RCS) is drained for the safe storage period. Sectioning and packaging of the RPV is delayed until the deferred dismantlement period. The postulated procedures for these activities are presented in this appendix, together with estimates of the time and cost of these activities.

E.1 Basic Disassembly Plan

To facilitate the disassembly and packaging operations, two plasma-arc cutting systems are postulated to be installed inside the reactor containment. 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 refueling cavity, together with a cutting table and appropriate jigs for holding the various pieces during cutting operations in the refueling cavity. All cutting of stainless steel materials with the plasma-arc systems is performed underwater, with the exception of the insulation surrounding the RPV and the RCS piping.

Before cutting of the RPV internals begins, the reactor coolant is deionized, removing the residual dissolved boron and other residual contaminants, to avoid many of the difficulties encountered at TMI-2(4) and thereby improve performance of the plasma-arc cutting torches. The refueling cavity 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.

Much of the reactor vessel internals is held together with bolts or nuts, which must be removed to disassemble the internals. There are basically two types of bolts to be removed: those whose heads are protruding above the surface of the part and are accessible directly from above, as in the upper core assembly and in the lower support structure; and those whose heads are countersunk into the part, are flush with the surface, and must be accessed from above using a right-angle tool, as in the case of the core shroud and shroud former plates. In the first case, an appropriately-sized socket on a long extension, driven by an impact wrench, is used to remove or break off the head of the bolts. In the second case, a special tool is used that is braced against the opposite surface to provide firm engagement of the tool with the bolt head and driven by an underwater impact wrench. Using the socket system, the removal time is estimated to be about 2 minutes per bolt. Using the right-angle tool, the removal time is estimated to be about 6 minutes per bolt.

In the event that any of the 48 nuts attaching the support columns to the top plate cannot be removed using the socket system, a "nut cracker" (a device that mechanically splits the nut, freeing it from the bolt) is postulated to be used. Operation of the "nut cracker" is estimated to take about 10 minutes per nut.

The number of head-accessible bolts is about 1,072, which would require about 2,144 minutes, or about 36 hours to remove. The number of nuts that could require a nut cracker is 48, which would require up to 480 minutes, or about 8 hours to remove. The number of countersunk bolts is about 2,076, which would require about 12,456 minutes, or about 208 hours to remove. The total time for bolt removal is estimated to be about 252 hours. The total time for cutting and packaging of the internals components is estimated to be about 1,216 hours. Because only half of the cutting crew can be engaged in actual cutting operations in the refueling pool at any given time, it is estimated that the bolt removal operations can be performed by the remainder of the crew essentially in parallel with the cutting operations, at no increase in total labor hours.

During the deferred dismantlement period, a support structure is installed beneath the RPV, to support the RPV during the sectioning. The seal between the RPV and the biological shield enclosure is removed, so as to provide access for cutting the RCS piping at the nozzles, and 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 RPV is performed in air within the concrete biological 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(5) for cutting thick (9 in.) sections of carbon steel clad with thin stainless steel on one side.

The dimensions of the RPV and its internal structures used in these analyses are derived from information given in the reference PWR report(2) and from backup information supporting that report.

E.2 Upper Core Support Assembly

The Upper Core Support Assembly, illustrated in Figure E.1, is comprised of a top plate, 61 Control Rod Drive (CRD) guides, 79 support/mixer columns, and a bottom plate (called the upper grid plate). The upper grid plate is postulated to be GTCC material. The rest of the assembly is classified as Class A, Class B, or Class C material.

E.2.1 CRD Guides

Approximately 244 bolts that attach the CRD guide collars to the top plate of the upper core support assembly are removed or broken off. The 61 CRD guides, which are 7.6 in. dia. and 167 in. in length, are removed from the assembly by lifting up through the top plate and are placed on the cutting table in the refueling cavity. The lower 4 ft is cut from each tube and packaged for shielded shipment in an 8-120B cask liner (62 in. OD x 72 in. high) with a packaged volume of 126 ft^3, or

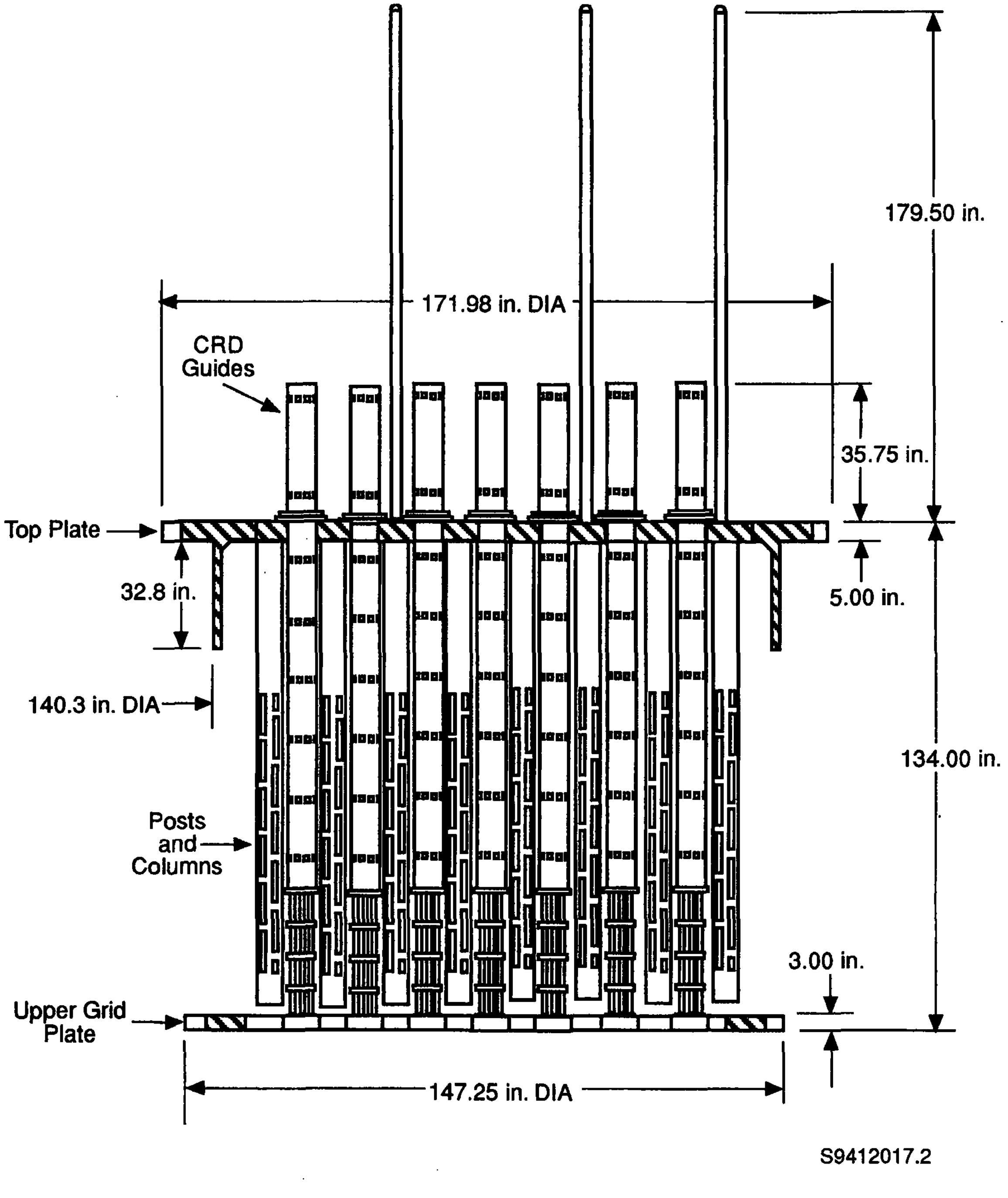


Figure E.1 Upper core assembly

$3.6\ m^3$. The upper sections of the tubes and the collars are packaged in 2 steel boxes (4 ft x 4 ft x 6 ft, packaged volume of 192 ft^3, or 5.4 m^3) for unshielded shipment. One hundred twenty-two cuts, for 2,928 linear inches, are required.

E.2.2 Top Plate

The 48 nuts are removed from the top ends of the support columns and mixer columns, freeing the top plate from the rest of the assembly. The top plate is removed to the cutting table for sectioning. The plate, which is 172 in. dia., is cut across the face on the 90-270 degree line, turned over and the support ring and webs severed on the same line. The two pieces are packaged in a special U-shaped steel box (174 in. dia. x 210 in. long x 45 in. high, package volume of 470 ft^3, or 13.3 m^3) for unshielded shipment. Seven cuts, for 353 linear inches, are required.

E.2.3 Posts and Columns

The 316 bolts that attach the 79 support posts and mixing columns to the upper grid plate are removed. The 79 columns, which are 7.6 in. dia. and from 126 to 134 in. in length, are removed to the cutting table and the lower 4 ft of each column is cut off for packaging in an 8-120B cask liner, together with the bolts. The upper sections of the columns are packaged in four steel boxes (4 ft x 4 ft x 6 ft packaged volume of 10.9 m^3) for unshielded shipment. The lower 4 ft of the columns are packaged in a cask liner for the 8-120B cask (packaged volume of 3.6 m^3) for shielded shipment. Seventy-nine cuts, for 1,896 linear inches, are required.

E.2.4 Upper Grid Plate

The upper grid plate, which is 147.25 in. in diameter and 3 in. thick, with 61 holes that are 8.8 in. diameter and 132 holes that are 5.6 in. diameter, is placed on the cutting table for sectioning. The calculated full-density volume of the plate is:

$$(\pi/4)[(147.25)^2 - 61(8.8)^2 - 132(5.6)^2]\ \text{in.}^2 \times 3\ \text{in.} = 30{,}204\ \text{in.}^3,\ \text{or}\ 0.495\ \text{m}^3$$

The weight of the plate is:

$$30{,}204\ \text{in.}^3 \times 0.29\ \text{lb/in.}^3 = 8{,}759\ \text{lb, or}\ 3{,}973\ \text{kg}$$

This plate is cut into 8.5 in.-wide strips for packaging in the 9 in. x 9 in. x 180 in. long canisters postulated for GTCC material. The equivalent of 10.4 strips are cut, which are loaded 2 strips per canister. Thus, 5.2 canisters are loaded. It is assumed that the material left over after filling 5 canisters can be placed into one of the other partially filled canisters, so that the packaged volume of the upper grid plate is 5 canisters. Eighteen cuts, for 2,115 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

5.2 canisters x 0.24 m^3 = 1.25 m^3,
3,973 kg/5.2 canisters = 764 kg/canister, and
3,973 kg/[5.2 cans x 0.24 m^3/can] = 3,183 kg/m^3.

This markedly lower density reflects the poorer loading efficiency and the reduced average density of the plate material due to the holes.

E.3 Lower Core Assembly

The lower core assembly, illustrated in Figure E.2, is comprised of the upper core barrel, the lower core barrel with thermal shields, the core shroud plates and shroud former plates, the lower grid plate, and the lower core support structure. This assembly is unbolted from the RPV and lifted from the RPV and placed upright on its stand in the refueling cavity. Disassembly and packaging of this assembly is described in the following subsections.

E.3.1 Upper Core Barrel

This component is a cylindrical shell that surrounds the upper core support assembly. The barrel has an outer diameter of 153.5 in., a length of 108 in., and a thickness of 2.5 in. Circumferential cuts are made in the upper core barrel at distances of approximately 46 in. and 108 in. below the barrel top flange. The rings are removed to the cutting table for further sectioning, with the upper ring cut into 11 pieces, 46 in. x 46.7 in., for packaging in two 4 ft x 4 ft x 6 ft steel boxes (packaged volume of 5.4 m^3), for unshielded shipment. The lower ring is sectioned into 10 pieces that are 62 in. in length (4 ea. 54 in. wide w/nozzle rings, 2 ea. 50 in. wide, 2 ea. 45 in. wide, 2 ea. 38 in. wide). The lower ring pieces are packaged in 3 cask liners (62 in. OD x 65 in. high) for the 8-120B cask (packaged volume of 3.1 m^3), for shielded shipment. Twenty-three cuts, for 2,090 linear inches, are required.

E.3.2 Thermal Shields

The thermal shields consist of 4 segments of stainless steel attached to the outside of the lower core barrel to absorb neutrons and reduce the neutron dose to the pressure vessel wall in those locations closest to the corners of the fuel core. All of the shields are 148 in. in length and 2.8 in. thick. Two of the shields are 36 in. wide and two are 48 in. wide. The approximately 156 bolts attaching the thermal shields to the outside of the lower core barrel are removed and the shields removed to the cutting table for sectioning. The full-density volume is:

$$148 \text{ in.} \times 2.8 \text{ in.} \times 2\ (36 + 48) \text{ in.} = 69{,}619 \text{ in.}^3, \text{ or } 1.141 \text{ m}^3$$

The weight of the thermal shields is:

$$69{,}619 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 20{,}190 \text{ lb, or } 9{,}158 \text{ kg}$$

The shields are cut into strips 8.5 in. wide, and assembled into strips 175 in. in length, for packaging as GTCC material:

$$[36/8.5 = 4 \text{ strips plus a 2-in. strip}] \times 2$$

$$[48/8.5 = 5 \text{ strips plus a 5.5-in. strip}] \times 2$$

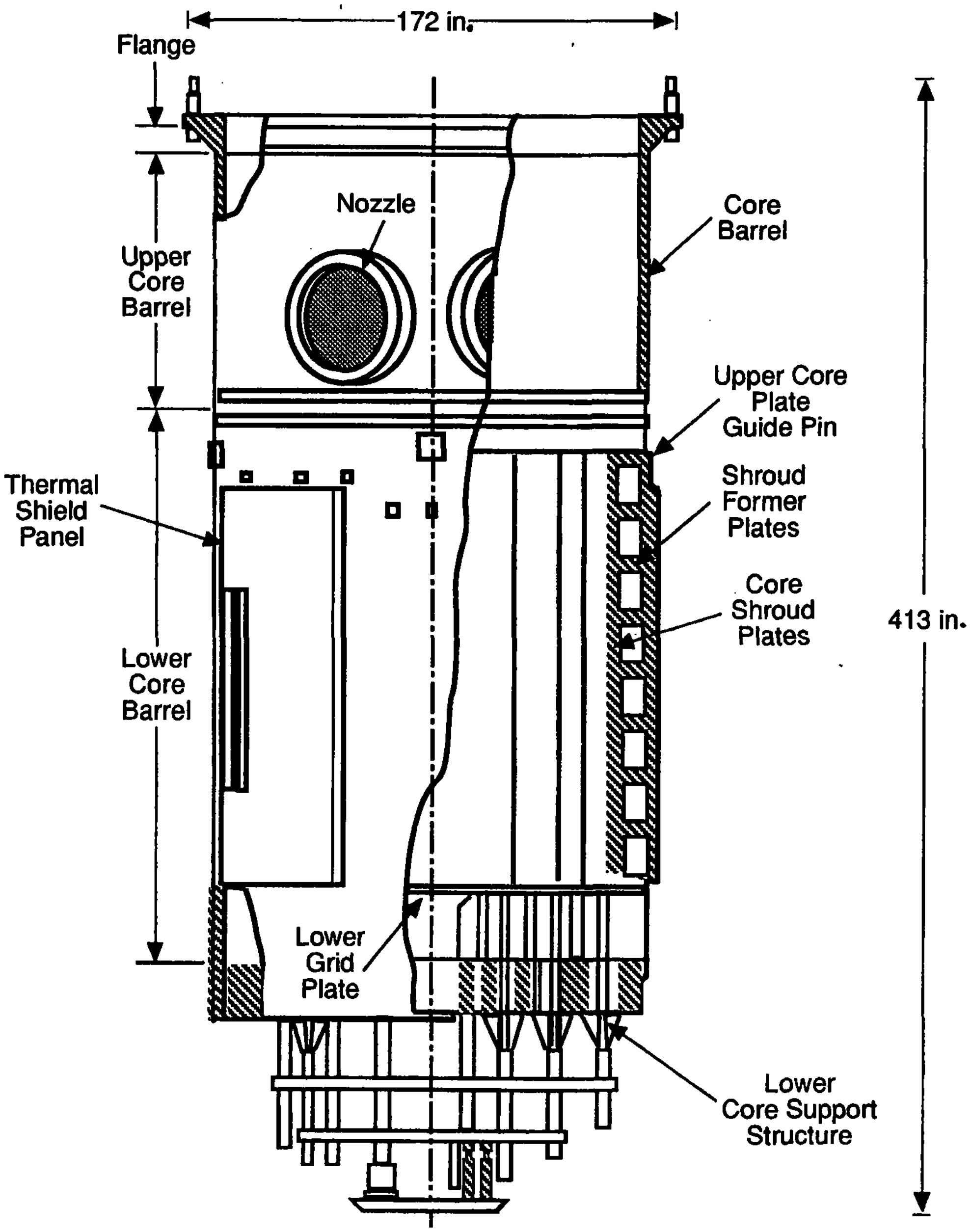


Figure E.2 Lower core assembly

The total number of strips is: 2 (4 + 5 + 1) = 20 strips that are 148 in. long. Assembling the strips into units 175 in. long yields:

$$20 \times 148/175 = 17 \text{ strips}$$

which can be loaded 3 strips per canister, for a total of 6 canisters (packaged volume of 1.4 m^3, rounded to the nearest whole canister). Thirty-four cuts, for 2,800 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canister are:

6 canisters x 0.24 m^3 = 1.44 m^3,
9,158 kg/6 canisters = 1,526 kg/canister, and
9,158 kg/[6 cans x 0.24 m^3/can] = 6,360 kg/m^3

E.3.3 Core Shroud Plates

These components consist of flat plates 160.5 in. long that enclose the fuel core vertically. Removal of the core shroud plates is accomplished by removing the approximately 900 bolts holding the plates to the shroud former plates. Disassembly of the shroud plates is accomplished by removing the approximately 17 bolts that hold each corner together and, if necessary, making a vertical cut in one of the wide plates to make enough space to permit removal of the plate assemblies from the vessel. The plate assemblies are moved to the refueling cavity cutting table for removal of the rest of the corner bolts and for sectioning.

The vertical plates are 0.75 in. in thickness and are in segments: 4 ea. 7.75 in. wide, 12 ea. 8.5 in. wide, 8 ea. 17 in. wide, and 4 ea. 61 in. wide. The full-density volume is:

$$[4(7.75) + 12(8.5) + 8(17) + 4(61)] \times 160.5 \times 0.75 = 61{,}752 \text{ in.}^3\text{, or } 1.012 \text{ m}^3$$

The weight of the vertical plates is:

$$61{,}752 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 17{,}908 \text{ lb, or } 8{,}123 \text{ kg}$$

The vertical plates are cut into 8.5 in. (or less) wide strips for packaging as GTCC material. The strips, which are 160.5 in. long, when assembled into 175-in. strips yield an effective 56 strips. With 11 strips per canister, the number of 9-in.-square canisters is 56/11 = 5.1 canisters. Ninety-one cuts, for 6,246 linear inches, are required.

E.3.4 Shroud Former Plates

Eight shroud former plates surround the vertical plates and fit against the inside surface of the lower core barrel. The approximately 700 bolts attaching the shroud former plates to the lower core barrel are removed, and the shroud former plates are removed to the cutting table for sectioning.

The full-density volume of a former plate is found by computing the area of a disk whose diameter is that of the inside of the lower core barrel (148 in.), minus the area occupied by the fuel assemblies and the vertical shroud plates, and multiplying that area by the plate thickness (1.25 in.):

$$\{[\pi/4](148)^2 - 186(8.5)^2 - 513(0.75)\} \text{ in.}^2 \times 1.25 \text{ in.} = 4225 \text{ in.}^3\text{, or } 0.069 \text{ m}^3$$

The weight of the eight shroud former plates is:

$$4225 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 \times 8 = 9802 \text{ lb, or } 4{,}446 \text{ kg}$$

The shroud former plates are less regular in shape but can be arranged into reasonably compact strips for packaging as GTCC material. The total length is about 2640 in., which, when cut into 175-in. lengths, will yield 15.1 strips. With a thickness of 1.25 in., 6 strips can be loaded per canister, for a total of 2.5 canisters. Twenty-six cuts, for 315 linear inches, are required.

The leftover pieces from the shroud vertical plates are loaded into the partially loaded former plate canister, making a total of 5 + 3 = 8 canisters.

The total weight of the core shroud and former plates is:

$$17{,}908 \text{ lb} + 9{,}800 \text{ lb} = 27{,}708 \text{ lb, or } 12{,}568 \text{ kg,}$$

and the full-density volume is:

$$1.012 \text{ m}^3 + 8(0.069 \text{ m}^3) = 1.566 \text{ m}^3.$$

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

8 canisters x 0.24 m^3/can = 1.92 m^3,
12,568 kg / 8 canisters = 1,571 kg/canister, and
12,568 kg/[8 cans x 0.24 m^3/can] = 6,546 kg/m^3.

E.3.5 Lower Grid Plate

The lower grid plate is a disk 149.4 in. in diameter and 2 in. thick, with numerous holes of various sizes. The reference PWR report gives the weight of the lower grid plate as 3,946 kg, and the calculated volume of the plate (ignoring the holes) is:

$$[\pi/4](149.4)^2 \text{ in.}^2 \times 2 \text{ in.} = 35{,}061 \text{ in.}^3\text{, or } 0.575 \text{ m}^3.$$

The 384 bolts attaching the lower grid plate to the core support posts are removed, freeing the plate from the rest of the lower support assembly. The 60 bolts attaching the lower grid plate to the lower core barrel are removed or broken off, freeing the plate from the core barrel. The grid plate is removed to the cutting table for sectioning.

The grid plate is cut into strips 8.5 in. wide, and arranged into strips having a total length of 2042 inches, for packaging as GTCC material. Dividing this length into strips 175 in. long yields 11.7 strips, which are loaded 4 strips per canister. Thus, approximately 3 canisters are filled. The leftover space can be filled with the scraps from other packages. Thirty cuts, for 2,276 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

3 canisters x 0.24 m^3/can = 0.72 m^3,
3,946 kg/3 canisters = 1,315 kg/canister, and
3,946 kg/[3 cans x 0.24 m^3/can] = 5,481 kg/m^3.

E.3.6 Lower Core Barrel

This component is a cylindrical shell, 153 in. dia., which surrounds the core, extending the distance between the upper and lower core plates (160.5 in.), and is 2.5 in. thick. The full-density volume is given by:

$$\{\pi/4[(153)^2 - (148)^2]\}\ \text{in.}^2 \times 203\ \text{in.} = 239{,}951\ \text{in.}^3,\ \text{or}\ 3.932\ \text{m}^3.$$

The weight of the core barrel is:

$$239{,}951\ \text{in.}^3 \times 0.29\ \text{lb/in.}^3 = 69{,}586\ \text{lb, or}\ 31{,}563\ \text{kg}.$$

A circumferential cut is made in the lower core barrel just above the core support forging, making a section approximately 203 in. high. The barrel section is removed to the cutting table for sectioning.

The core barrel is cut into long strips that are 8.5 in. wide for packaging as GTCC material. The circumference of the core barrel is 153π, or 480.7 in., which when divided by 8.5 in. yields 56.5 strips, 203 in. in length. To package in the space available in the canister, the total length of the strips is computed and divided by 175 in., to obtain the effective number of full-length strips to package.

$$57\ \text{strips} \times 203\ \text{in.} / 175\ \text{in.} = 66.1,\ \text{or 66 strips, plus an 18-in. piece.}$$

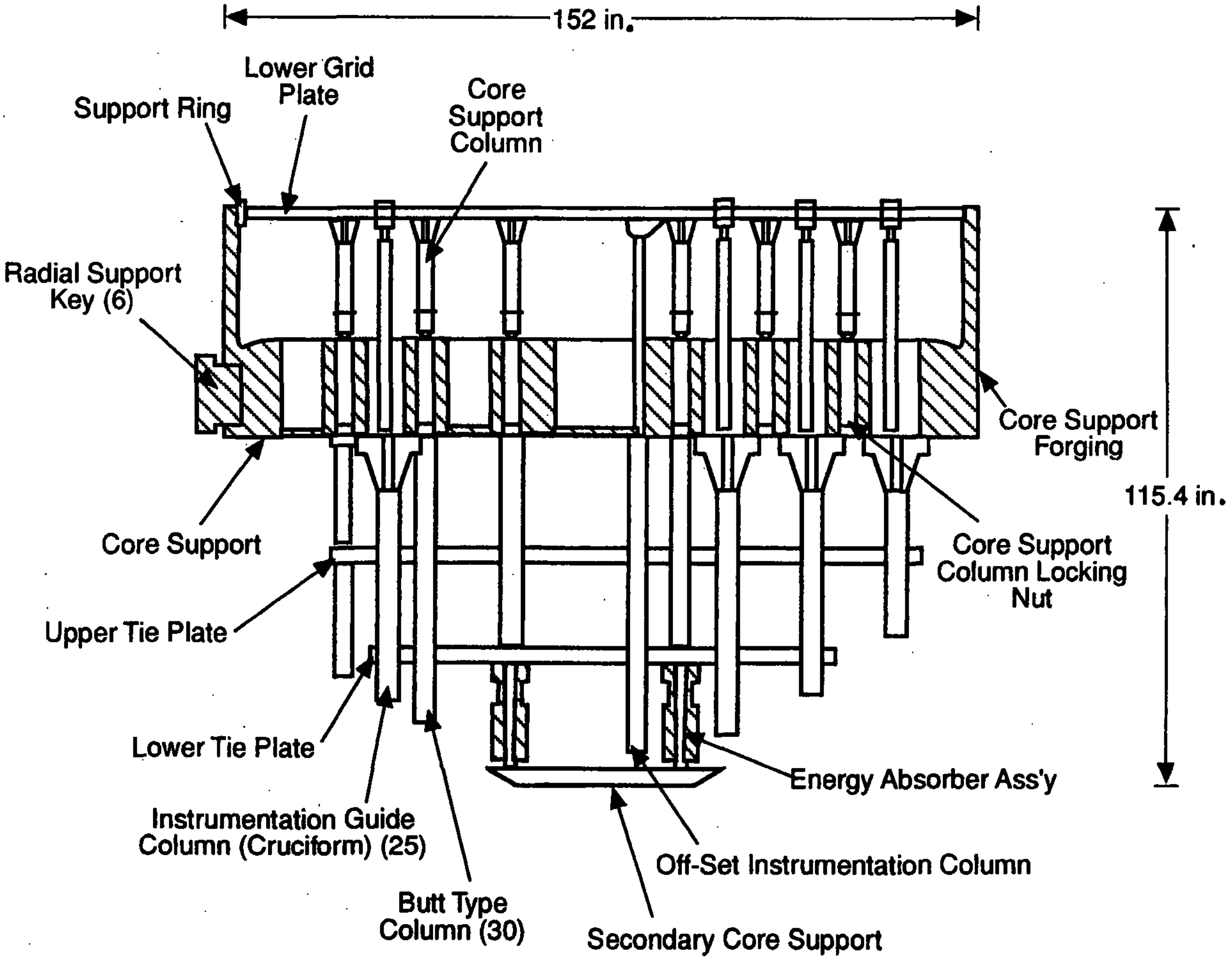
With the thickness of 2.5 in., only 3 strips can be placed into a 9-in.-square canister, yielding 22 canisters (rounded to the nearest whole canister). One hundred and twenty-three cuts, for 12,272 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

22 cans x 0.24 m^3 = 5.28 m^3,
31,563 kg/22 cans = 1,435 kg/canister, and
31,563 kg/[22 cans x 0.24 m^3/can] = 5,977.8 kg/m3.

E.3.7 Lower Core Support Structure

This assembly, illustrated in Figure E.3, is comprised of the core support forging, tie plates, support columns and instrument guides, and the secondary support plate. Those portions of the 96 support columns (about 3 in. dia.), and the 25 instrument guides (about 2 in. dia.), which protrude above the core support forging about 24 in., are cut off flush with the upper face of the forging, and packaged in 2 canisters as GTCC material. The remainder of the support columns and instrument guides are handled as described on the next page. One hundred and twenty-one cuts, for 336 linear inches, are required.



S9304067.8a

Figure E.3 Lower core support structure

The core support forging, which is about 152 in. dia. and 20 in. in thickness, is turned face down, and the approximately 236 bolts that attach the support columns and instrument guides to the forging are removed. The remainder of the lower core support assembly is lifted off, turned over, and placed face up to permit removal of the approximately 236 bolts attaching the columns and guides to the upper and lower tie plates. The columns and guides are removed for packaging. The bolts attaching the lower support columns to the lower tie plate and the secondary support plate are removed and packaged. The tie plates are removed to the cutting table for sectioning. The lower forging is removed to the cutting table for sectioning. All of the lower core support structure is packaged in six 8-120B cask liners (packaged volume of 22 $m^{3)}$ for shielded shipment. Eighty-three cuts, for 1,660 linear inches, are required.

E.4 Reactor Pressure Vessel

The RPV, illustrated in Figure E.4, is a right circular cylinder with an outside diameter of 190 in. and hemispheric ends, with 8 RCS pipes attached to the 8 nozzles. The seal between the RPV and the surrounding biological shield is removed, to permit separating the RPV from the RCS piping, and to permit removal and packaging of the insulation surrounding the RPV. With the insulation and the RCS pipes removed, access to the outside of the RPV is available for sectioning the RPV using the oxyacetylene torches. Disassembly and packaging of the RPV is described in the following subsections.

E.4.1 Insulation

The vessel insulation is comprised of packages of multiple layers of thin stainless steel that 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 cut into sizes for packaging. The lower 200 inches of the side wall insulation is packaged in an 8-120B cask liner (packaged volume of 3.6 m^3) for shielded shipment. The remainder of the insulation is packaged in two 4 ft x 4 ft x 6 ft steel boxes (packaged volume of 5.4 m^3) for unshielded shipment. One hundred and thirteen cuts, for 9,300 linear inches, are required.

E.4.2 RPV Upper Head and Flange

The 61 CRD guides, which are about 3.8 in. dia., and assorted instrumentation penetrations on the RPV upper head are cut off flush with the hemispheric surface, and are packaged in a 4 ft x 4 ft x 6 ft steel box for unshielded shipment. About 63 cuts, for 240 linear inches, are required.

A circumferential cut is made just above the upper head flange. The flange is cut into 14 segments and packaged 4 segments/ per box in 4 ft x 4 ft x 6 ft steel boxes. The remainder of the upper head is cut into 22 segments approximating 46 in. x 46 in. in area and packaged 6 segments/box. One hundred cuts, for 2,689 linear inches, are required.

E.4.3 RPV Lower Flange and RCS Piping

The RCS piping is cut at the vessel nozzles. A circumferential cut is made about 27 in. below the surface of the RPV lower flange. The flange is cut into 14 segments and packaged 4 segments/box in 4 ft x 4 ft x 6 ft steel boxes. The combined packaging for the upper and lower vessel flanges is 7 boxes (packaged volume of 19 m^3). Fifteen cuts, for 975 linear inches, are required. The cutting of the RCS piping is accounted for in Section 3.4.4 of Chapter 3.

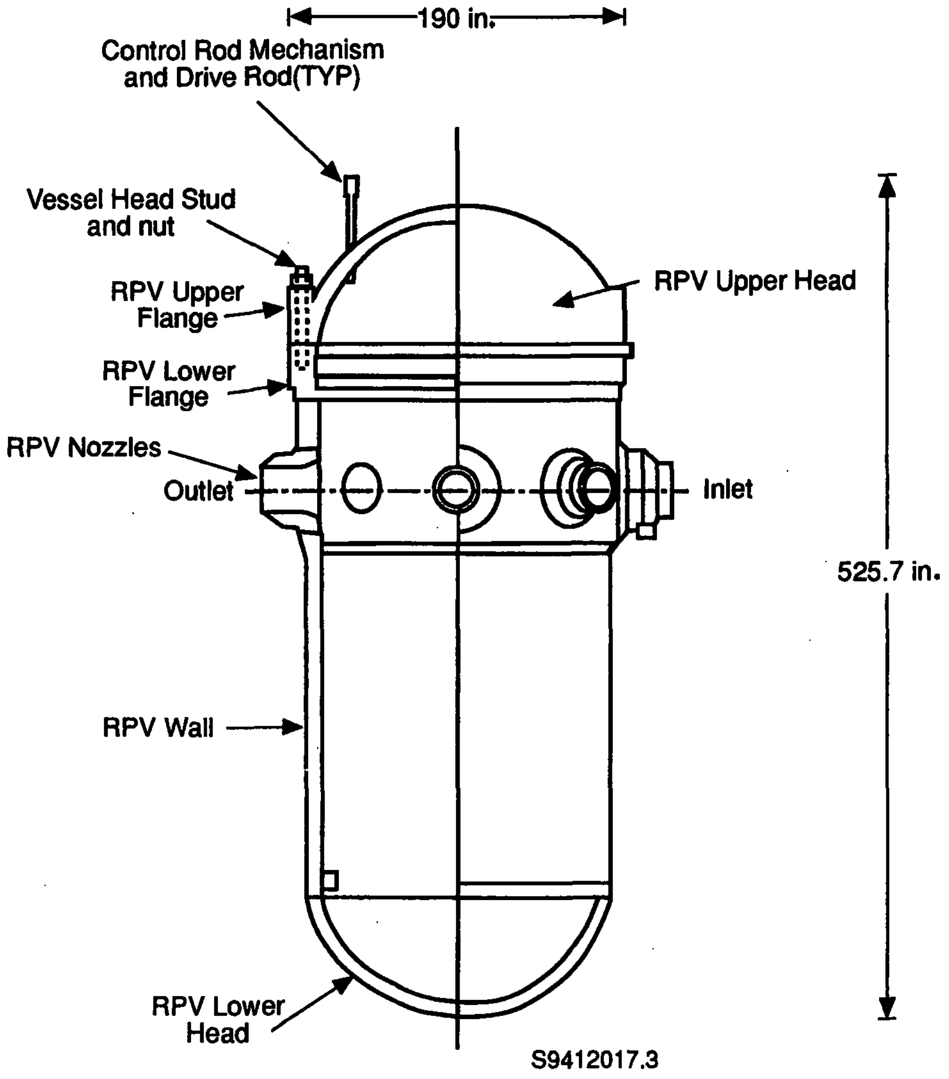


Figure E.4 Reactor pressure vessel

E.4.4 RPV Nozzles

A circumferential cut is made about 131 in. below the surface of the RPV lower flange, just below the RPV nozzles. This ring is cut into 8 segments, 1 segment/nozzle. These segments are packaged by placing each piece in a form-fitting box that covers the inside surface of the piece and welding the box to the piece. The nozzle is capped and welded. The 8 pieces (packaged volume of 14.2 m^3) are shipped unshielded. Nine cuts, for 1,429 linear inches, are required.

E.4.5 RPV Wall

Four circumferential cuts are made every 50 in. down the length of the remaining RPV wall. The rings are cut into 11 segments. These segments are packaged in special cask liners for the 8-120B cask. The liners are fitted to contain 2 segments/liner, for a total of 22 shielded shipments (packaged volume of 22.5 m^3). Forty-eight cuts, for 4,588 linear inches, are required.

E.4.6 RPV Lower Head

The 58 instrument guide penetrations are cut off flush on the inside and outside of the RPV lower head, and the head is sectioned into 35 segments that are packaged in 4 ft x 4 ft x 6 ft steel boxes. The combined packaging of the upper and lower heads is 7 boxes (packaged volume of 19 m^3). One hundred cuts, for 2,735 linear inches, are required.

E.5 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.5.1 Cutting Team Compositions

Removal of the RPV internals and the RPV requires a sequence of operations, repeated many times, to cut and package these 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 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 180 in.) that are compatible with storage in the spent fuel racks in the spent fuel pool and 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 operating at the far end of the refueling cavity and one operating at the location of the stand for the core barrel assembly in the refueling cavity. During subsequent RPV sectioning, a manipulator system for carrying the oxy-acetylene cutting torch is required within the reactor vessel cavity.

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 crew leader, 2 utility 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 receives 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 receives an average radiation dose of 35 mrem/crew-hr. These costs are included in the non-dedicated labor costs.

E.5.2 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

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		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.

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.

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 [4] 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, TE_j, 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(4) suggests that a torch fails about every 7.5 cuts. Assuming the change-out time is 2 hours each occurrence, and the 890 plasma arc cuts made in stainless steel from Table E.2, 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:

$$TE_j = T_j\,(1.574)(1.20) = 1.88\ T_j$$

The exposure hours for the cutting crews are given by $TE_j/1.574$, since only actual contact hours apply.

The cost of the cutting operation for the jth component is calculated as the product of the effective crew-time for that component, TE_j, and the cost per crew-hour, as displayed in the next-to-last column of Table E.2.

E.5.3 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.

Table E.2 Reactor pressure vessel and internals cutting details

Component	Thickness (inches)	No. of cuts	Total length (inches)	Cutting rate (inches/min.)	Cutting time (minutes)	Operating time (minutes)	Effective time (minutes)	Labor costs[a] (1993 $)	Dose[b] (person -rem)
RPV Internals Removal and Sectioning									
Equipment Setup/Testing and Post-Use Removal							6 crew-wks	77,973	2.16
Upper Core Assembly									
Top Plate	2.5 - 5	7	353	7 - 5.5	64	274	630	3,411	
CRD Guides	0.5	122	2,928	14	209	3,869	8,890	48,138	
Support Columns	0.5	79	1,896	14	135	2,505	5,756	31,168	
Upper Grid Plate	3.0	18	2,115	7	302	842	1,935	10,478	
Lower Core Assembly									
Upper Barrel	2.5	23	2,090	7	298	989	2,272	12,303	
Lower Barrel	2.5	123	12,272	7	1,753	5,443	12,506	67,718	
Shroud Plates	0.75	91	6,246	12	520	3,251	7,470	40,449	
Former Plates	1.25	26	315	10	31	812	1,866	10,104	
Lower Grid Plate	2.0	30	2,276	8	284	1,185	2,723	14,745	
Thermal Shields	2.8	34	2,800	7	400	1,420	3,263	17,669	
Lower Forging	2 - 6	83	1,660	8 - 5	332	2,822	6,484	35,110	
Tie Plates	3	20	80	7	11	611	1,404	7,602	
Support Columns	3.5	121	336	6	56	3,686	8,469	45,858	
Insulation	0.5	113	9,301	14	664	4,054	9,315	50,439	
Subtotal		890			5,059 (84 hrs)		72,982 (1,216 hrs)	$473,161	61.83
Reactor Pressure Vessel Removal and Sectioning									
Equipment Setup/Testing and Post-Use Removal							4 crew-wks	51,982	1.44
Top Penetrations	3.5	63	240	9	27	1,917	3,620	19,602	
Top Flange	9 - 14	14	399	3	133	553	1,044	5,653	
Top Dome	6.5	24	2,050	5.5	373	1,093	2,064	11,176	
Lower Flange	9 - 15	14	378	3	126	546	1,031	5,583	
Nozzles	8.5	8	832	4.5	185	425	803	4,348	
Vertical Wall	8.5	50	5,782	4.5	1,285	2,785	5,260	28,482	
Lower Dome	5.5	42	2,648	6.5	407	1,667	3,148	17,046	
Lower Penetrations	1.5	58	87	13	7	1,747	3,299	17,864	
Subtotal		273			2,543 (42.4 hrs)		20,270 (388 hrs)	$161,738	16.24
Totals								$634,898	81.67

(a) Does not include a 25% contingency.
(b) Includes radioactive decay for 7 years since reactor shutdown.

E.5.4 GTCC Cutting and Packaging

The details of the cutting and packaging of material postulated to be activated levels to greater than Class C are presented in Table E.3.

These materials are postulated to be packaged in 9-in. x 9-in. x 180-in.-square canisters whose envelope approximates that of a PWR fuel assembly and are compatible with PWR spent fuel racks and spent fuel cask baskets. The components are listed in column 1, and the component weights calculated from the reference PWR 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.

Table E.3 Calculated weights, full-density volumes, packaged volumes, and numbers of canisters of GTCC LLW generated during the decommissioning of the reference PWR

Reactor core components	Component weight (kilograms)	Full-density volume (m^3)	Packaged volumes (m^3)[(a)]	No. of canisters
Lower Core Barrel	31,563	3.932	5.28	22
Shroud and Former Plates	12,568	1.556	1.92	8
Thermal Shields	9,158	1.141	1.44	6
Lower Grid Plate	3,946	0.575	0.72	3
Upper Grid Plate[(b)]	3,973	0.495	1.20	5
Lower Support Columns[(b)]	2,922	0.363	0.48	2
Totals	64,130	8.062	11.04	46

(a) 9-in.-sq. by 180-in.-high canisters, disposal volume of 0.24 m^3 each.

(b) These items were not classified as GTCC LLW in the NUREG/CR classification reports[(2, 3)] but are included here as potential candidates.

E.5.5 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 and its internals are summarized in Table E.4.

E.5.6 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 information listed in Table E.4 and Appendix B.

Table E.4 Summary of information on RPV and internals packaged for disposal

	Containers							
Component	Number	Ci/ea.	Liner dose-rate (R/hr)	Weight(h) (lb)	Volume (ft^3)	Weight/ shipment	Number of shipments	Disposal volume (ft^3)
Insulation, Top Half	2(h)	<1	<2	1,730	96	3,460	1	192
Insulation, Lower Half(a)	1(c)	<100	5	4,570	126	63,890	1	126
Upper Core Assembly								
Top Plate(a)	1(d)	<10		52,740	470	52,740	1	470
Upper Part of CRD Guide(a)	2(h)	<50		12,465	96	24,930	1	192
Upper Part of Posts and Columns(a)	4(h)	<50		4,957	96	19,826	1	384
Lower Part of Posts, Columns, CRD Guides(a)	2(c)	<22,000	30	10,850	126	70,170	2	252
Lower Core Assembly								
Upper Barrel(a)	2(h)	<1,000	5	11,645	96	23,290	1	192
	3(c)	<1,000	5	9,250	126	68,570	3	378
Thermal Shields	6(e)	130,000		3,665(i)	8.4	54,865	6(j)	50.4
Shroud Plates and Formers	8(e)	3.065 M		3,764(i)	8.4	54,964	8(j)	67.2
Upper/Lower Grid Plates, Upper Part of Support Posts	10(e)	505,000		20,442(i)	8.4	83,288	5(k)	84.0
Lower Barrel	22(e)	586,000		3,463(i)	8.4	54,663	22(j)	184.8
Forging, and Tie Plates(a)	6(c)	<2,500	10	12,700	126	72,020	6	756
Lower Posts, Inst. Guides(a)	1(c)	<300	5	12,400	126	71,720	1	126
Reactor Vessel								
Upper/Lower Heads	7(h)	<5		25,100	96	50,200	3.5	672
Upper and Lower Head Flanges	7(h)	<10		24,030	96	48,060	3.5	672
Nozzle Sections	8(f)	<20		22,260	62.5	44,520	4	500
Lower Wall	22(g)	<17,000	2	15,234	36	74,000	22	792
Stud and Nuts	2(h)	<10		18,400	96	36,800	1	192
CRD and Instrument Guide Penetrations	1(h)	<1		1,600	96	1,600	1	96

(a) Classified as Class B/C waste.
(b) Standard Box, 4 ft x 4 ft x 6 ft, (600 lb empty) ($645 ea.).
(c) Cask Liner for 8-120B cask, 62 in. OD x 72 in. high, (2,000 lb empty) ($4695 ea.). Empty cask wt. 59,320 lb.
(d) Special Container, U-shaped steel box (174 in. dia. x 210 in. long x 45 in. high), (1,500 lb empty) ($1,565 ea.).
(e) 9 in. x 9 in. x 180 in. canister for GTCC material, (300 lb empty) ($520 ea.).
(f) Special Container, Fitted to inner wall shape, welded to wall, nozzle capped, (300 lb empty) ($470 ea.).
(g) Cask Liner for 8-120B cask, Oval-shaped, 16.5 in. x 60 in. x 52 in., (1,200 lb empty) ($4,695 ea.).
(h) Includes Container Weight.
(i) Averaged over all canisters of this set.
(j) NAC-LWT cask carrying 1 canister per shipment. Empty cask wt. 51,200 lb.
(k) TN-8 cask carrying 2 canisters per shipment. Empty cask wt. 79,200 lb.

Table E.5 Summary of costs for cutting, packaging, transport, and disposal of the reactor pressure vessel and its internal structures(a)

	Costs in 1993 dollars				
Components	Cutting(b)	Containers(c)	Transport(d)	Disposal(e)	Total
Insulation, Top Half	50,439	1,290	1,332	9,311	108,600
Insulation, Lower Half(f)		4,695	33,189	8,345	
Setup/Teardown	77,974				77,974
Top Plate(f)	3,409	1,565	1,332	34,508	40,813
Upper Portion, CRD Guides(f)		1,290	1,332	11,441	
Upper Portion, Posts & Columns(f)	79,304	2,580	1,332	18,622	212,155
Lower Portion, Posts, Columns, CRD Guides(f)		9,390	39,852	47,013	
Upper Core Barrel(f)	12,305	1,290 14,085	1,332 47,396	13,780 36,840	127,028
Thermal Shields(g)	17,667	3,120	124,864	327,600	476,382
Shroud Plates and Formers(g)	50,551	4,160	159,111	436,800	653,751
Upper/Lower Grid Plates(g)	25,219	4,160	125,970	436,800	595,489
Upper Portion of Support Posts & Inst. Guides(g)	22,930	1,040	61,446	109,200	194,616
Lower Core Barrel(g)	76,720	11,440	401,358	1,201,200	1,681,718
Support Forging and Tie Plates(f)	42,712	28,170	68,537	84,170	223,589
Lower Posts and Instrument Guides(f)	22,930	4,695	33,449	11,643	72,717
Setup/Teardown	51,982				51,982
Upper/Lower RPV Heads	28,224	4,515	4,661	107,139	144,539

Table E.5 (Continued)

Components	Costs in 1993 dollars				
	Cutting(b)	Containers(c)	Transport(d)	Disposal(e)	Total
Upper/Lower RPV Flanges	11,238	4,515	4,661	69,864	90,278
Nozzle Sections	4,346	3,760	5,327	66,847	80,281
Lower Wall	28,480	103,290	184,231	257,783	573,784
Studs & Nuts	--	1,290	1,332	14,636	17,258
CRD & Instrument Penetrations	37,468	645	1,332	4,656	44,101
Totals	634,899	210,985	1,303,375	3,308,196	5,457,456

(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.
(f) Classified as Class B/C waste.
(g) Classified as greater than Class C (GTCC) waste.

E.5.7 Postulated Schedule for Cutting and Packaging the RPV and Its Internals

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 refueling cavity area. The core assembly is removed from the RPV and placed in its stand in the refueling cavity during this period. Cutting and packaging of the RPV internals proceeds in the sequence shown in Figure E.5. Upon completion of the cutting and packaging operations, a final week is devoted to removal of the cutting systems and to final packaging and shipping from the refueling cavity. At that time, the remaining water in the refueling cavity is drained and the cavity is available for decontamination. The elapsed calendar time for the cutting and packaging of the RPV internals is estimated to be about 3½ months.

The initial week (10 shifts) of the RPV sectioning is devoted to installing and testing the plasma arc and oxyacetylene torches and the manipulator system in the reactor vessel, and to installing the RPV support structure beneath the RPV. Cutting and packaging of the RPV proceeds in the sequence shown in Figure E.6. 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 is estimated to be about 1½ months.

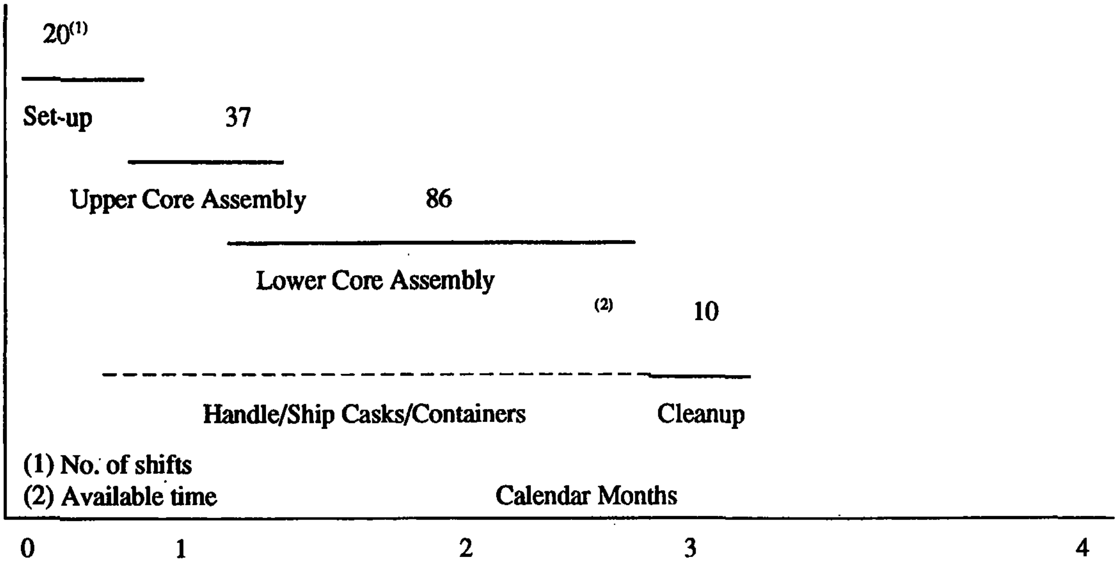


Figure E.5 Postulated schedule for cutting/packaging the RPV internals

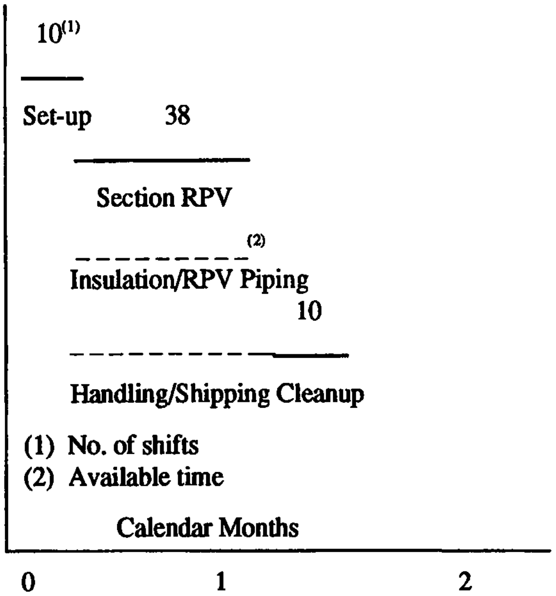


Figure E.6 Postulated schedule for cutting/packaging the RPV

E.5.8 Impacts on Transport and Disposal Costs of Disposal at Barnwell

The transport and disposal costs for LLW are sensitive to the distance between the reactor site and the disposal facility, and to the charge schedule at the disposal site. The analyses presented previously in this appendix are based on transport of the LLW portion of the sectioned and packaged segments of the reactor pressure vessel and the vessel internal from the Trojan site to and disposal at the U.S. Ecology facility at Hanford, Washington. All of these materials are assumed to be transported by truck. These same analyses were repeated for transport from the Trojan site to and disposal at the Chem-Nuclear facility at Barnwell, South Carolina. The results of these analyses are presented in Table E.6. The estimated transport cost to Barnwell is about a factor of 3 larger than the transport cost to Hanford, reflecting the much greater distance traveled. Similarly, the disposal cost at Barnwell is nearly a factor of 6 larger than the disposal cost at Hanford, reflecting the much higher disposal rate structure at Barnwell.

Table E.6 Sensitivity of transport and disposal costs for the LLW portions of the reactor vessel and vessel internals to disposal facility location and rates[a]

Location	Transport costs (1993 $)	Disposal costs (1993 $)
Hanford LLW	430,626	796,596
Barnwell LLW	1,330,489	4,585,646

(a) Costs do *not* include a 25% contingency.

E.6 References

1. Title 10, Code of Federal Regulations Part 61.55 - *Waste Classification*, January 1, 1990.

2. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station*. NUREG/CR-0130, 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 Pressurized Water Reactor Power Station - Classification of Decommissioning Wastes*. NUREG/CR-0130, Addendum 3, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

4. M. S. McGough, W. E. Austin, and G. J. Knetl, "Performance of the Automated Cutting Equipment System During the Plasma Cutting of the Three Mile Island Unit 2 Lower Core Support Assembly," *Nuclear Technology*, Vol. 87, pp. 648-659, November 1989.

5. R. A. Lundgren. 1981. *Reactor Vessel Sectioning Demonstration*. PNL-3687 (Revision 1), U.S. Department of Energy Report by Pacific Northwest Laboratory, Richland, Washington.

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

Steam Generators Dismantlement and Disposal Activities, Manpower, and Costs

Appendix F

Steam Generators Dismantlement and Disposal Activities, Manpower, and Costs

The postulated dismantlement and disposal activities for the steam generators, together with estimated manpower, costs, and schedule, are presented in this appendix. It should be recognized that most dismantlement costs can be estimated using standard costs per unit of removed quantity. After construction of the plant, quantities of material and equipment required in the plant can be estimated. These quantities can then be multiplied by a standard removal cost per unit, which includes the values of any work-related adjustment factors, to obtain total removal costs. This is not generally true, however, in the case of extra-large components such as the steam generators, which are more complex and reactor-specific in nature. Therefore, such items are estimated separately (as in this appendix) and are presented in cost summaries elsewhere in this study as an aggregate cost line item, with reference to this appendix for details.

Because of the many variables involved, the analysis presented in this appendix is not intended to result in an "exact" solution concerning costs or occupational doses for steam generator removal during decommissioning. The resultant cost and dose values are intended as reliable updated estimates (based on the key assumptions given in Section F.1) for the removal of steam generators from the reference pressurized water reactor (PWR) during decommissioning and their subsequent disposal. Consequently, the results of this analysis make a useful addition to the already existing decommissioning database and increase its general applicability.

Following the assumptions, the methodology used in this analysis is presented in Section F.2, followed by a brief description of the steam generators in Section F.3. The steam generators removal and disposal activities are described in Section F.4. Section F.5 covers the radwaste handling and processing associated with the steam generator removal project. The results of a reevaluation of the anticipated occupational radiation dose for the project are discussed in Section F.6. Estimated costs and schedules and a discussion of important considerations associated with recent steam generator removal projects are presented in Sections F.7 and F.8, respectively. The references for the appendix are given in Section F.9.

F.1 Assumptions

In developing scenarios and the subsequent analyses, the following assumptions were used:

- The removal of the reference plant's steam generators is based, in part, upon a reassessment of cost and dose estimates for removal of steam generators during decommissioning presented in Reference 1, which included a comprehensive review of recent steam generator changeout programs.

- One-piece steam generator removal is postulated, based upon three of the most important considerations: adequacy of plant equipment hatch egress, reduced radiation exposure, and a shorter overall schedule duration.

- The radiation dose rates used in the analyses remain essentially unchanged from those estimated in the original study, NUREG/CR-0130,(2) 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.

- Steam generator exterior surfaces will be decontaminated, as required. Following injection of low-density cellular concrete to ensure encapsulation of the internal contaminants, all openings will be seal-welded, since the steam generators are anticipated to serve as their own burial containers. It is further assumed that the NRC issues Certificates of Compliance for shipments of the steam generators on an open waterway, as Type A low specific activity (LSA) transport packages.

- Steam generator removal, transport, and disposal is handled by an experienced contractor, who is well established in steam generator changeout and associated integrated outage activities, under contract to the decommissioning operations contractor (DOC). Heavy-lift rigging, barge, and overland transport costs for the steam generators are based on information provided by a qualified vendor of these services, who has handled the barge, overland transport, and installation of nuclear steam supply system (NSSS) components for several plants.

- The waste disposal costs presented in this study were specifically developed for the reference PWR, which is located within the Northwest Compact, assuming disposal at the U.S. Ecology site in Richland, Washington. Steam generators are removed sequentially and barged one at a time to U.S. Ecology, Inc. This scenario will consolidate shipping and reduce mobilization costs for the heavy haul vehicles used by the vendor mentioned above. To provide additional information, the costs also were estimated for shipping and disposal of the reference steam generators at the Barnwell site in Barnwell, South Carolina.

F.2 Methodology

Two removal scenarios were considered: (1) sectioning each steam generator into two or more pieces for subsequent transport by rail as delineated in NUREG/CR-0130[2] and (2) removing them intact for subsequent transport by barge. The one-piece removal scenario appeared to have the greatest estimated potential for minimizing cost and occupational radiation exposure (ORE) and was analyzed in this study.

F.3 Steam Generators (4 Each)

The approximate weight of each of the reference steam generators is 312 Mg (688,000 lb), and about 321 Mg (about 708,000 lb) with shipping saddle and lifting beams. The steam generator shown in Figure F.1 is a vertical shell and U-tube unit with integral moisture-separating equipment. The present steam generators at the reference plant are Westinghouse Series 51 models.

Each steam generator is supported on four hinged columns. Lateral resistance is provided by two ring girders. The lower girder is designed to permit the thermal movements of the support columns, vessel, and primary piping in the horizontal and vertical directions. The upper girder is located close to the center of gravity of the steam generator. Lateral resistance at this level is provided by four bumper stops and two hydraulic suppressors (snubbers), as shown in Figure F.2. The pertinent features of the reference plant's steam generators used in this analysis are given in Table F.1.

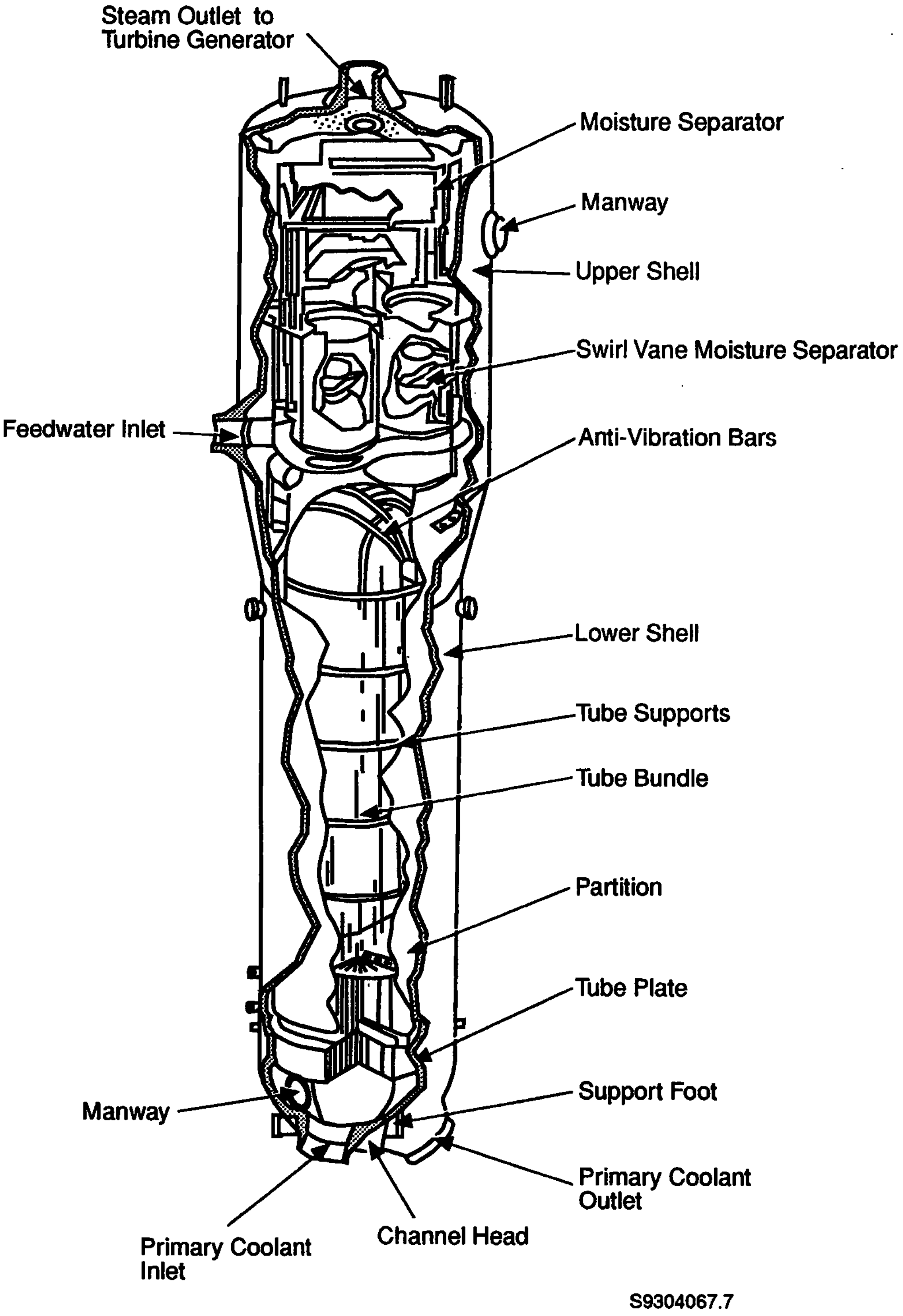


Figure F.1 Steam generator

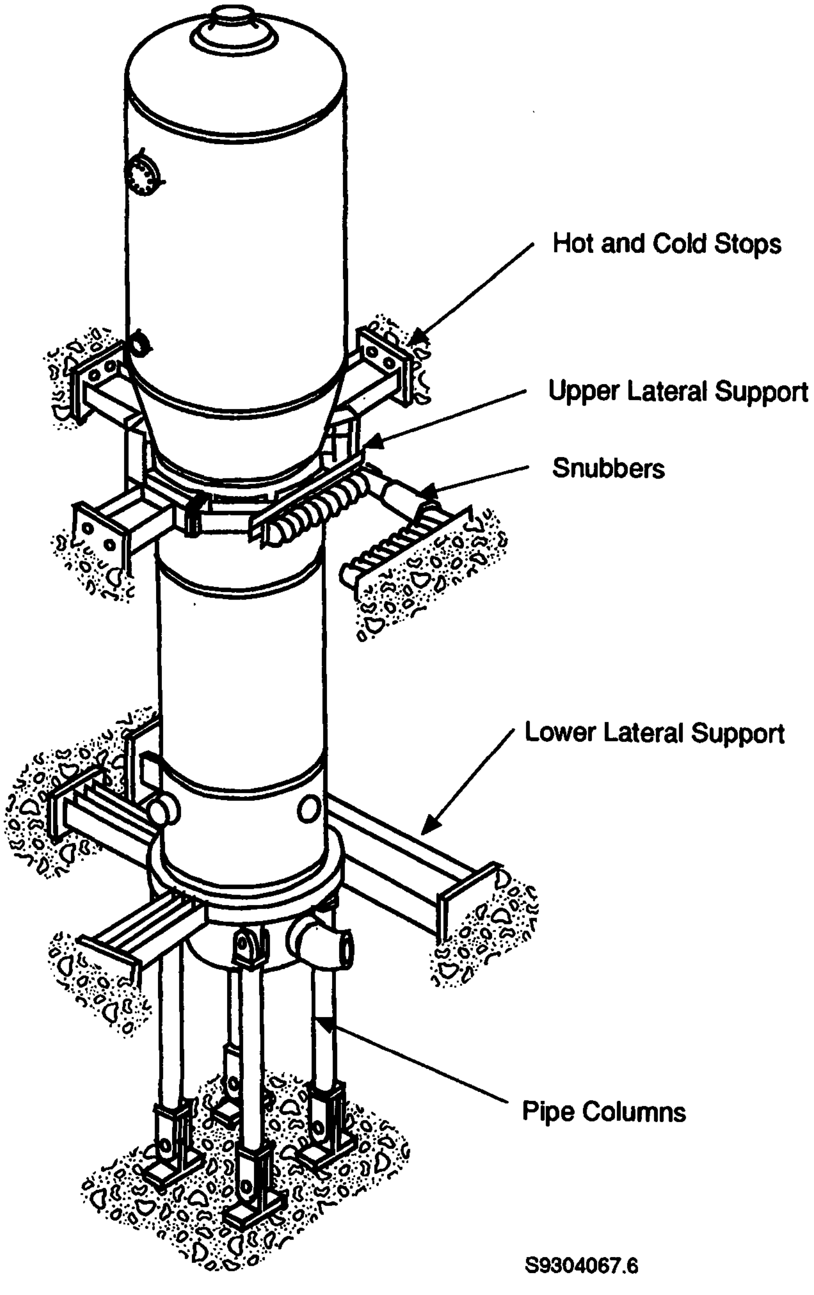


Figure F.2 Steam generator supports

Table F.1 Steam generator data

Total Heat Transfer Surface Area	4786 m^2	(51,500 ft^2)
Overall Height	20.63 m	(67.67 ft)
Diameter, Upper Portion	4.47 m	(14.67 ft)
Lower Portion	3.43 m	(11.25 ft)
Number of U-tubes	3388	
U-tube outer diameter	22.2 mm	(0.875 in.)
Tube wall thickness, nominal	1.27 mm	(0.050 in.)
Number of manways	4	
Estimated volume	230.2 m^3	(8130 ft^3)

F.4 Steam Generators Removal and Disposal

For the purpose of this analysis, the steam generator removal and disposal operations were developed in four phases: Phase 1-Precursor Tasks, Phase 2 - Preparatory Activities, Phase 3 - Removal Activities, and Phase 4 - Heavy-Lift Rigging, Transport, and Disposal Activities.

F.4.1 Phase 1 - Precursor Tasks

The selected Phase 1 precursor tasks (presented in Table F.2) are postulated as being completed before removing the steam generators.

F.4.2 Phase 2 - Preparatory Activities

The estimated labor hours for preparatory activities, per steam generator, from the Point Beach Nuclear Plant Number 1 (PBNP-1) two-piece removal program(1,3,4) were ratioed down to reflect actual hours as closely as possible for the one-piece removal scenario analyzed in this study. Those results, per steam generator, were compared to similar tasks for the Surry steam generator removal program.(5) Where both numbers were available, an average value per steam generator was computed and used in this analysis (see Table F.3).

It is estimated that two dedicated 60-person crews, working one crew on each of two shifts, will be required to complete the Phase 2 activities in approximately 1.75 months. Each crew is assumed to consist of the staff listed in Table F.4. The work

Table F.2 Phase 1 - precursor tasks for steam generators removal[a]

1. Chemical decontamination of the reactor coolant system (done within the first year after final reactor shutdown).
2. The transferring of the spent nuclear fuel from the fuel pool to an independent spent fuel storage installation (as discussed in Appendix D, the fuel pool could not be finally emptied until at least 7 years following reactor shutdown).
3. Disassembly, decontamination (as deemed appropriate), packaging, and disposal of all spent fuel storage racks.
4. Draining and decontamination of the spent fuel pool.
5. Decontamination of the 93-ft elevation in the Fuel Building.
6. Removal of appropriate sections of the Fuel Building roof to provide clearance for lifting the steam generators by a contractor. For the purpose of this analysis, the cost associated with this activity has been classified as a cascading cost[b] because no radioactively contaminated materials are anticipated to be involved.
7. Barge slip preparations (primarily dredging operations) - a cascading cost.[b]
8. Completion of a job training program for all staff participating directly in the steam generator removal operations.[c]

(a) Precursor tasks 1 through 5 are listed here for completeness. However, since they are accounted for elsewhere in this study, they are not costed in this appendix to avoid double-counting.

(b) 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).

(c) It is assumed that existing, onsite training mockups and facilities will be used for this program. Recent steam generator removal project experience reveals the highly successful nature of such training programs in maximizing the productivity and reducing person-rem exposure.

duration adjustment factors considered appropriate for the steam generator preparatory tasks (given in Table F.3) and for the steam generator removal tasks (given in Table F.5) are:

Duration Adjustment Factors	
• Radiation Protection/ALARA	10.0%
• Respiratory Protection	20.0%
• Height/Access Adjustment for Scaffold Work	10.0%
Lost-Time Adjustment Factors	
• Protective Clothing	36.4%
• Break Time	9.1%

Table F.3 Phase 2 - preparatory activities

Task description[a]	Estimated labor (person-hours)
Polar Crane Modification	745
Install Steam Generator Transport System	3,446
Remove Containment Obstructions	513
Protection of Containment Components	769
Install Temporary Ventilation System	566
Temporary Scaffolding	5,795
Temporary Lighting and Power	680
Cleanup and Decontamination[b]	8,367
Polar Crane Operator	616
Health Physicist/Radiation Monitors[c]	3,080
Shielding	7,262
Install Service Air System	742
Work Platform Modification	2,312
Miscellaneous[c]	2,052
Subtotal Phase 2	36,945

(a) For the purpose of subsequent use in summary line-item cost presentations in this study, all tasks shown in the table are essentially associated with removal activities (as opposed to decontamination activities), unless indicated otherwise.

(b) This task has been designated a decontamination task; also see footnote (a).

(c) The subsequent calculated costs associated with this task have been evenly divided between removal and decontamination.

Table F.4 Staffing and labor rates postulated for removal crews

Person-hrs/crew-hr	Category	Labor rate ($/hr) ($/labor-hr)	Cost[(a)] ($/crew-hr)
26.0	Craftsman	49.70	1,292.20
23.0	Laborer	26.37	606.51
5.0	Foreman	54.84	274.20
6.0	H. P. Tech.	36.82	220.92
60.0			2,393.83
	Average labor cost per crew-hour[(b)] =		$2,513.52

(a) Includes 110% overhead, 15% DOC profit.

(b) Includes 10% shift differential for second shift.[(5)]

F.4.3 Phase 3 - Removal Activities

The estimated labor hours for removal activities, per steam generator, from the PBNP-1 removal program[(1,3,4)] were ratioed down to reflect actual hours as closely as possible for the one-piece removal scenario analyzed in this study. Those results, per steam generator, were compared to similar tasks for the Surry steam generator removal program.[(5)] Where both numbers were available, an average value per steam generator was computed and used in this analysis (see Table F.5).

It is estimated that two dedicated 60-person crews, working one crew on each of two shifts, will be required to complete the Phase 3 activities in approximately 2.35 months. Each crew is assumed to consist of the staff listed in Table F.4.

Most of the steam generator insulation is comprised of packages of mineral fiber material, sandwiched between multiple layers of thin stainless steel, which are contoured to surround the entire generator, top and bottom heads and the cylindrical side wall. These packages are approximately 4 in. thick. The total volume of insulation for all 4 steam generators is estimated at about 11,028 cubic feet. Because the insulation package sizes are designed to facilitate installation and removal, very little, if any, cutting is anticipated before packaging. Using an estimated packing efficiency factor of 1.5, twelve 8-ft x 8-1/2-ft x 20-ft maritime containers (Sea-Vans) are packed with the insulation for unshielded shipment to Hanford. It is assumed that virtually all of the insulation is disposed of in this manner, since it could be argued that interior spaces between layers could not be proven to be contamination free without complete disassembly.

Once the insulation has been removed from a steam generator and packaged, the piping from the reactor coolant system (2 RCS cuts per generator), the feedwater system (1 cut per generator), the steam outlet to the turbine generator (2 cuts per generator), as well as the miscellaneous instrument and control lines, are accessible for cutting. After cutting, the openings are seal-welded, since the steam generator is anticipated to serve as its own burial container. The steam generator is rigged and supported, as needed, in preparation for disengagement from the steam generator's support mechanisms (see Figure F.2). The lower support ring is cut as necessary, with oxyacetylene torches, to allow clearance for RCS piping stubs when the steam generator is subsequently lifted. Similarly, the upper lateral support ring is cut as necessary to provide adequate clearance for lifting. With the insulation and the pipes removed, lifting of the steam generator can proceed.

Table F.5 Phase 3 - removal activities

Task description[a]	Estimated labor (person-hours)
Removal of Insulation	2,594
Removal of Miscellaneous Piping	2,580
Cutting of Reactor Coolant Piping	--[b]
Cutting of Mainstream and Feedwater Piping	1,657
Disassembly of Steam Generator Supports	1,280
Removal of Steam Generator Level Instruments and Blowdown Piping	1,952
Temporary Scaffolding	3,296
Temporary Lighting and Power	14,548
Cleanup and Decontamination[c]	8,370
Polar Crane Operator	827
Health Physics Technicians[d]	4,136
Material Handling, Equipment Maintenance and Miscellaneous Construction Activities[d]	8,372
Subtotal Phase 3	49,612

(a) For the purpose of subsequent use in summary line-item cost presentations in this study, all tasks shown in the table are essentially associated with removal activities (as opposed to decontamination activities), unless indicated otherwise.
(b) This task is listed here for completeness. However, since the cost of this task is accounted for elsewhere in this study, it is not costed in this table to avoid double-counting.
(c) This task has been designated a decontamination task; also see footnote (a).
(d) The subsequent calculated costs associated with this task have been evenly divided between removal and decontamination.

F.4.4 Phase 4 - Heavy Lift Rigging, Transport, and Disposal

This work is assumed to be done by a contractor, and consists of rigging, handling, temporary storage, and placement of the steam generators on a barge, one to a barge, for hauling to the Hanford site for disposal. The contractor furnishes test equipment, test weights, test lifting equipment, and related items to be used in the performance of the work. The contractor is anticipated to use the polar bridge crane without charge. This crane is designed for both trolley and bridge travel under a 455-ton lifting capacity.

Inside the containment, the steam generator is raised by the polar bridge crane. It is placed in an upending device or skid (which is assumed to be furnished by the utility) and lowered to a horizontal position for extraction from the containment vessel. The steam generator is then filled with ultra-low density grout and sealed for transport. An auxiliary trolley placed on the Reactor Building bridge crane rail is used in conjunction with a runway and the Fuel Building crane, located outside the equipment hatch, to move the generator from the Reactor Building to the Fuel Building laydown storage area. In turn, each steam generator is placed in the laydown area at the 93-foot elevation in the Fuel Building in preparation for the 48-foot lift to grade level. It is estimated that this particular effort might amount to one work day for each generator. The generator is then lifted out of the Fuel Building, via an opening created in the building roof, and placed onto a cradle/trailer for movement to the barge slip and onto a barge for river shipment to the U.S. Ecology, Inc., commercial disposal site at Hanford.

F.5 Radwaste Handling and Processing

The handling and processing of the steam generator removal project's radwaste is postulated to be accomplished as an integrated effort between the DOC and the licensee's personnel. It is assumed that limited storage facilities at the reference site require the continuous handling, processing, and shipping of radwaste. DOC personnel are responsible for the removal of waste as it is generated inside containment during steam generator removal. Waste is anticipated to be removed from containment and deposited at a temporary holding area. DOC personnel will prepare and package the waste for disposal.

Two drum compactors are assumed to be available during the steam generator removal project for the compaction of compressible waste. Noncompressible waste is packaged in B-25 metal containers (96 cubic feet disposal capacity). All of the waste is shipped from the site, as the accumulated waste volume dictates optimal use of shipping vehicles.

The initial cleanliness of the Containment Building, and a continuing effort to control contamination, is anticipated to prevent the contamination of much of the equipment brought into containment. This effort is expected to result in a minimization of radwaste volumes.

The estimated radwaste volume for the reference PWR was ratioed from the PBNP-1 steam generator project radwaste volumes reported in Reference 4. Activities associated with the steam generator preparatory and removal phases for the reference PWR are estimated to generate a radwaste volume of 15,684 cubic feet, of which about 3,780 cubic feet are estimated to be compressible wastes and the remaining 11,904 cubic feet are estimated to be non-compressible wastes. These waste volumes do not include the steam generators (see Table F.1) or the insulation (discussed previously in Section F.4.3). The compressible wastes are shipped as LSA material to Hanford from the reference PWR in 55-gallon drums. Approximately 504 drums are estimated to be utilized as shipping containers. Noncompressible wastes are shipped to Hanford using an estimated 124 B-25 containers.

F.6 Occupational Radiation Dose

The results of an analysis to evaluate and compare the occupational radiation doses of recent PWR steam generator changeout programs with the dose estimates previously developed for DECON of the reference PWR described in NUREG/CR-0130 are contained in Reference 1. For ease of reference and because they provide the bases for the steam generator removal scenario analyzed in this study, the principal results are given, in brief, in the following subsections.

The comparison of the reported exposures for the steam generator removal project at the Point Beach Nuclear Power Plant No. 1 (PBNP-1), which was selected for examination in Reference 1, considers in detail the tasks involved to determine their applicability to decommissioning under the DECON alternative. Data on the occupational exposure for that removal/replacement project were obtained from the literature as well as from personal communication with utility personnel.

Analysis of those data involved assessing the reported doses concerning all specified tasks and then eliminating those doses associated with tasks determined to be unrelated to decommissioning. In addition, dose adjustments were made where it was determined that the task was performed in a different sequence or manner than envisaged during decommissioning. The adjusted doses were then compared to the doses previously estimated in NUREG/CR-0130. The comparison showed that the estimated total radiation dose to decommissioning workers for the removal of steam generators during DECON remained essentially unchanged from the total dose initially estimated in NUREG/CR-0130 for this task.

It should be emphasized that the dose consequences for any decommissioning alternative in which the steam generators are to be physically removed are quite different from the dose consequences associated with the replacement of steam generators during reactor outages. This is because, during a replacement effort, significant additional activities are necessary to assure continued operation, including preservation of building structures, concern for capital equipment, materials, continuing use of air, water, etc. On the other hand, large-component removal (such as steam generator removal) during decommissioning does not require any activities to assure future operability, and thus involves a much smaller commitment of resources than does removal and replacement of the steam generators.

Upon examination and discussion (with PBNP-1 staff) of the elemental constituents of each activity given in Table F.6, the occupational radiation dose was adjusted by PNL in Reference 1 for the "removal only" tasks concerning both PBNP-1 steam generators. The results are presented in Table F.7, together with the rationale for the adjustments used to derive the estimated occupational radiation doses for steam generator removal during DECON. The estimated dose resulting from the postulated removal of the four steam generators similar to the PBNP-1 units during DECON, but without the benefit of a chemical decontamination of the reactor coolant system (RCS), and the estimated dose resulting from the removal of four steam generators during DECON following a RCS chemical decontamination, are presented. Events likely to be affected by the chemical decontamination are identified in the table with an asterisk. Only those activities that would be performed during decommissioning, or would fall under the task description of steam generator removal in NUREG/CR-0130, are included. The adjusted total dose shown in the table (77.1 person-rem) is based on the conservative assumption that the chemical decontamination of the RCS results in a decontamination factor (DF) of 5. If a DF of 2 is assumed, the total occupational radiation dose is calculated to be about 136.2 person-rem.

The DECON values shown in Table F.7 were calculated for the reference PWR in Reference 1, based upon the steam generator removal program occurring at about 18 months following final reactor shutdown. However, for purposes of this analysis, the steam generator removal program is postulated to occur about 8 years following final shutdown, after the fuel pool is finally emptied (see Chapter 3 for details) and after the Fuel Building is decontaminated. Therefore, based on ^{60}Co decay, the applicable dose rates shown in Table F.7 can be expected to be further reduced by approximately a factor of two.

For the purpose of this study, the information shown in Table F.7 was adjusted to reflect the estimated labor hours given previously in Tables F.3 and F.5 for the preparatory activities and removal activities, respectively. In addition, as many as 13 subcontractor staff are estimated to be involved in the steam generator heavy-lift operations, including mobilization and demobilization activities. However, only about 9 of these workers are anticipated to be actually involved in working in radiation zones, near the steam generators. It is further anticipated that approximately 59,700 hours will be expended by all of the workers, in radiation zones that average about 1.0 mR/hr.

Table F.6 Summary of occupational radiation doses from the Point Beach steam generator replacement project[a]

Task	Dose (rem)
Containment access building preparation	0.09
Equipment move-in/set-up in containment	7.09
Containment access modification	2.27
Temporary shielding - install/remove	44.52
Biological shield - install/remove	0.13
S/G supports - remove/refurbish[b]	6.83
S/G temporary supports and restraints - install/remove	7.26
Temporary power installation	5.98
Temporary power removal--restoration of permanent power	0.18
Protection of containment components	4.29
Interference removal	0.92
Foundation shoring of containment access	0.83
Communication system - install/remove	0.58
Tenting	14.42
Breathing air system install/remove	0.15
Polar crane modification	11.97
Load test	0.52
Equipment decontamination	6.63
Cleanup and decontamination of containment	62.97
Insulation removal	15.16
S/G girth cuts	3.82
Steam drum handling	0.45
S/G main steam and feedwater pipe cuts	1.62
S/G small bore piping and instrument line cuts	2.10
S/G reactor coolant pipe cuts	35.13

Table F.6 (Continued)

Task	Dose (rem)
S/G lower assembly removal	22.19
S/G laydown stands	0.37
Steam drum modification	16.22
S/G lower assembly installation	2.45
Reactor coolant pipe weld	35.70
S/G girth weld	6.18
S/G main steam and feedwater pipe weld	4.27
S/G blowdown pipe and instrument line weld	12.18
Post weld heat treatment	0.18
Insulation installation	39.36
Containment restoration	17.49
System integrity	3.76
Primary side search and retrieval	5.62
Secondary side search and retrieval	0.83
General containment entry and miscellaneous work	75.60
Total Occupational Dose	589.65

(a) The information in this table is extracted from References 3 and 4.
(b) S/G = steam generator.

Table F.7 Estimated occupational dose for the postulated removal of four steam generators similar to PBNP-1 units during immediate dismantlement with and without chemical decontamination of the reactor coolant system[a]

	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)[d]	
Immediate dismantlement task	**Initial dose for two SGs[b,c]**	**Estimated dose for two additional SGs**	**Estimated total dose for four SGs**	**Cause**	**Effect**	**Without chemical decontamination of the RCS**	**With chemical decontamination of the RCS**
Containment access building (CAB) preparation	0.09	--[e]	0.09	Although a CAB is considered an optional structure at the reference PWR, it is included in this study for conservatism.	Negligible, no change in estimate.	0.090	0.090
Equipment move-in/set-up in containment	7.09	--	7.09	Includes the movement and set-up of numerous items and materials not related to decommissioning, including refurbishment/repair tasks as well as SG installation, post-installation and startup activities.	Examination of PBNP-1 data suggests that approximately 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	2.363	2.363
Temporary shielding install/remove*[f]	44.52	44.52	89.04	This activity is somewhat mislabeled since it also includes installing and removing scaffolding (which was done twice). The majority of these activities are required only once during immediate dismantlement.[g]	Therefore, the total dose for 4 SG's is estimated to be 44.52 rem without chemical decontamination.	44.520	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		8.904
S/G supports remove/refurbish*	6.83	6.83	13.66	Refurbishment is not necessary for decommissioning--simply remove and box for disposal.	Dose reduced by a factor of 10 due to severely reduced time and staff labor requirements.	1.366	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		0.273

Table F.7 (Continued)[a]

	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)[d]	
Immediate dismantlement task	**Initial dose for *two SGs*[b,c]**	**Estimated dose for two *additional SGs***	**Estimated total dose for *four SGs***	***Cause***	***Effect***	**Without chemical decontamination *of the RCS***	**With chemical decontamination *of the RCS***
Temporary power installation	5.98	--	5.98	Cable runs for 15 or more TV cameras and sound equipment, welding machines, etc. Much of the needed cutting equipment will already be inside the containment vessel (see schedule delineated in Figure G.2-2 of Reference 1). In addition, only 3 to 4 TV cameras are anticipated to be used during decommissioning. Power needs associated with SG installation, post-installation, and startup activities are not required.	It is estimated that approximately 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	1.993	1.993
Temporary power removal--restoration of permanent power	0.18	--	0.18	Restoration of permanent power is an unnecessary step for decommissioning.	It is estimated that approximately 1/2 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	0.090	0.090
Protection of containment components	4.29	--	4.29	An inventory is taken from prints and drawings to identify those components that must be protected for use during subsequent startup of the reactor. It is not known precisely how many of these components will be needed for decommissioning but according to the schedule presented in Figure G.2-2 of Reference 1, the reactor pressure vessel has already been removed and the RCS is empty.	It is estimated that approximately 1/2 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	2.145	2.145

Table F.7 (Continued)[a]

Immediate dismantlement task	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)[d]	
	Initial dose for two SGs[b,c]	estimated dose for two additional SGs	Estimated total dose for four SGs	Cause	Effect	Without chemical decontamination of the RCS	With chemical decontamination of the RCS
Interference removal*	0.92	0.92	1.84	Conduits and minor piping which might interfere with the removal of the lower assemblies are identified, locations are precisely marked (for subsequent reinstallation), removed, and stored.	It is estimated that approximately 1/4 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 25%.	1.380	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		0.276
Foundation shoring of containment access	0.83	--	0.83	This task is included in this study for conservatism, because such shoring may be necessary at the reference PWR.	Negligible, no change in estimate.	0.830	0.830
Communication system install/remove	0.58	--	0.58	No dose reduction for this task is anticipated.	No change in estimate.	0.580	0.580
Tenting*	14.42	14.42	28.84	Tenting requirements inside the SG cubicles for removal and installation activities; tenting requirements for cutting and welding RCS piping; and staging associated with these tasks.		28.840	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		5.768
Breathing air system install/remove	0.15	--	0.15	Backup system to existing containment vessel system; includes laying down hoses from a compressor located outside of the containment vessel.	No change in estimate.	0.150	0.15

Table F.7 (Continued)[a]

	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)[d]	
Immediate dismantlement task	**Initial dose for two SGs[b,c]**	**Estimated dose for two additional SGs**	**Estimated total dose for four SGs**	**Cause**	**Effect**	**Without chemical decontamination of the RCS**	**With chemical decontamination of the RCS**
Polar crane modification	11.97	--	11.97	It should be recognized that many aspects of this task are unique to PBNP-1. This task includes erection of a reinforced steel structure over the reactor cavity that was used to support a center beam that extended from the structure to the polar crane bridge. This upgrade increased the lifting capacity of the polar crane from 100 to 230 tons. Additional, but smaller modifications were made during the upgrade as well.	Upgrading the polar crane for SG removal at the Trojan plant (the reference PWR) is a far less complex operation than the upgrade at the PBNP-1. It consists of the installation of a blocking arrangement located at the same height in the containment vessel as the polar crane itself. It is estimated that approximately 1/2 of the staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	5.985	5.985
Load test	0.52	--	0.52	During load testing, the crane load block bearings and a motor starter on the hoist failed and had to be replaced.	It is estimated that approximately 1/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 33%.	0.347	0.347

Table F.7 (Continued)

Immediate dismantlement task	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)(d)	
	Initial dose for two SGs(b,c)	Estimated dose for two additional SGs	Estimated total dose for four SGs	Cause	Effect	Without chemical decontamination of the RCS	With Chemical Decontamination of the RCS
Equipment decontamination*	6.63	6.63	13.26	This task includes SG hose-down and waxing as well as attempts to decontaminate RCS pipe cuts in preparation for subsequent welding.	For the most part, the decontamination of RCS pipe cuts proved futile, but somewhat costly in terms of pers-rem. It is estimated that approximately 1/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 33%.	8.884	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		1.777
Cleanup and decontamination of containment	62.97	--	62.97	An ongoing (but not continuous) effort throughout the project at PBNP-1.	No change in cleanup procedure is anticipated at the reference PWR, except that the project starts in the 16th month after final reactor shutdown and after other major decommissioning tasks have been completed (e.g., reactor pressure vessel segmentation and removal). It is estimated that approximately 2/3 of these staff labor requirements are not necessary at this stage in the schedule; therefore, the dose is reduced by a factor of 3.	20.990	20.990

Table F.7 (Continued)[a]

Immediate dismantlement task	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)[d]	
	Initial dose for two SGs[b,c]	Estimated dose for two additional SGs	Estimated total dose for four SGs	Cause	Effect	Without chemical decontamination of the RCS	With chemical decontamination of the RCS
Insulation removal*	15.16	15.16	30.32	At PBNP-1, this task involved the removal of an older type of insulation; subsequently, it was replaced with the stainless steel strap-on type of insulation.	A reduction in staff labor of about 25% is anticipated at the reference plant because it uses the newer type of insulation.	22.740	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		4.548
S/G girth cuts*[i]	3.82	3.82	7.64	Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.	7.640	1.528
Steam drum handling[i]	0.45	0.45	0.90	This task included lifting the steam drums, placing them in storage stands inside the containment vessel and includes all refurbishment work that was subsequently done.	It is estimated that fully 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	0.300	0.300
S/G main steam and feedwater pipe cuts	1.62	1.62	3.24	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	1.620	1.620

Table F.7 (Continued)(a)

Immediate dismantlement task	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)(d)	
	Initial dose for two SGs(b,c)	Estimated dose for two additional SGs	Estimated total dose for four SGs	Cause	Effect	Without chemical decontamination of the RCS	With Chemical decontamination of the RCS
S/G small-bore piping and instrument line cuts*	2.10	2.10	4.20	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	2.100	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		0.420
S/G reactor coolant pipe cuts*	35.13	35.13	70.26	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	35.130	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		7.026
S/G lower assembly removal*	22.19	22.19	44.38	A large number of preparations are required for this task.		44.380	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		8.876
S/G laydown stands(i)	0.37	--	0.37	This task included building the stands, inside containment, for holding the steam drums in upright positions. These were special stands for a special purpose.	Much simpler devices can be used for decommissioning; therefore, the task time/dose is reduced by at least a factor of 2.	0.185	0.185

Table F.7 (Continued)[a]

	Removal of four SGs of PBNP-1 type (base data from PBNP-1 project) Estimated dose (pers-rem)			Rationale for dose reduction		Removal of four steam generators during immediate dismantlement Estimated dose (pers-rem)[d]	
Immediate dismantlement task	Initial dose for two SGs[b,c]	Estimated dose for two additional SGs	Estimated total dose for four SGs	Cause	Effect	Without chemical decontamination of the RCS	With chemical decontamination of the RCS
General containment entry and miscellaneous work*[j]	75.60	--	75.60	This general category of activities is encompassed by the 170 man-rem originally estimated in Table G.3-1 of NUREG/CR-0130 for "miscellaneous activities" for the entire immediate dismantlement effort, including removal of the reference PWR's steam generators. Therefore, the category "General containment entry and miscellaneous work" is not included in the total for steam generator removal only.		0	0
Total dose	324.41	153.79	478.20			234.646	77.064

(a) The information in this table is extracted from Table F.6 and modified for this study (see text for details).

(b) SG = steam generator.

(c) The information in this column is taken directly from Table F.6.

(d) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures. Immediate dismantlement values shown in the table were calculated based upon the steam generator removal program occurring about 18 months following final reactor shutdown.

(e) Dash indicates that the task is required to be done only once per plant.

(f) Events likely to be affected by chemical decontamination of the RCS are designated by an asterisk.

(g) Private communication with Douglas F. Johnson of Wisconsin Electric Power Company on September 24, 1987.

(h) Chemical decontamination of the RCS is the largest dose reduction factor of commonality used in this table. For the purpose of this study, it is conservatively estimated to reduce doses by a factor of five.

(i) Not applicable when a steam generator is removed in one piece.

(j) Table G.3-1 of NUREG/CR-0130 allows a total of 170 pers-rem for miscellaneous work during the entire immediate dismantlement effort.

F.7 Estimated Costs and Schedules

The major contributors to the estimated total cost of steam generators removal, transport, and disposal at US Ecology and at Barnwell are summarized in Table F.8. The total cost for these activities is estimated at about $15.3 million at US Ecology and about $39.4 million at Barnwell, including a 25% contingency.

Table F.8 Summary of estimated costs for steam generators dismantlement and disposal activities at US Ecology and at Barnwell

Cost item	Estimated cost ($)(a)	
	US Ecology	Barnwell
Phase 1 - Precursor Tasks:(b)		
Items 1 through 5	--(c)	--(c)
Item 6 Fuel Bldg. Roof Preparations(d,e)	31,486	31,486
Item 7 Barge Slip Preparations(d)	110,250	110,250
Item 8 Job Training Program(f)	208,885	208,885
Phase 2 - Preparatory Activities:(g)		
Labor	1,547,811	1,547,811
Phase 3 - Removal Activities:(h)		
Labor	2,078,495	2,078,495
Phase 4 - Heavy Lift Rigging, Transport, and Disposal Activities:		
Subcontractor Labor & Equipment	2,765,455(i)	2,924,703
Hanford Site Support Services:(j)	529,200	0
Disposal of Radioactive Materials:		
Steam Generators (4)	1,699,735	13,948,648(k)
Compressible Dry Active Waste (DAW)	204,885	1,099,485
Non-Compressible DAW	745,023	3,508,804
Insulation(l)	875,177	4,646,119
Steam Generator Transport System:(m)		
Upender	27,600	27,600
Low-Profile Saddle	55,100	55,100
Transfer Skid	198,500	198,500

Table F.8 (Continued)

Cost item	Estimated cost ($)[a] US Ecology	Estimated cost ($)[a] Barnwell
Frame Trailer with Shipping Cradle(2)	496,200	496,200
Materials and Equipment[n]	374,735	374,735
Protective Clothing & Equipment Services[o]	227,212	227,212
Subtotal	12,175,749	31,484,033
Contingency (25%)	3,043,937	7,871,008
Total	15,219,686	39,355,041

(a) Values are in constant 1993 dollars. The number of significant figures is for computational completeness and does not imply accuracy to that many significant figures.
(b) See Table F.2 for details concerning Items 1 through 8.
(c) Precursor Tasks 1 through 5 are accounted for elsewhere in this study and are not costed in this table to avoid double counting.
(d) For purposes of this study, this item is considered to be a cascading cost (see Table F.2, footnote (b) for additional details).
(e) Labor and materials associated with both the removal and the reinstallation of the Fuel Building roof are included in this cost estimate.
(f) Included in Period 4 undistributed costs.
(g) See Table F.3 for itemized task descriptions and estimated labor hours.
(h) See Table F.5 for itemized task descriptions and estimated labor hours.
(i) See Table F.11 for itemized cost breakdown of subcontractor cost components.
(j) See text, Section F.7, for details concerning these costs.
(k) See Table F.10 for details.
(l) Assumes all insulation is contaminated and no compaction.
(m) Included in steam generator transport costs.
(n) Comprised of scaffolding and shielding, included in steam generator removal cost.
(o) Based upon discussions with industry personnel, these services are estimated to be approximately $21/day/person, included in laundry services, Period 4 undistributed costs.

Phase 1, Item 6, Fuel Building Roof Preparations, shown in Table F.8, is estimated to cost approximately $31,500, based upon information contained in References 6 and 7. It is estimated that one large structural support beam and 5 smaller roof support beams as well as about 317 m^2 of roofing material must be removed (to allow room for the Phase 4 contractor to extract the steam generators) and replaced (to provide adequate weatherization for storage of the Fuel Building and/or subsequent re-use of the building by the utility). For purposes of this study, this cost is considered to be a cascading cost (see Table F.2, footnote (b) for details).

The dredging cost (Phase 1, Item 7 shown in the table) is a study estimate, based on discussions with industry personnel. The job training costs (Phase 1, Item 8 shown in the table) for the Phase 2 and 3 staff is based upon one week's training at the labor rates given in Table F.4. The literature review conducted as part of this reevaluation study indicates that training programs are highly successful in maximizing the productivity and reducing person-rem exposure. In addition to basic project introduction as well as security and health physics indoctrination, medical examination, whole body count, and respirator fit test, the training program is postulated to include detailed activity training, including mockup training for selected activities. Remote TV and video tapes of actual work may be used during the training to fine tune crew performance on special activities.

The decommissioning operations contractor (DOC) labor costs (Phases 2 and 3 in Table F.8), over the estimated 4.1-month removal period, are derived from the average cost per crew hour, based upon the crew compositions discussed previously in Section F.4, and include an additional 10% for second shift operations, where applicable.

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 steam generators, to the low-level waste burial ground operated by US Ecology, Inc. 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, resulting in a total cost of $529,200 for these services for the four steam generators.

Three distinct waste forms require disposal during the steam generator removal project: 1) the steam generators themselves, which are shipped in one piece, one to a barge, 2) dry active waste (DAW), both compressible and non-compressible, and 3) the insulation that was removed from the steam generators. The steam generators and the dry active waste are anticipated to be shipped to the U.S. Ecology, Inc. commercial low-level waste burial ground at Hanford. The insulation is packaged in Sea-Vans for unshielded shipment to Hanford as discussed previously in Section F.4.3. As can be seen from Table F.8, disposal of radioactive materials at Hanford is estimated to cost approximately $3.5 million. The disposal costs shown in the table for DAW and insulation include the container, transportation, and burial costs. The costs for the four steam generators shown in the table represent only the burial costs. Transportation costs for the steam generators are accounted for in the total shown for Phase 4. The direct labor costs for removing and packaging these materials are accounted for in the Phase 2 and Phase 3 labor costs. A detailed breakdown of the disposal costs at US Ecology for these items is presented in Table F.9.

Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B) and upon vendor information concerning heavy-haul and barge transport, the total estimated cost for disposal at Barnwell for the aforementioned three distinct waste forms from the steam generator removal project is about $23.2 million (see Table F.10 for details).

The steam generator transport system (consisting of an upender, low-profile saddle, transfer skid, and frame trailer with shipping cradle) cost is a study estimate, based on discussions with industry personnel. The materials and equipment cost given in Table F.8 includes $94,800 (without contingency) for the purchase and installation of two drum compactors for the project. Protective clothing and equipment services are anticipated to be provided by an offsite subcontractor for the duration of the steam generator project, at an estimated cost of $21 per day per person, based on discussions with industry personnel.

A summary of the contractor costs (presented as Phase 4 costs in Table F.8) and schedule for removal, handling, and transport of the steam generators to the U.S. Ecology, Inc., commercial disposal site at Hanford is presented in Table F.11. It can be seen from the table that the contractor's total time onsite - including mobilization, removal of four steam generators, and demobilization - is estimated at 2 months, which is the basis for the equipment rental costs shown in the table. To scope the work, schedule the Lampson TransiLifts (LTLs), develop the plans, procedures, training requirements and calculations associated with the removal, handling, and transport of the steam generators, a minimum 6-month lead time is estimated to be required. Contractual approval by the utility/DOC is assumed to be required for all contractor activities. Security measures required during the steam generator removal project are assumed to be the responsibility of the utility.

Table F.9 Estimated costs for disposal of radioactive materials at US Ecology from steam generator removal project

Component	No. of disposal containers	Container costs ($)(a)	No. of shipments	Transport costs	Disposal		Total disposal cost ($)
					Volume (ft^3)	Cost ($)(b)	
Steam Generators	4(c)	--(d)	2(e)	--(f)	32,520	1,699,735	1,699,735
DAW, Compressible	504(g)	13,583	6	7,991	3,780	183,311	204,885
DAW, Non-Compressible	124(h)	79,980	21	21,730	11,904	643,313	745,023
Insulation	12(i)	43,800	6	7,991	16,320	823,386	875,177
Totals	644	137,363	35	37,712	64,524	3,349,745	3,524,820

(a) Based on information in Section B.4 of Appendix B.
(b) Based on information in Section B.7 of Appendix B; includes all surcharges, taxes, and fees, as applicable.
(c) Packaged as own container, openings welded closed, placed in shipping cradle.
(d) Not applicable.
(e) Shipped by barge, see text for details.
(f) Included with Phase 4 costs, see Table F.10 for details.
(g) Drums; see Section B.4 of Appendix B for details.
(h) B-25 containers; see Section B.4 of Appendix B for details.
(i) Sea-Vans; see Section B.4 of Appendix B for details.

Table F.10 Estimated costs for disposal of radioactive materials at Barnwell from steam generator removal project

Component	No of disposal containers	container costs ($)(a)	No. of shipments	Transport costs	Disposal		Total disposal cost ($)
					Volume (ft^3)	Cost ($)(b)	
Steam Generators	4(c)	--(d)	4(e)	4,755,000(f)	32,520	9,193,648	13,948,648
DAW, Compressible	504(g)	13,583	6	25,929	3,780	1,059,973	1,099,485
DAW, Non-Compressible	124(h)	79,980	21	90,752	11,904	3,338,072	3,508,804
Insulation	12(i)	43,800	6	25,929	6,320	4,576,390	4,646,119
Totals	644	137,363	35	4,897,610	64,524	18,168,083	23,203,050

(a) Based on information in Section B.4 of Appendix B.

(b) Based on information in Section B.7 of Appendix B; includes all surcharges, taxes, and fees, as applicable.

(c) Packaged as own container, openings welded closed, placed in shipping cradle.

(d) Not applicable.

(e) Shipped by barge.

(f) Included: $3.0 million barge costs; $0.6 million bridge ramp costs; $0.075 million Barnwell ramp cost; $0.11 million barge slip preparations at Savannah; $0.265 million Savannah site movement costs (assumed similar to Hanford site movement costs); $0.3 million offloading and transport to Barnwell costs; $0.4 million for NRC Certificate of Compliance for steam generators as Type A, LSA transportion on open waterway; and about $5,000 in permit costs.

(g) Drums; see Section B.4 of Appendix B for details.

(h) B-25 containers; see Section B.4 of Appendix B for details.

(i) Sea-Vans; see Section B.4 of Appendix B for details.

Table F.11 Summary of estimated contractor costs and schedule for removal, handling, and transport of the steam generators to Hanford(a)

Component	Estimated cost (1993 $)	Estimated time (as shown)
Mobilization for shipment to reference PWR:	--	2 weeks
Labor	65,070	--
Transportation Inbound	93,713	--
Mobilization of Equipment at reference PWR:	--	2 weeks
Labor	65,070	--
Remove 4 each Steam Generators/Loadout Aboard Barge:	--	4 weeks
Labor	125,729	--
Mobilization for shipment to Hanford Burial Site:	--	2 weeks
Labor	65,070	--
Transportation Inbound	93,713	--
Mobilization of Equipment at Hanford:	--	2 weeks
Labor	65,070	--
Receive 4 each Steam Generators at Port of Benton/Transport to Hanford Burial Site and Offload:	--	2 weeks
Labor	65,070	--
Demobilize Equipment at Reference Plant:	--	2 weeks
Labor	65,070	--
Transportation Outbound	93,713	--
Demobilize Equipment at Hanford Burial Site:	--	2 weeks
Labor	65,070	--
Transportation Outbound	93,713	--
Major Equipment at Reference Plant:	--	(b)
1. 100-ton Truck Crane	18,743	--
2. 200-ton Crawler Crane	28,665	--
3. 550-ton Trailer System	79,380	--
4. 550-ton Prime Movers	37,485	--
5. LTL-900-ton Crane	275,625	--
Major Equipment at Hanford Burial Site:	--	(b)
1. 100-ton Truck Crane	18,743	--
2. 200-ton Crawler Crane	28,665	--
3. LTL-900-ton Crane	275,625	--

Table F.11 (Continued)

Component	Estimated cost (1993 $)	Estimated time (as shown)
Major Equipment/Tidewater Barge Lines (50 ft x 200 ft Barge with Tug Boats)	--	[c]
Transportation Cost (Reference Plant to Port of Benton, 4 trips)	177,504 $1,896,504	--
(30% Markup)	568,951	
Grouting of Steam Generators	300,000	4 weeks
Estimated Total Cost	$2,765,455	--

(a) Based on letters: (1) William N. Lampson, Neil F. Lampson, Inc., to George J. Konzek, Battelle Northwest, transmitting rough-order-of-magnitude data on decommissioning costs for steam generators removal from the reference PWR, dated January 31, 1992; (2) Paul Parish, Neil F. Lampson, Inc., to George J. Konzek, Battelle Northwest, transmitting updated cost information on decommissioning costs for steam generators removal from the reference PWR, dated April 6, 1993.

(b) Based on 2 months rental cost for each piece of equipment.

(c) Based on travel times of about 39 hours upstream per trip and about 35 hours downstream per trip.

F.8 Discussion

It was determined in Reference 1, and again in this analysis, that specific steam generator repair/replacement cost data were generally not available, due to the inherently proprietary nature of this highly competitive type of reactor outage work in the U.S. However, the estimated costs and conditions for removal of a steam generator during decommissioning can be much more sharply defined now than they could be in earlier studies.

The activities associated with the removal process are no longer first-of-a-kind, but rather reflect direct applications of developed techniques and equipment. Recent learning experiences can be used to guide the industry in planning for future steam generator removal operations.

While relevant information on steam generator removal during reactor outages is now available, similar information from actual decommissioning experience is still largely unavailable. From the experience base reviewed in Reference 1 and again for purposes of this analysis, it is clear that (1) precise estimates of occupational doses for this type of large-component removal during decommissioning will probably remain uncertain because of the uncertainties in the exact procedures which could be utilized (e.g., harsher decontamination methods and more extensive dismantling operations could be used in decommissioning than would be allowed during a replacement project); and (2) the feasibility as well as the practicality of the reactor-specific procedures concerning steam generator removal will remain primary considerations for decommissioning planners, since the estimated occupational dose is highly dependent on the degree and manner of decommissioning envisioned.

In general, it is concluded that dose reduction during decommissioning, relative to recent steam generator repair/replacement projects at the U.S. operating power plants examined in this study, would be attributable to:

- Essentially no channel head or manway entries required for decommissioning.
- Chemical decontamination of the RCS, including the steam generators, which is anticipated to significantly reduce both contact and background radiation dose rates for decommissioning workers. Chemical decontamination processes for the RCS will be dictated by cost, decontamination effectiveness, and radioactive waste management considerations during decommissioning. However, if a significant reduction in worker dose is to be achieved, the value of chemical decontamination of the RCS cannot be overemphasized in the steam generator removal process during immediate dismantlement.
- Partially filling the steam generators with water for shielding after the chemical decontamination task, thus providing further reductions in background radiation during the initial preparatory and the actual removal cutting operations. This preparatory ALARA step also was done at Surry, Turkey Point, and H. B. Robinson.
- Removal of each steam generator in one piece (or in as few pieces as possible), thus minimizing the cutting and welding operations inside containment.

It is further concluded that, historically, it appears that a combination of poorly-defined data, controversial assumptions, and modeling difficulties for large-component removal projects have often resulted in significantly different occupational radiation doses than originally estimated. It seems reasonable, therefore, that the actual occupational radiation doses for steam generator changeout projects at operating PWRs in the future can probably be expected to continue to vary for a variety of reasons. It is anticipated that the occupational radiation dose during decommissioning will also vary considerably from plant to plant. In all cases, the total dose for this large-component removal operation is sensitive to (1) the amount of preparations required; (2) the quality and thoroughness of the preparations; (3) the degree of success of the chemical decontamination campaign; (4) the duration and working conditions; (5) the steam generator design and other plant-specific conditions; (6) the technology applied, involving to a large extent the need for and the successful use of purpose-built tools and equipment; (7) the removal methodology employed; (8) the skills of properly trained and qualified workers; (9) the degree of success of the management commitment to maintain the occupational doses within the 10 CFR Part 20 limits and as low as reasonably achievable (ALARA).

One potential change identified in Reference 1, and reaffirmed again in this analysis, is that fewer segmentation cuts per steam generator may be required for removal during decommissioning than were envisioned in NUREG/CR-0130. For decommissioning planners, additional emphasis is recommended on the initial general cleanup and decontamination of containment as well as on the periodic housekeeping and decontamination of walkways, platforms, tools, and equipment. All of these activities will be beneficial in reducing worker skin contamination, airborne radioactivity, and the need for respiratory-protection devices during steam generator removal projects.

In summary, there are definite advantages to removing and transporting steam generators in one piece, if possible, including reduced radiation exposure and a shorter overall schedule duration. Other factors include crane and crane support capacities, space limitations, architectural clearances, and transportation routing considerations.

F.9 References

1. G. J. Konzek and R. I. Smith. 1988. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule*. NUREG/CR-0130, Addendum 4, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station*. NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

3. *Nuclear Engineering International*. "Point Beach 1 Steam Generators Replaced Ahead of Schedule." pp. 38-42, January 1985.

4. D. F. Johnson. "Health Physics and Exposure Management Aspects of the Point Beach Nuclear Plant Steam Generator Replacement Project," Paper presented at the Westinghouse Radiation Exposure Management Seminar, October 2, 1984, Pittsburgh, Pennsylvania.

5. T. S. LaGuardia, et. al. 1986. *Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates*. AIF/NESP-036, Atomic Industrial Forum, Inc. Report by TLG Engineering, Inc., Brookfield, Connecticut.

6. "Building Construction Cost Data 1993," Robert Snow Means Company, Inc., Kingston, Massachusetts.

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

Appendix G

Decommissioning Methods

Appendix G

Decommissioning Methods

Methods, equipment, and disassembly procedures postulated to be used to accomplish various decommissioning activities at nuclear facilities, such as the reference pressurized water reactor (PWR), were discussed in considerable detail in NUREG/ CR-0130.(1) Some of those methods are no longer state-of-the-art, other methods/techniques have seen improvements, some never fully materialized 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 and is not repeated here. Decommissioning methods used in this reevaluation study are presented in this appendix, together with the development of selected cost estimates that are not presented elsewhere in this reevaluation study. The information is presented in the following order:

- system decontamination
- surface decontamination
- removal techniques and equipment
- water treatment and disposal.

G.1 System Decontamination

For the purpose of this reevaluation study, the full-system chemical decontamination (recirculatory method) is used where dilute chemical decontamination solutions can be recirculated 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 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, who specialize in chemical decontamination services and are currently under contract to Consolidated Edison of New York to perform the first full-system decontamination of a commercial PWR in the U.S..

The major contributors to the estimated total cost and occupational radiation exposure (worker dose) for full-system chemical decontamination at the reference PWR are summarized in Table G.1. The total cost for these activities is estimated at about $14 million, not including contingency. The total worker dose is estimated to be about 46 person-rem.

---

[1] To date there is insufficient operating data to accurately compare arc saw cutting to other more conventional means. This technique could well provide a viable method for segmenting components; operating data from experimental or prototype units should be evaluated when available.(2)

Table G.1 Summary of estimated costs and radiation dose for full-system chemical decontamination of the reference PWR

Cost item	Estimated cost (1993 $)[a]	Estimated dose (person-rem)
1. Deboration of the Primary Coolant by the Utility:[b,c]		
a. Labor	usc[d]	3.6
b. Energy (Oil)	64,900[e]	--[f]
2. Chemical Decontamination;		
a. Fixed-cost Contract (Specialty Contractor)[g]	12,500,000	12
b. Utility Support	usc	28
3. Disposal of Radioactive Materials from Chem Decon:		
a. 18 High-Integrity Containers	404,498[h]	--[i]
4. Electricity[j]	238,000[f]	--
5. Water Treatment/Release:[c]		
a. Fixed-Cost Contract (Specialty Contractor)[g]	750,000	~ 2
b. Utility Support	usc	--
6. Disposal of Radioactive Materials from Water Treatment:[c]		
a. 5 High-Integrity Containers	61,803[k]	<0.1
7. Protective Clothing & Equipment Services (vendor only)[l]	22,176	--
Totals (w/o contingency)	14,041,377	~45.7

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) A pretreatment conditional step considered necessary for optimal results from the subsequent chemical decontamination operations.
(c) Even without chemical decontamination, this step would be necessary during decommissioning.
(d) "usc" indicates that costs are included in the utility staff costs during this period.
(e) Included in Period 2 undistributed costs.
(f) A dash means not applicable, unless indicated otherwise.
(g) See text for details.
(h) 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 given in Step 3.a. is $1,731,780.
(i) Included in Utility Support.
(j) Assumes the use of various pumps, including the 4 primary pumps, for about 2 weeks consumes approximately 7 x 10^3 MWh of electricity, as described in NUREG/CR-0130.[1]
(k) 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 5 HICs given in Step 6 is $373,800.
(l) Based upon discussions with industry personnel, these services are estimated to be approximately $21/day/person for rad-zone workers only. Included in Period 2 undistributed costs.

The assumptions used in these reevaluation analyses are described below, followed by a general discussion of the estimated cost, worker dose, volumes of radwastes, and schedule associated with the full-system chemical decontamination of the reference PWR.

G.1.1 Assumptions

In developing the chemical decontamination scenario and the subsequent analysis, the following assumptions were used:

- The PWR primary system components description and radioactive inventory were taken from NUREG/CR-0130.
- Full-system chemical decontamination of PWRs by a specialty contractor (vendor) is postulated to be routine work by the time this operation commences at the reference PWR (i.e., it is assumed that at least three such campaigns have been successfully completed prior to the reference PWR campaign).
- The full-system chemical decontamination will be completed during the first year following final shutdown, after defueling of the reactor and deborating of the primary coolant water (to less than 100 ppm) by the utility.
- 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 worker 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 PWR 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 PWR, 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 PWR wastes at the Barnwell site in Barnwell, South Carolina.

G.1.2 Discussion

Just as in NUREG/CR-0130,(1) the principal systems considered for chemical decontamination in this reevaluation study are the reactor coolant system (RCS), the chemical volume control system (CVCS), 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 the aforementioned 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, significant radiation exposures would be encountered if the plant had not been previously decontaminated. It should be noted that even without chemical decontamination, the amounts given for Cost Items 1. and 5. (i.e., deboration and water cleanup prior to release) 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 the CVCS will be isolated from the spent fuel pool system. All possible branches of the CVCS 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 Pacific Nuclear Services (PNS), located in Richland, Washington. 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) since no commercial PWR has yet undergone a full-system chemical decontamination in the United States, a first-of-a-kind (FOAK) full-system chemical decontamination of a PWR could cost in the range of $20 to $25 million. However, when such decontaminations of PWRs become "routine" (defined here as after at least 3 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 for the resultant waste, and transportation costs, but not final burial costs of the high-integrity containers (HICs).

Based upon the information obtained from Pacific Nuclear 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 PWR. About 2 months are 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 containment 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 45.7 person-rem has been assigned to this work.[2]

---

[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.

- 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 the assumptions, it is calculated that each HIC contains approximately 278 curies.

Under the postulated conditions just described and based upon disposal cost information provided by U.S. Ecology for the Richland, WA, site (see Appendix B), the total estimated burial cost for the 18 HICs given in Step 3.a. in Table G.1 is $404,498. 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 given in Step 3.a. in Table G.1 is $1,731,780.

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, Step 5, the cost for final water treatment is estimated at $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 ORE 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 required. Based upon disposal cost information provided by U.S. Ecology for the Richland, WA, site (see Appendix B), the cost of subsequent disposal of the HICs (Step 6 in Table G.1), estimated at $61,803,[3] is assumed to be the responsibility of the utility. 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 5 HICs given in Step 6 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; deborating the primary system water; 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 BWRs. However, the author states that the information presented is applicable to both BWRs and to PWRs. This study's approach is similar. Typical support staff for the reference PWR are assumed to include:

---

[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.

Position	Estimated number required
Station Project Manager (days) or Responsible Engineers (1/shift)	3
Plant Technical Support (1/shift)	3
Head Liaison Engineer (1/shift)	3
Consultant (1/shift)	3
Dedicated Health Physics Support (2/shift)	6
One Chemist Plus One Chemical Technician/Shift	6
Pipe fitters (2/shift on standby)	6
Instrument Technician (1 each/shift on standby)	3
Electrician (1 each/shift on standby)	3
Laborers (2/shift on standby)	6

The aforementioned persons are part of the existing Period 2 utility staff.

In addition, Pacific Nuclear 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 PWR is not postulated to be chemically decontaminated before disassembly.

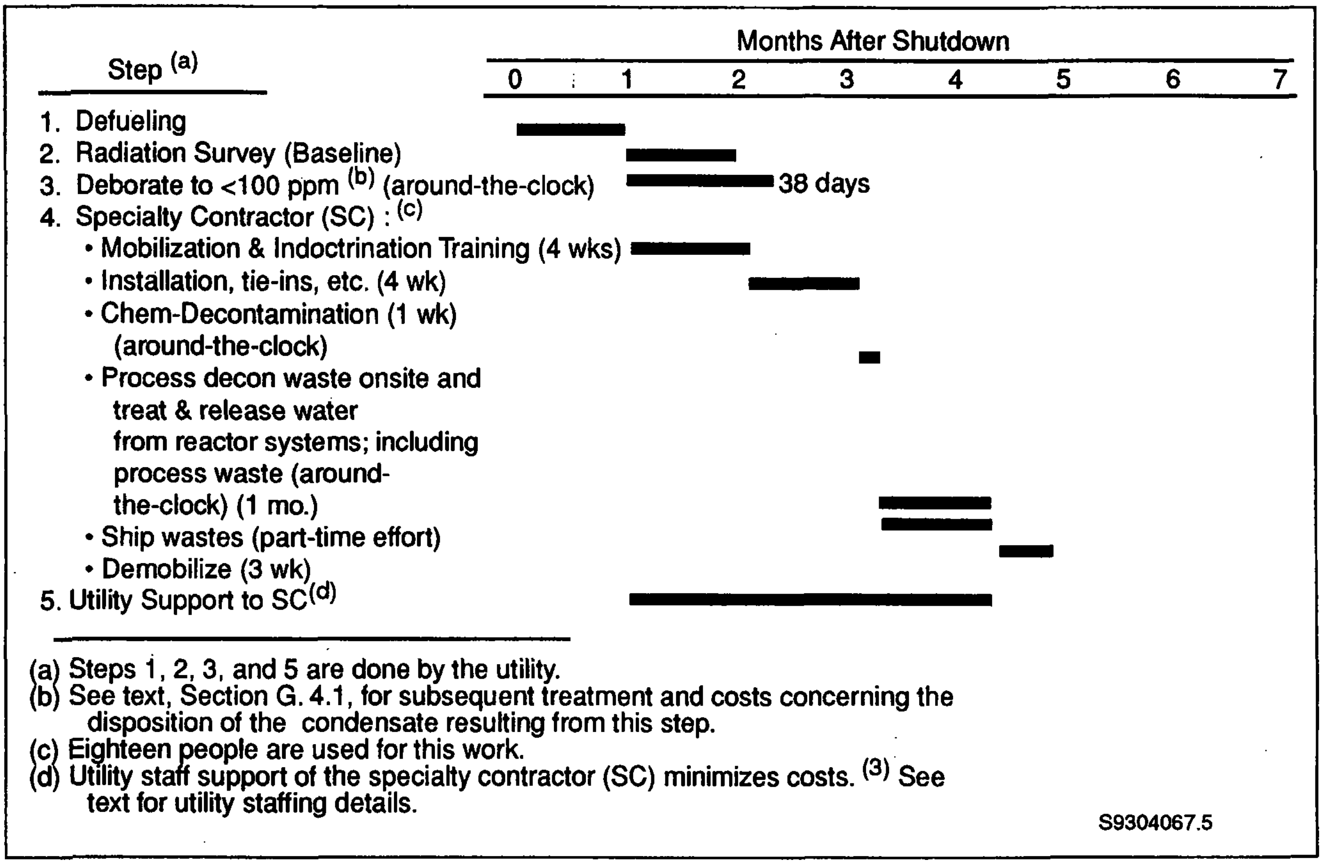
G.1.3 Estimated Task Schedule and Sequence

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. Only a brief discussion of the water-jet/vacuum decontamination activity is presented in this section, since the specifics associated with this activity are described in detail in Appendix C. Likewise, the costs per square foot of surface cleaned are developed in Appendix C and are not repeated here.



(a) Steps 1, 2, 3, and 5 are done by the utility.
(b) See text, Section G. 4.1, for subsequent treatment and costs concerning the disposition of the condensate resulting from this step.
(c) Eighteen people are used for this work.
(d) Utility staff support of the specialty contractor (SC) minimizes costs. (3) See text for utility staffing details.

Figure G.1 Estimated task schedule and sequence for chemical decontamination

G.3 Removal Techniques and Equipment

The various removal techniques and equipment used in this study for the removal of contaminated and uncontaminated structural materials are discussed below.

G.3.1 Removal of Contaminated Concrete Surfaces

Those contaminated horizontal surfaces that are not sufficiently decontaminated using the high-pressure washing system (see Section 1.1.1) are removed using a commercially available pneumatically operated surface chipper removal system. Commercial systems that 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 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 (i.e., a cut 1-inch deep, 1 foot long, equals 1 inch-foot). Based on 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 and are not repeated here.

G.3.3 Removal of Cranes

The Containment Building polar crane and the Fuel Building crane are anticipated to be disengaged from their 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 from each of the cranes will be packaged and shipped to the low-level waste disposal site at Hanford. In both buildings, these are the last scheduled decommissioning activities to occur before the license termination survey commences.

The major contributors to the estimated total cost of cranes removal, decontamination operations, and transport are summarized in Table G.2. The total cost of these activities is estimated at about $616,000, including a 25% contingency.

The estimated removal/labor costs and schedules for the removal of the Containment Building crane and the Fuel Building crane are discussed below. Two conceptual methods for the removal of the Containment Building crane are presented in Table G.3 (Method 1) and Table G.4 (Method 2), respectively, with the conceptual methods depicted in Figure G.2 (Method 1) and Figures G.3 and G.4 (Method 2), respectively. The postulated work plan associated with each method is included with the respective figures. For the purpose of this study, Method 2 at $237,020 is selected over Method 1 at $229,100 as the preferred choice because of the lesser manpower commitment, better schedule (i.e., fewer days to do the project), and because the Containment Building roof is not violated and thus subsequent repair costs are avoided.

Table G.2 **Summary of estimated costs for dismantlement and disposal of the polar crane and the Fuel Building bridge crane**

Cost item	Estimated cost (1993 $)[a]
Removal of Reactor Bldg. Polar Crane Using Method 2[b]	237,020
Removal of Fuel Bldg. Crane[c]	75,780
Decontamination/Survey of Cranes[d]	15,083
Disposal of Radioactive Materials:	
Maritime Containers (2)	7,300[e]
Transportation (2 OWT shipments)	2,837[f]
Disposal	153,206[g]
Subtotal	491,226
Contingency (25%)	122,807
Total	614,033

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) See Table G.4 and Figures G.2 and G.3 for details concerning Method 2 removal activities.
(c) See Table G.5 for details.
(d) Based on Table G.6 staffing and labor rates.
(e) Based on Table B.2 in Appendix B.
(f) Based on direct quote from Tri-State Motor Transport Co. for two OWT shipments from Trojan plant to the low-level waste burial ground at Hanford. With Barnwell as the disposal site destination, the transportation costs are estimated at $15,688, based on a direct quote from Tri-State Motor Transport Co.
(g) Based upon disposal cost information provided by Chem-Nuclear Systems, Inc., the total estimated disposal cost for the waste at the Barnwell site is $770,102.

Table G.3 Summary of estimated contractor costs, manpower, and schedule for removal of the Containment Building polar crane using method 1[a]

Method 1 - Using center hole jacks & associated equipment[b]

Component	Manpower	Estimated cost (1993 $)[c]	Estimated time days[d]
Equipment[e]	--	132,300	--
Labor:			
Jack Installation and Disassembly (2 ea.)	4 people	42,240	24
Remove Corbel	4 people	8,800	5
Lower Bridge Crane	4 people	1,760	1
Disassemble Bridge Crane[f]	8 people	35,200	10
Closure of Center Holes	5 people	8,800	4
Totals, Method 1		229,100	44

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.
(b) See Figure G.1 for postulated work plan.
(c) $55/person-hour is used in the calculations to estimate built-up job cost.
(d) Assumes 1-shift per day operations; 2-shifts per day would halve these values.
(e) Includes mobile crane and manbasket, center-hole jacks, and associated equipment.
(f) This step also includes removal and packaging of the trolley drum and cable (~40,000 lb) for subsequent shipment in a maritime container to the low-level waste disposal site at Hanford.

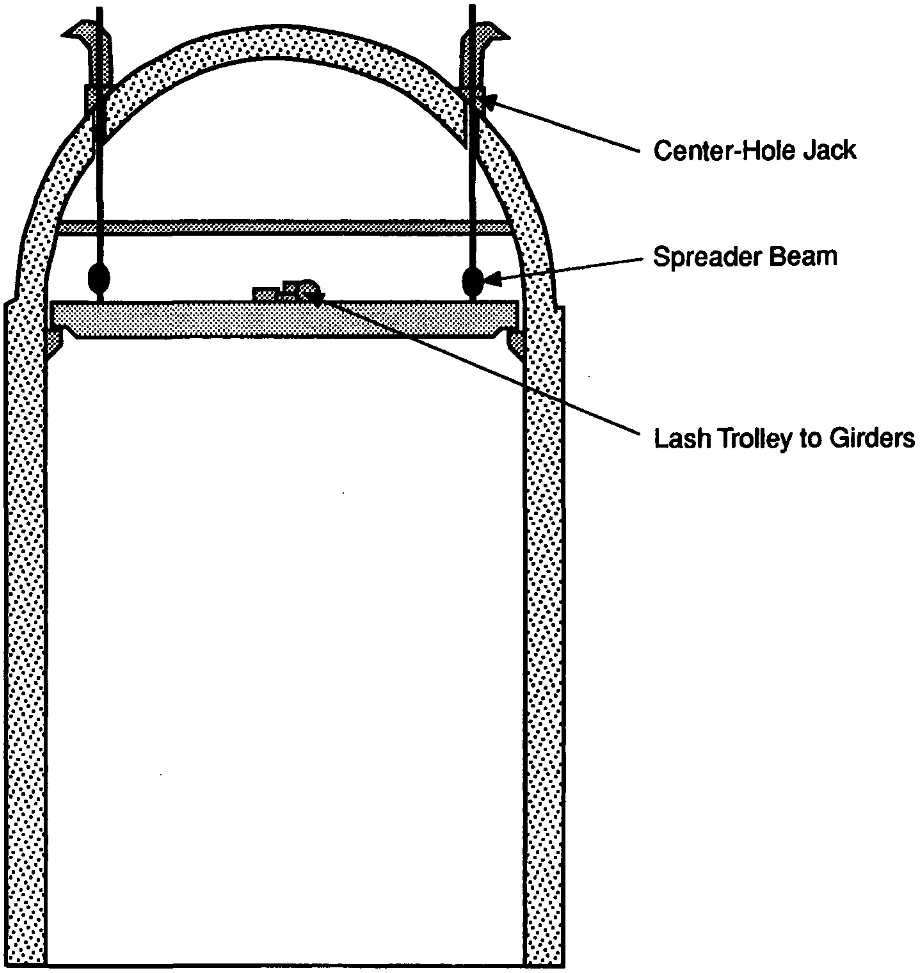
Table G.4 Summary of estimated contractor costs, manpower, and schedule for removal of the Containment Building polar crane using method 2[a]

Method 2 - Using bar climber and associated equipment[b]

Component	Manpower	Estimated cost (1993 $)[c]	Estimated time days[d]
Equipment[e]	--	132,300	--
Labor:			
Tower Erection (4 ea.)	8 people	35,200	10
Lifting Bridge	5 people	1,650	0.75
Remove Corbel	4 people	8,800	5
Lower Bridge	5 people	2,750	1.25
Disassemble Bridge Crane[f]	8 people	35,200	10
Tower Disassembly (4 ea.)	8 people	21,120	6
Totals, Method 2		237,020	33

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.
(b) See Figures G.2 and G.3 for details.
(c) $55/person-hour is used in the calculations to estimate built-up job cost.
(d) Assumes 1-shift per day; 2-shifts per day would halve these values.
(e) Includes bar climber and associated equipment.
(f) This step also includes removal and packaging of the trolley drum and cable (~40,000 lb) for subsequent shipment in a maritime container to the low-level waste disposal site at Hanford.

Center Hole Jacking



S9304067.1

Work Plan:

Secure the trolley to bridge girders.

Using the center hole jacks, raise the bridge crane assembly to the limits allowed by overhead clearances.

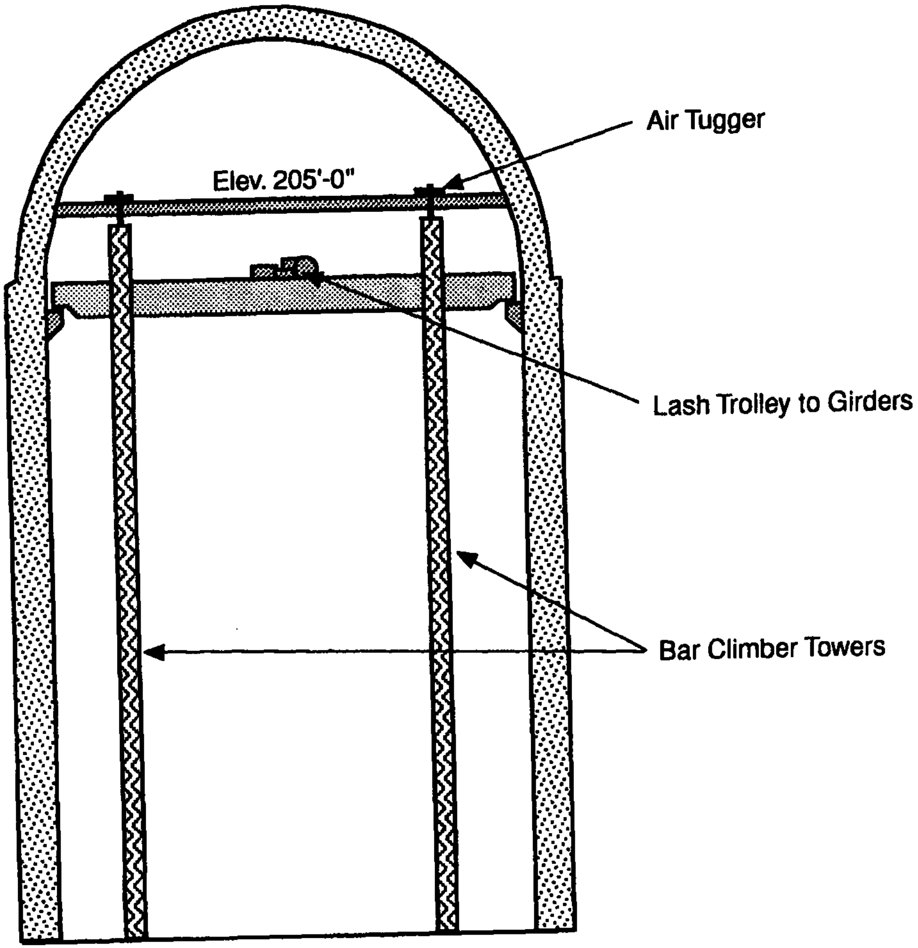
Using linear charges, remove the concrete corbel and rail.

Lower the bridge crane using center hole jacks, the crane may act as a work platform to remove any remaining rebar, etc. to allow the crane to pass the corbel

Using the centerhole jacks, lower the bridge crane to grade.

Figure G.2 Conceptual decommissioning plan for the polar crane using method 1

Bar Climber



Work Plan:

Using polar crane, assemble bar climbing towers to the upper hook limit.

Using air tuggers mounted at elevation 205'-0", set the top tower sections.

Using the polar crane, set a bar climber header beam between each of the two sets of towers at ground elevation.

Lash the trolley to the bridge girders.

Raise the bar climber/header assembly and lift the bridge girders.

Using linear shape charges, remove a section of the corbel and rail.

Using the bar climbers, lower the bridge girders to ground elevation.

Figure G.3 Conceptual decommissioning plan for the polar crane using method 2, Part 1

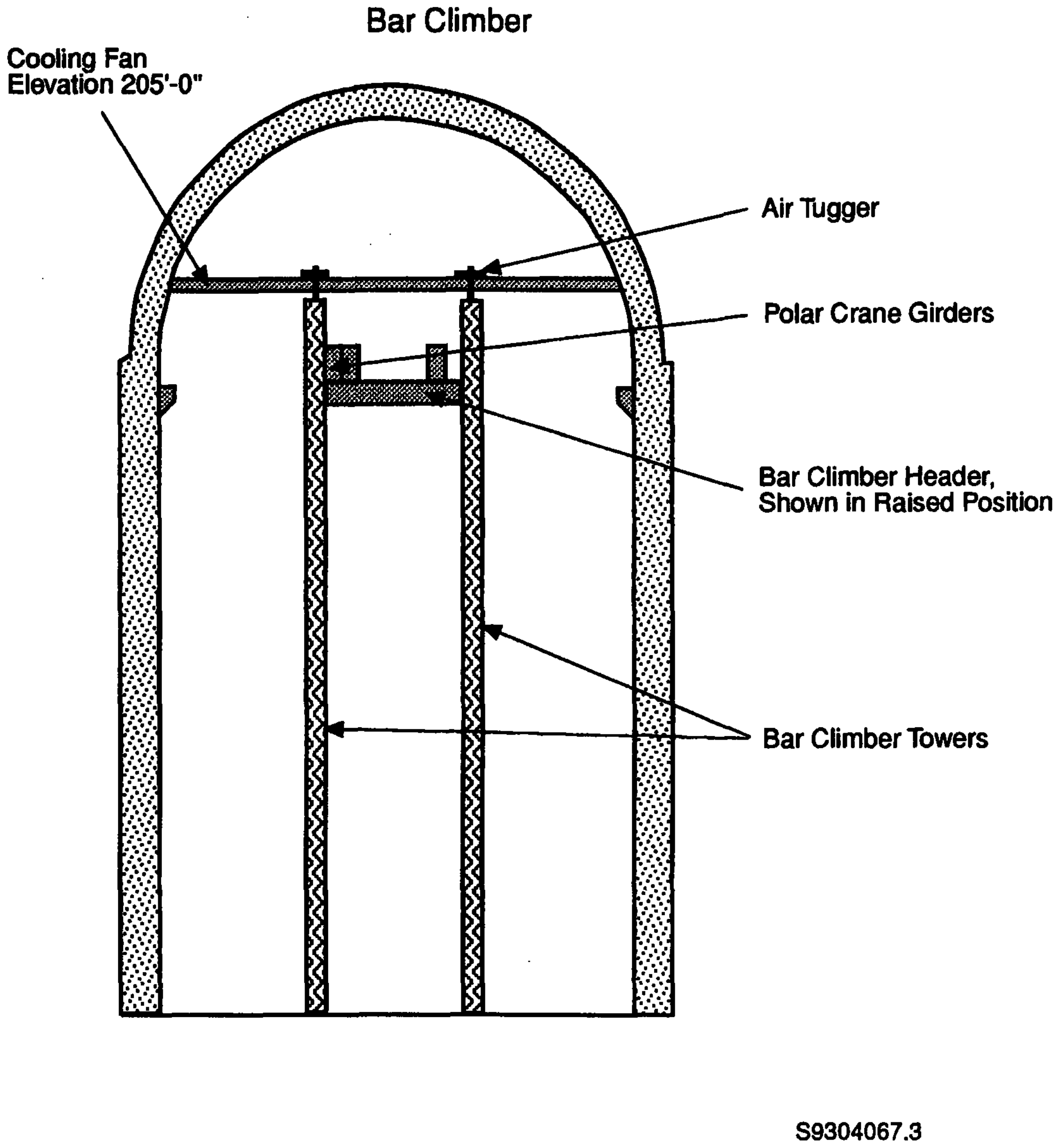


Figure G.4 Conceptual decommissioning plan for the polar crane using method 2, Part 2

The estimated removal/labor costs and schedule for the removal of the Fuel Building crane are given in Table G.5. The postulated method used for the removal of the crane is illustrated in Figure G.5. The estimates presented in the tables are based upon information provided by Advanced Engineering Services.[4]

---

[4] Letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.

Table G.5 Summary of estimated contractor costs, manpower, and schedule for removal of the Fuel Building crane(a)

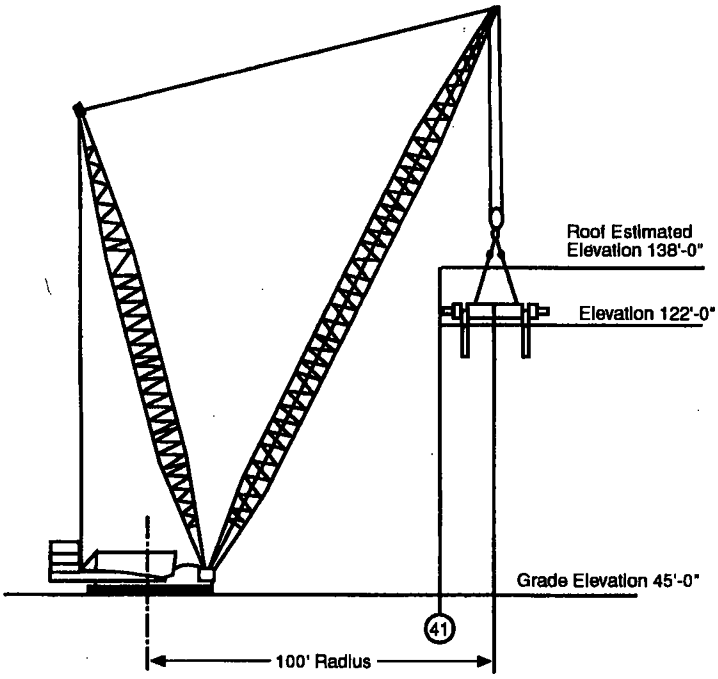
Component	Manpower	Estimated cost (1993 $)(b)	Estimated time days(c)
Equipment	--	22,050	--
Mobil./Demobilization	5 people	22,050	10
Labor:			
Rigging Operations	8 people	14,080	4
Mechanical Disassm.(d)	5 people	17,600	8
Totals		75,780	22

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.

(b) $55/person-hour is used in the calculations to estimate built up job cost.

(c) Assumes 1-shift per day operations; 2-shifts per day would halve these values.

(d) This step also includes removal and packaging of the trolley drum and cable (~40,000 lb) for subsequent shipment in a maritime container to the low-level waste disposal site at Hanford.



S9304067.4

Figure G.5 Conceptual decommissioning plan for the Fuel Building crane

After removal of the trolley drums and associated cables, the decontamination process is estimated to require one week for each of the cranes. It is estimated that two dedicated 5-person crews, working one crew on each of two shifts, will be required to complete these activities at a total cost of $15,083. Very little, if any, occupational radiation exposure is anticipated from these activities. Each crew is assumed to consist of the DOC staff listed in Table G.6.

Table G.6 Composition and exposure rates postulated for crane cleanup crews

Man-hrs/ crew-hr	Category	Labor rate ($/hr)	$/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[(c)]			$197.52	

(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.

G.4 Water Treatment and Disposal

Selected water treatment and disposal operations associated with decommissioning the reference PWR are described in this section.

G.4.1 Treatment and Disposal of the Concentrated Boron Solution

The deboration process (Cost Item 1. in Table G.1) is estimated to have resulted in the temporary storage of approximately 179,100 gallons of reactor grade boric acid solution. Pacific Nuclear's Radioactive Waste Volume Reduction System (RVR-800)™ or equivalent is presumed to be used by a vendor for the disposition of this borated water, at an estimated cost of $6 per gallon, resulting in a total cost of $1,074,600.[5] The end-product, a pelletized powder, will be packaged in sixty-four 55-gallon drums for subsequent transport to the low-level waste disposal facility at Hanford.

Based upon information contained in Appendix B, the cost for in-compact burial of these drums at U.S. Ecology is estimated at $23,278. Based upon information contained in Appendix B, the cost for out-of-compact burial of these drums at Barnwell is estimated at $134,600.

---

[5] Subsequent transportation costs for the resultant radioactive wastes are included in this unit cost estimate, but radwaste burial costs are the responsibility of the utility.

Assuming 10% equipment downtime, it is calculated that approximately 164 consecutive working days will be required to complete this task. Two 12-hour shifts, with three people per shift, are involved in these operations. A cumulative worker dose of about 3 person-rem is anticipated.

G.4.2 Spent Fuel Pool Water Treatment and Disposal

Upon reduction of the spent nuclear fuel inventory to zero, approximately 7 years after final shutdown (see Appendix D for details), 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 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 SFP and associated systems will be left dry.

This task is very similar in nature to Task 5, shown in Table G.1. Discussions with a qualified vendor have suggested that the estimated vendor's cost for this task 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). Protective clothing and equipment for vendor's staff are expected to cost the utility about $11,340.

Since the spent fuel pool 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, 1) a worker dose of approximately 2 person-rem is anticipated for these activities; and, 2) it is roughly estimated that about five 5.72 m^3 HICs could be required.

Based on information contained in Appendix B, the cost of five HICs is estimated at $39,125. The transportation cost for the HICs from the manufacturer to the plant site is estimated at $4,210, based on a direct quote from the Tri-State Motor Transport Company. Twenty-one days of cask rental charges come to an estimated $26,250. Burial costs at U.S. Ecology are estimated at $67,590. Burial costs at Barnwell are estimated at $373,800. The burial cost estimates are based on 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 worker dose for this activity is presented in Table G.7.

G.4.3 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 hence liquid radwaste generation, treatment, transport, and disposal) is 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 27,330 gallons of high solids, low activity waste solutions will result from the surface cleaning tasks at the reference PWR. 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 PWR. Based upon discussions with senior staff at Pacific Nuclear Services, the waste solutions are estimated to be processed for disposal (i.e., evaporated/solidified in seven 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 $293,300 for this fixed-price contract. Overall, about 36 days are required to complete the task, including mobilization/demobilization. Occupational radiation exposure is anticipated to be less than 0.7 person-rem.

Table G.7 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, Specialty Contractor[(b)]	750,000	~2
Transport of HICs, Plant Site from Mfgr.[(c)]	4,211	--[(d)]
High-Integrity Containers[(e)]	39,125	--
Cask Rental[(f)]	26,250	--
Transportation	--[(g)]	--
Burial[(h)]	67,590	--
Totals	887,176	~2
Protective Clothing & Equipment (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 U.S. Ecology. 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 5 HICs is $373,800.
(i) Included in laundry services, Period 4 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 $54,775; 25 days of cask rental come to $31,250; total transportation costs are estimated at about $24,350; and disposal costs at U.S. Ecology are estimated at $86,525. Burial costs at Barnwell are estimated at $513,275. The burial cost estimates are based on 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.8.

Table G.8 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, Specialty Contractor[b]	293,300	<0.7
Disposal of Radioactive Materials:		<0.1
High-Integrity Container[c]	54,775	
Cask Rental[d]	31,250	
Transportation[e]	24,343	
Burial[f]	86,525	
	196,893	—
Totals	490,193	~0.8

(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.2.

(d) Based on Table B.3.

(e) Based on direct quote from Tri-State Motor Transport Company. Includes transportation charges for the empty cask from Barnwell, SC to Trojan, the loaded casks from Trojan to Hanford, and the empty cask back to Barnwell, SC.

(f) Derived from information provided by U.S. Ecology. 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 7 HICs is $513,275.

G.5 References

1. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. T. S. LaGuardia and J. F. Risely. 1986. *Identification and Evaluation of Facilitation Techniques for Decommissioning Light Water Power Reactors.* NUREG/CR-3587, U.S. Nuclear Regulatory Commission Report by TLG Engineering, Inc., Brookfield, Connecticut.

3. EPRI NP-6023, Project 1329-3. 1988. *Chemical Decontamination Experience at Commonwealth Edison Nuclear Power Plants.* Electric Power Research Institute Final Report by Niagara Technical Consultants, Niagara Falls, New York.

4. D. M. Vandergriff. August 1987. *Evaluation of Recent Utility Experience With BWR Chemical Decontamination Technology.* EPRI Report NP-5515, Electric Power Research Institute, Palo Alto, California.

Appendix H

Mixed Wastes

Appendix H

Mixed Wastes

The estimated volume of mixed radioactive/hazardous waste (i.e., mixed waste)[1] and the costs associated with its removal, packaging, and either storage or disposal were not considered in the original decommissioning study on the reference pressurized water reactor (PWR).(1) Disposal of mixed wastes, especially solid mixed waste, generated by the commercial nuclear power industry in the United States is presently very difficult, if not impossible, since there are no disposal sites licensed for radioactive wastes and permitted for hazardous wastes. Consequently, licensees must store mixed wastes until a disposal site becomes available. The statutory and regulatory requirements, current NRC guidance on the management of mixed waste, what is currently being done to deal with the problem of mixed wastes, estimated production of mixed wastes during operation at selected light water reactors, the postulated production of mixed wastes during decommissioning at the reference PWR, and the estimated costs for storage and disposal of mixed wastes are discussed in this appendix. The conclusions of this appendix are presented in Section H.7.

H.1 Statutory and Regulatory Requirements

The U.S. Environmental Protection Agency (EPA) has authority under the Resource Conservation and Recovery Act (RCRA)[2] over the management of hazardous wastes. Radioactive material, as defined in the Atomic Energy Act (AEA), is excluded from the definition of solid waste in the RCRA. Accordingly, commercial use and disposal of source, byproduct and special nuclear materials, and wastes are regulated by the NRC to meet the environmental standards developed by EPA. Low-level radioactive wastes (LLW) containing source, byproduct, or special nuclear material that also contain chemical constituents which are hazardous under EPA regulations in 40 CFR Part 261, *Identification and Listing of Hazardous Waste* are referred to as Mixed Waste (mixed LLW).

The Low-Level Radioactive Waste Policy Amendments Act of 1985 defines LLW as radioactive material that (A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material as defined in section 11e(2) of the AEA (i.e., uranium or thorium mill tailings) and (B) the NRC classifies as LLW consistent with existing law and in accordance with (A). Listed hazardous wastes include hazardous waste streams from specific and non-specific sources listed in 40 CFR Parts 261.31 and 261.32 and discarded commercial chemical products listed in 40 CFR Part 261.33. If LLW contains a listed hazardous waste or non-AEA regulated materials that cause the LLW to exhibit any of the hazardous waste characteristics - ignitability (Section 261.21), corrosivity (Section 261.22), reactivity (Section 261.23), and toxicity, as determined using the Toxicity Characteristic Leaching Procedure (Section 261.24) - the waste is mixed LLW. The waste must be managed and disposed of in compliance with EPA's Subtitle C hazardous waste regulations in 40 CFR Parts 124, and 260 through 270, and NRC's regulations in 10 CFR Parts 20, 30, 40, 61, and 70. The generator is responsible for determining whether LLW contains listed or

---

[1] Mixed low-level radioactive and hazardous waste (mixed LLW) is defined as waste that satisfies the definition of low-level radioactive waste (LLW) in the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) and contains hazardous waste that either 1) is listed as a hazardous waste in Subpart D of 40 CFR Part 261, *Identification and Listing of Hazardous Waste* or 2) causes the LLW to exhibit any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261.

[2] RCRA means the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976 (Public Law 94-580, as amended by Public Law 95-609 and Public Law 96-482, 42 U.S.C. 6901 et seq.)

characteristic hazardous wastes. Furthermore, management and disposal of mixed LLW must be conducted in compliance with state requirements in states with EPA-authorized regulatory programs for the hazardous components of such waste and NRC agreement state radiation control programs for LLW.(2)

In summary, NRC regulations exist to control the byproduct, source, and special nuclear material components of commercial mixed LLW; EPA has the authority to control the non-radioactive component of the mixed LLW. Thus, the individual constituents of commercial mixed LLW are subject to either NRC or EPA regulations. When the components are combined to become mixed LLW, neither statute has exclusive jurisdiction; however, RCRA Section 1006(a) states that the AEA requirements have precedence in the event an inconsistency is found between the requirements of the two statutes. This has resulted in a situation of joint regulation where both NRC and EPA regulations may apply to the same waste. To aid commercial LLW generators in assessing whether they are currently generating mixed LLW, the NRC and the EPA jointly developed a revised guidance document entitled, "Joint EPA/NRC Guidance on the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste," Directive No. 9432-00-2, October 4, 1989. It is based on NRC and EPA regulations in effect on December 31, 1988. Application of the methodology to identify mixed LLW, as delineated in this document, will reveal the complexities of the definition of mixed LLW. Generators with specific questions about whether LLW is mixed LLW can call NRC and EPA contacts given in the document.

States are authorized to promulgate mixed waste regulations under the RCRA as long as their regulations are no less stringent than applicable federal regulations. States, however, have been slow to receive authorization to regulate mixed waste under their approved RCRA programs. Mixed waste is regulated as a RCRA hazardous waste in those states where EPA implements the entire RCRA Subtitle C program (i.e., unauthorized states) as well as in authorized states which have obtained specific authorization from EPA to implement a mixed waste program. Currently, there are five unauthorized states (Alaska, California, Hawaii, Iowa, and Wyoming) and, as of January 31, 1992, 29 additional states and territories with mixed waste authorization.

In any state previously authorized by EPA to regulate hazardous waste, but not mixed waste, the generation, transport, treatment, storage or disposal of mixed waste is not regulated under the federal RCRA program until the state's mixed waste authorization is approved. But in states not authorized to run their own RCRA program, federal RCRA mixed waste regulations become effective upon promulgation. A further complication comes about since no one, not even the federal government, has reliable data on the number of facilities producing mixed waste or the volumes produced annually. EPA estimates that 2 to 30% of all low-level radioactive waste contains RCRA-hazardous components. There is also a recognized absence of treatment and disposal facilities. In addition, 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.(3,4)

The NRC and the EPA have been working together for several years to resolve the issues associated with mixed waste. The agencies conducted a survey of generators of commercial mixed radioactive/hazardous waste and are completing two joint technical guidances on testing and storage of such wastes. Oak Ridge National Laboratory, which conducted the voluntary generator survey for the two agencies, sent out questionnaires to over 1,300 potential mixed waste generators in November 1991. The results of the survey, presented in NUREG/CR-5938,(5) have been used to develop a national profile that is expected to provide needed information to states and compact officials, private developers, and federal agencies to assist in planning and developing adequate disposal capacity for low-level radioactive waste, including mixed waste, as mandated by the LLRWPAA of 1985. The report also contains information on existing and potential commercial waste treatment facilities that may provide treatment for specific waste streams identified in the national survey. The report provides a reliable national database on the volumes, characteristics and treatability of commercial mixed waste in the United States. Data from the survey also may serve as a basis for possible federal actions to effectively manage and regulate the treatment and disposal of mixed waste.

NRC and EPA also are developing a joint guidance on safe storage of mixed waste. Given the current lack of treatment and disposal capacity for most mixed wastes, both agencies are concerned with problems that could arise from long-term storage of such wastes. The joint guidance will address issues associated with onsite storage, including inspection and surveillance of waste, waste compatibility and segregation, storage container requirements, and time limitations on storage of untreated waste. For each issue, the agencies are attempting to identify acceptable practices.(4)

In instances where regulatory authority can be delegated, the EPA may delegate regulatory authority to the state for state programs that meet or exceed EPA requirements. Where regulatory authority is not delegated, EPA is responsible for reviewing and evaluating compliance with the EPA regulations. This includes interpreting regulations and consulting with reactor owners and their contractors to aid regulation implementation and inspection of facilities at the sites.

H.2 NRC Guidance on the Management of Mixed Waste

Guidance on storage and disposal of mixed wastes at nuclear power plants is provided in Draft Regulatory Guide DG-1005.(6) The draft guide describes elements to be included in the radioactive waste management plan, which is part of the final decommissioning plan submitted by the licensee to the NRC. The radioactive waste management plan should contain a description of the procedures, processes, and systems used for disposing of all radioactive wastes as well as a detailed characterization of the wastes to be generated with projected volumes, radionuclide concentrations, waste forms and classification, and information on any significant quantities of special wastes such as *mixed wastes* and chelating agents. Expected dispositions of these materials should also be identified with respect to treatment, packaging, interim storage, transportation, and disposal. The need for changes to the site radwaste process control plan and transportation plan should be addressed.

If radioactive wastes are to be stored onsite, the quantities of waste, the expected length of storage, the location of storage areas, radiation levels at access points, and the manner in which positive control will be maintained should be described. The plan should indicate the extent to which the site has been previously used to dispose of low-level radioactive wastes by land burial and indicate the remedial measures that are appropriate before the site can be released for unrestricted use and the license terminated.

In addition, the NRC has published a draft guidance document intended for use by NRC licensees entitled, "Clarification of RCRA Hazardous Waste Testing Requirements for Mixed Waste," March 1992. Described in the guidance are: 1) the current regulatory requirements for determining if a waste is a RCRA hazardous waste; 2) the waste analysis information necessary for proper treatment, storage, and disposal of mixed waste;[3] and 3) the implications of the RCRA land disposal restrictions (LDRs) on the waste characterization and analysis requirements. This information will be useful for radioactive mixed waste generators, who must determine if their waste is a mixed waste; for those generators storing mixed waste onsite in tanks or containers for longer than 90 days, who consequently become responsible for meeting RCRA and NRC storage requirements; and for those facilities who accept mixed waste for offsite treatment, storage, or disposal.

---

[3] The requirements and frequency of waste analysis for a given facility will be spelled out in the facility's waste analysis plan (WAP). The WAP specifies the parameters for which each hazardous waste will be analyzed, the rationale for selecting these parameters (i.e., how analysis for these parameters will provide sufficient information on the waste's properties), and the test methods that will be used to test for these parameters. The WAP also will specify the sampling method to be analyzed and the frequency with which the initial analysis of the waste will be reviewed or repeated to ensure that the analysis is accurate and up to date. The appropriate parameters for each WAP are determined on an individual basis as part of the permit application review process.

H.3 What is Currently Being Done to Deal with the Problem of Mixed Wastes

Although primary responsibility for the development of treatment and disposal technologies rests with the nuclear industry and the Department of Energy, NRC is currently conducting several activities that should facilitate development by clarifying the regulatory framework for mixed waste management. NRC and EPA are jointly developing guidance documents on waste characterization, inspection, and storage of mixed waste. The waste characterization guidance will address occupational exposures during testing. The inspection guidance will provide NRC Regional, Agreement State, EPA Regional, and Authorized State inspectors with background information on mixed waste licensing and permitting, inspection planning and coordination, cross-training, and conduct of mixed waste inspections. The storage guidance will combine the NRC radioactive waste storage recommendations with EPA storage requirements. In addition, NRC is providing assistance to EPA in the permit writers' workshop on mixed waste regulation.(7)

EPA has set some treatment standards for mixed waste. Incineration is an applicable technology for low-level waste combined with organic compounds in wastewater and non-wastewater, as well as ignitable liquids (listed waste number D001 under RCRA). With the exception of scintillation fluids containing low levels of carbon-14 and mercury, DOE has the exclusive franchise on mixed-waste incineration in the United States. Incineration of mixed wastes destroys organic chemicals and reduces volume. An experimental DOE reactor at the Idaho National Engineering Laboratory, for example, is getting a 250-to-1 reduction rate; thus, substantial savings could be realized from commercial application of this technique, if it were available.[4] But at the Rocky Flats Plant, near Denver, Colorado, DOE abandoned plans to start an incinerator for mixed hazardous and radioactive wastes when public opposition combined with problems during the plant's testing phase.(8)

Diversified Scientific Services, Inc. (DSSI), Kingston, Tennessee, is the only commercial company in the United States currently licensed and permitted to treat/store selected liquid, mixed low-level wastes. In addition, the nation's largest low-level waste processor, Scientific Ecology Group, Inc. (SEG) in Oak Ridge, Tennessee, has applied for permits and a license to operate the first commercially available incinerator for solid and liquid mixed waste. The incinerator is currently licensed only for low-level radioactive waste. The company submitted an RCRA Part A permit application in March 1991.(3) The associated Part B permit application was submitted to the Tennessee Division of Solid Waste in early 1993. These permits, when granted, will allow SEG to store and treat characteristic hazardous wastes.

U.S. Ecology, Inc. is developing a new low-level waste burial ground at Ward Valley, California. The company has said that it expects ultimately to store mixed waste at Ward Valley; however, it prefers to develop the part of the site needed for the estimated 95% of the expected LLW that is not chemically hazardous.(9) As previously mentioned, EPA estimates that 2 to 30% of all low-level radioactive waste contains RCRA-hazardous components. At present, it appears that no one is exactly certain what percentage of low-level radioactive waste generated during the decommissioning process will contain RCRA-hazardous components. Additional LLW may be identified as mixed LLW in the future, as generators implement the definition of mixed LLW and as EPA revises the definition of hazardous waste. At currently estimated costs as high as $20,000 per cubic foot for disposal of some mixed wastes, there exists strong incentive to implement mixed waste minimization techniques.(4)

In August 1991, EPA decided not to enforce RCRA land disposal restrictions (Section 3004) for mixed LLW for two years, since neither treatment nor disposal is available for such wastes. In effect, EPA outlined a policy that can be used on a site-specific basis to provide reduced enforcement priority to the storage of some mixed wastes. Thus, the new policy acknowledges the impossibility of enforcing the land-ban restrictions for these wastes. Generators of less than 1,000 cubic feet per

---

[4] The DOE plant, part of the Waste Experimental Reduction Facility, has been processing low-level radioactive wastes since 1984. The facility is a pilot-scale plant, with a maximum capacity of burning 400 pounds of wastes per hour. By contrast, DOE's mixed waste incinerator in Oak Ridge, Tennessee, burns 3,000 pounds per hour. The Oak Ridge plant is the only full-scale incinerator for mixed wastes that is now licensed and operating in the U.S.(8)

year of mixed waste will not be interfered with so long as they are managing wastes in a responsible manner, as defined by EPA. This includes: 1) an inventory of stored mixed waste, 2) identification of such waste and good records, 3) a mixed waste minimization plan, 4) documentation of "good faith" efforts to ascertain availability of treatment and disposal, and 5) cooperation with EPA on a mixed waste survey it is conducting jointly with NRC (see Section H.1 for details). This policy terminated December 31, 1993.[4]

As reported in Reference 4, the so-called "land-ban" restrictions have placed some mixed waste generators in a "Catch-22" situation. The Hazardous and Solid Waste Amendments Act of 1984 amended RCRA to, among other things, prohibit storage of hazardous waste subject to the LDRs "unless such storage is solely for the purpose of accumulating necessary quantities of waste to facilitate proper recovery, treatment, or disposal." However, for radioactive mixed waste falling under LDRs, neither treatment or disposal options exist, leaving generators unable to comply with the regulations.

H.4 Estimated Production of Mixed Wastes During Operation of Selected Light-Water Reactors

In 1990, the Nuclear Management and Resources Council (NUMARC) completed a study of mixed wastes in the commercial nuclear power industry.[10] This investigation developed estimates of generation and disposal rates for mixed wastes from light-water reactor operations (summarized in Table H.1). Two case estimates were developed for the NUMARC study, one based on a set of conservative assumptions and the other based on reasonable changes made to those assumptions. The "reasonable assumptions" case indicates a lower bound LWR mixed waste generation rate of 82 m^3/year and a disposal rate of 21 m^3/year. These "reasonable assumptions" are based on the following:

- It is possible to segregate wastes containing certain hazardous (EPA Code F003) spent solvents from other spent solvents.
- Characteristically hazardous wastes can be processed to render them nonhazardous.

Table H.1 Summary of NUMARC-estimated characteristics of mixed LLW from commercial LWR operations[a]

	Annual waste volume (m^3/year)	
Source	**Generated**	**Disposed**
PWR Operations	102	42.5
BWR Operations	119	59.5
LWR Total, Conservative Base Case	221	102
LWR Total, Reasonable Assumptions Case	82.1	21.2

(a) Based on the NUMARC study, Reference 10.

- Procedures can be implemented to minimize radiological contamination.
- Cadmium content in welds and weld rods may be shown to not exhibit the TCLP/EP toxicity characteristics.
- Explicit account can be made of the timing of mixed waste generated on an infrequent basis.
- Scintillation cocktails may be shown to not exhibit the ignitability characteristic.
- Chromate-bearing ion-exhange resins may be shown to not exhibit the TCLP/EP toxicity characteristics.
- Decontamination resins may be shown to not exhibit the corrosivity characteristic.
- Individual plants may have design and operating features that do not produce the mixed waste streams assumed in this estimate.

H.5 Estimated Production of Mixed Wastes During Decommissioning of the Reference PWR

The implementation of waste minimization techniques at the reference PWR during the operating years is assumed to carry over into active decommissioning periods, resulting in relatively small volumes of generated mixed wastes (either liquid or solid). As used here, waste minimization refers to reducing the volume or toxicity of waste by using source-reduction techniques (e.g., chemical substitution, process modifications, or recycling). These techniques are not to be confused with the broader definition usually associated with waste reduction, which includes source reduction and recycling, but it also acknowledges various waste treatment options as useful to reducing the volume or toxicity of waste. Under these definitions, compaction to decrease waste volume would be considered waste reduction, but not waste minimization.

H.6 Estimated Costs for Storage and Disposal of Mixed Wastes

If mixed wastes are required to be stored for a lengthy period at the reference PWR after final shutdown of the reactor, termination of the license would be delayed until the mixed waste inventory is reduced to zero, and DECON would not be possible. Similarly, ENTOMB would not be possible until the mixed waste inventory was reduced to zero, since entombment of mixed wastes is not covered by federal regulation. If either the hardened or passive SAFSTOR option is selected, the mixed waste inventory is anticipated to be added to the existing waste inventory that must be safely cared for. For the purpose of this study, it is assumed that: 1) if a RCRA permit existed during operation of the reference plant for the storage of mixed waste, the permit would be continued into the postulated decommissioning storage period, presumably until disposal of the mixed waste occurred; and 2) the RCRA-related costs (including liability requirements) and the ultimate disposal costs are considered to be operational costs.

A discussion with a representative of Diversified Scientific Services, Inc. (DSSI), Kingston, Tennessee, revealed that costs of about $35 per gallon (1991 dollars), not including transportation, for disposal of selected, liquid mixed wastes is a reasonable estimate to use.[5] Firm cost estimates for similar services concerning disposal of solid mixed LLW were not obtained, since

---

[5] Personal communications with L. Hembree, Customer Service Representative, October 9, 1991, Diversified Scientific Services, Inc., Kingston, Tennessee.

such services are not currently available in the U.S.(11) However, joint regulation by both NRC and 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.(12)

H.7 Conclusions

Currently, mixed waste is estimated to account for less than 3% of the annual generation rate of LLW (by volume). No off-site disposal or treatment facility for mixed waste has been available since 1985. 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, 13)

For purposes of this study, the ultimate cost of disposal of mixed wastes (either liquid or solid) expected to be present on the reference PWR site at final shutdown are considered to be operational costs, since they were incurred 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 do not currently exist. Based on projected astronomical disposal costs and on the uncertainties surrounding the ultimate disposition of solid mixed LLW, 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 PWR.

H.8 References

1. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. U.S. Nuclear Regulatory Commission. 1989. "Guidance on the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste."

3. *Hazardous Waste News*, July 1, 1991, pp. 256-257.

4. *Nuclear Waste News*, August 29, 1991, pp. 342-344.

5. J. A. Klein, et al. December 1992. *National Profile on Commercially Generated Low-Level Radioactive Mixed Waste.* NUREG/CR-5938, U.S. Nuclear Regulatory Commission Report by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

6. U.S. Nuclear Regulatory Commission Draft Regulatory Guide DG-1005, "Standard Format and Content for Decommissioning Plans for Nuclear Reactors," September 1989.

7. Letter, The Honorable Kenneth M. Carr, Chairman, U.S. Nuclear Regulatory Commission, to The Honorable Morris K. Udall, Chairman Committee on Interior and Insular Affairs U.S. House of Representatives, transmitting information on issues related to the treatment and disposal of mixed wastes, dated January 10, 1990.

8. *Tri-City Herald*, October 6, 1991. "Company Heads for Uncharted Territory," p. A9.

9. *Nuclear News*, April 1989. "NRC Issues Guidance on 1990 Certifications," p. 114.

10. Nuclear Management and Resources Council, *The Management of Mixed Low-Level Radioactive Waste in the Nuclear Power Industry*, NUMARC/NESP-006, prepared by Rogers and Associates Engineering Corporation with Nuclear Waste Management, Inc., Washington, D.C. (January 1990).

11. NUREG-1437, Volume 1. 1991. *Generic Environmental Impact Statement for License Renewal of Nuclear Plants - Main Report - Draft Report for Comment.* U.S. Nuclear Regulatory Commission, Washington, D.C.

12. GAO/RCED-92-61. January 1992. *Nuclear Waste - Slow Progress Developing Low-Level Radioactive Waste Disposal Facilities.* United States General Accounting Office Report to Congressional Requesters, Washington, D.C.

13. OTA-O-426. 1989. "Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste," Office of Technology Assessment, U.S. Congress, Washington, D.C.

Appendix I

Regulatory Considerations for Decommissioning

Appendix I

Regulatory Considerations for Decommissioning

In decommissioning, the facility licensee must be aware of applicable regulatory requirements and regulatory guidance. The U.S. Nuclear Regulatory Commission (NRC) provides decommissioning guidelines in the rule "General Requirements for Decommissioning Nuclear Facilities."(1) In addition, Regulatory Guide 1.86(2) contains guidance on decommissioning procedures.

The licensee also should recognize that two offices within the NRC share the responsibilities in the decommissioning process for power reactors -- the Office of Nuclear Reactor Regulation (NRR) and the Office of Nuclear Material Safety and Safeguards (NMSS). An overview of their decommissioning regulatory responsibilities is illustrated in Figure I.1. NRC project management responsibility shifts from NRR to NMSS upon approval of the decommissioning plan. Upon transfer of project management responsibility, NMSS takes on the responsibility of overview of the licensee's implementation of the approved decommissioning plan.

This appendix identifies and discusses regulations, guides, standards, and changes in regulatory requirements from those delineated in NUREG/CR-0130, which was published in June 1978.(3) This appendix is organized according to the following phases of decommissioning: planning and preparation, active decommissioning, and, in the case of storage modes of decommissioning, continuing care. For completeness, selected regulatory aspects associated with decommissioning prematurely shutdown plants are discussed. A discussion on decommissioning after a 20-year license renewal period concludes this appendix.

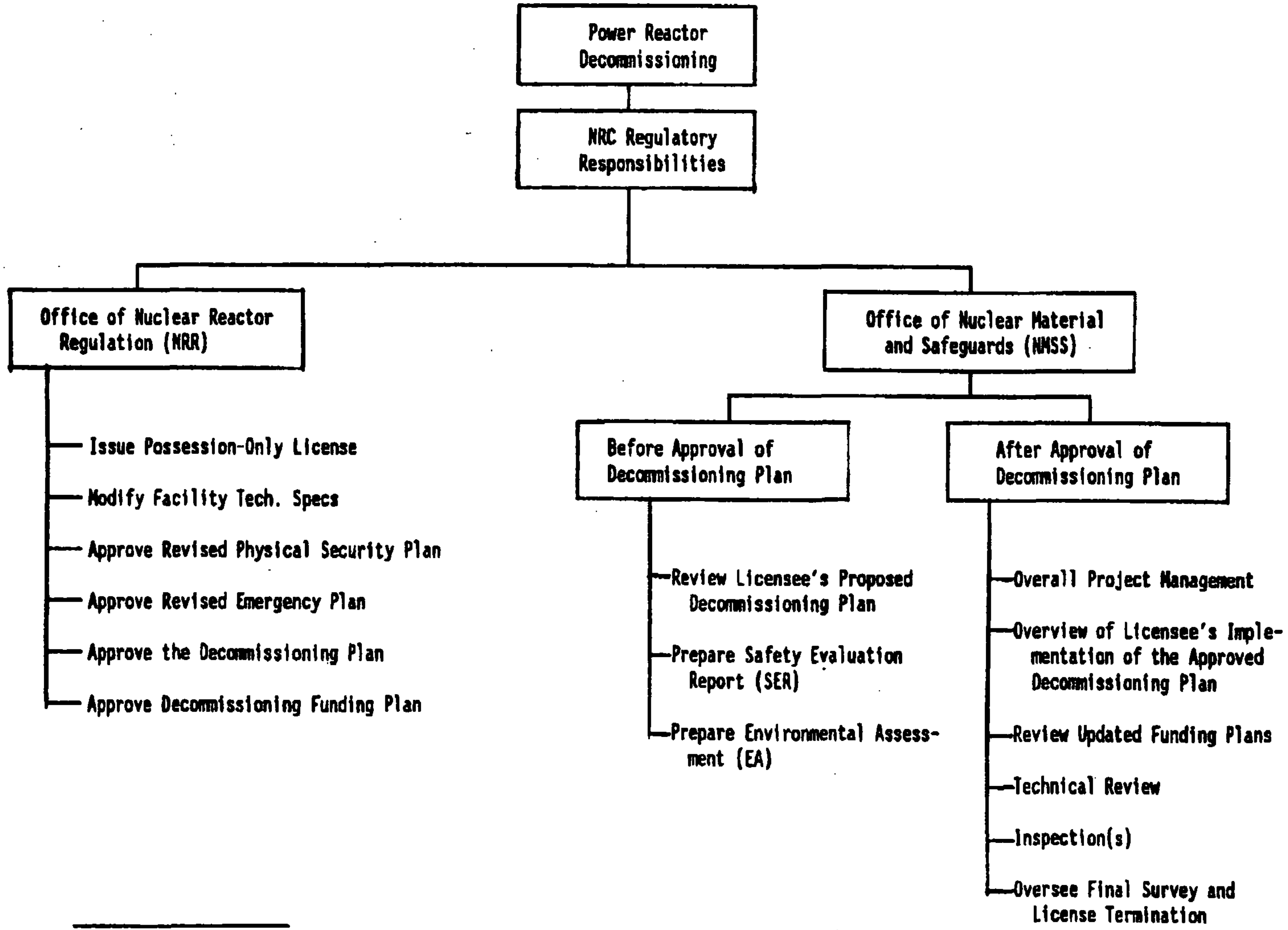
I.1 Planning and Preparation

During the planning and preparation phase of decommissioning prior to final shutdown, the licensee, with NRC approval, decides on and plans how to accomplish the final disposition of the plant. The licensee's major preparatory effort is to (1) provide the necessary documentation for amending the facility operating license to a "possession-only" license (POL), (2) renewing the license if necessary, and (3) obtaining an NRC decommissioning order, if required.

This section discusses the regulations, regulatory guides, and other guides that pertain to the planning and preparation phase of decommissioning, in the following sequence: licensing, decommissioning plan, licensing costs, financial assurance, and Internal Revenue Service involvement in decommissioning funding.

I.1.1 Licensing Requirements

The facility operating license is regulated by 10 CFR Part 50, *Domestic Licensing of Production and Utilization Facilities.* In 10 CFR 50.51, "Duration of License, Renewal," the operating license is permitted to be valid for a maximum of 40 years. The decommissioning rule(1) requires submittal of a preliminary decommissioning plan about five years before permanent



Source: NRC Internal Realignment of Responsibilities, December 1988 (SECY-88-355).

Figure I.1 Power reactor decommissioning regulatory overview shutdown (10 CFR 50.75(f)) and submittal of a decommissioning plan at the time of permanent cessation of operations (10 CFR 50.82(a)). Both of these plans will contain a description of planned decommissioning activities and a description of methods used to ensure protection of workers and the environment against radiation hazards during decommissioning.

Upon expiration, the license may be either renewed or terminated. The requirements that must be met to terminate the operating license are presented in 10 CFR 50.82, "Application for Termination of License."

I.1.2 Decommissioning Plan Requirements

Requirements for applications for license termination and decommissioning nuclear reactors are contained in 10 CFR Part 50, *Domestic Licensing of Production and Utilization Facilities*, and specifically in Section 50.82, "Application for Termination of License." On June 27, 1988, the NRC published amendments to 10 CFR Part 50,(1) along with other parts of its regulations, concerning general requirements for decommissioning nuclear facilities. The revised Section 50.82 requires that an application for license termination be accompanied or preceded by a proposed decommissioning plan.

The following subsections discuss the regulations and regulatory guides that pertain to the documentation requirements of a license amendment request or a decommissioning plan in the following sequence: standard format and content, radioactive waste management plan, quality assurance plan, security and safeguards plan, and environmental plans.

Standard Format and Content for a Decommissioning Plan

Draft Regulatory Guide DG-1005, "Standard Format and Content for Decommissioning Plans for Nuclear Reactors," was issued for public comment in September 1989, in conjunction with publication of the decommissioning rule. The purpose of the guide is to identify the information needed and to present a format acceptable to the NRC staff for preparing and submitting a decommissioning plan. The NRC staff suggests the use of the standard format contained in the guide for decommissioning plans to facilitate preparation by licensees and timely and uniform review by the NRC staff and as guidance in use of the Standard Review Plan for decommissioning plans. Title 10 CFR Parts 20, 50, and 70 provide the regulatory basis for the guide.

A decommissioning plan should show that the facility can be decommissioned in a safe manner and describe the licensee's plans to demonstrate that the facility and site will meet criteria for release for unrestricted use.[1] This plan must be approved by the NRC staff. The decommissioning rule requires a licensee to submit a proposed decommissioning plan within two years after permanently ceasing operation and no later than one year prior to expiration of the operating license. In addition to the decommissioning plan, paragraph 51.53(b) requires each applicant for a license amendment authorizing the decommissioning of a production or utilization facility to submit with its application a separate document entitled "Supplement to the Applicant's Environmental Report--Postoperating License Stage." This supplement would reflect any new information or significant environmental change associated with the applicant's proposed decommissioning activities.

The requirements of 10 CFR 50.51(b) apply to a plant going into DECON, SAFSTOR, or ENTOMB. If either the SAFSTOR or ENTOMB decommissioning method is selected, a decommissioning plan would contain (1) the details for preparing the facility for safe storage or for entombment, (2) plans for monitoring and surveillance during the storage period, (3) plans for assuring funds for maintaining the facility and completing decommissioning, including the means of adjusting cost estimates and associated funding levels over the safe storage or surveillance period [guidance on funding is delineated in Regulatory

---

[1] Unrestricted use refers to the fact that from a radiological standpoint, no hazards exist at the site, the license can be terminated, and the site can be considered an unrestricted area. This definition is consistent with the definition of an unrestricted area as it exists in 10 CFR 20.3 as being "any area access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials and any area used for residential quarters."(1)

Guide 1.159 (Task DG-1003), "Assuring the Availability of Funds for Decommissioning Nuclear Reactors"],(4) and (4) a commitment to submit an updated plan prior to starting final decommissioning activities.

It may take a year for a power reactor licensee to prepare a decommissioning plan for submittal and about a year for the NRC staff to review, evaluate, and approve the plan. Thus, preparation of a decommissioning plan should start as soon as practical after a licensee decides to permanently shut down a facility.

In some cases, the information requested - such as the (1) training program, (2) radiation protection provisions, (3) radioactive waste management plan, (4) updated cost estimate for decommissioning method chosen and plan for assuring availability of funds for completion of decommissioning, (5) quality assurance provisions in place during decommissioning, and (6) physical security plan provisions in place during decommissioning - may be the same or similar to information previously submitted. Information contained in previous submittals, statements, or reports may be incorporated by clear and specific references, and only changes need be submitted.

In order to terminate a license, the NRC must determine that release of the facility and site for unrestricted use 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. Residual radioactive contamination levels are the subject of interim guidance under preparation and in regulatory guides; present guidance is contained in Regulatory Guide 1.86.(2) In addition, the decommissioning rule requires submittal of a final radiation survey plan as part of the decommissioning plan.

The decommissioning plan and the associated approval process provide an adequate legal framework for the regulation of facilities undergoing decommissioning. Therefore, the licensee would submit, gain approval of, and carry out decommissioning plans in accordance with the requirements of 10 CFR 50.82 and the guidance of Regulatory Guide DG-1005. The NRC licensing offices evaluate the information contained in the plan on whether it is based on existing regulations applicable to reactors undergoing decommissioning. These regulations include applicable parts of Title 10 CFR Parts 20, 50, 61, 70, 71, and 73. NRC staff will also monitor the carrying out of the plans.

Radioactive Waste Management Plan

Regardless of the decommissioning mode, radioactive waste will be accumulated, treated, packaged, stored, and transported to a disposal site. Means for complying with the regulatory aspects of each of these areas must be defined in the decommissioning plan. Unless indicated otherwise, the following regulatory changes, since 1978, are taken from the Supplementary Information to the decommissioning rule.(1)

The DECON decommissioning alternative assumes availability of capacity to dispose of waste. Disposal capacity for Class A, Class B, and Class C wastes currently exists. The Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985 (Public Law 99-240, approved January 15, 1986, 99 Stat. 1842) provides that disposal of Greater-Than-Class C (GTCC) wastes is the responsibility of the Federal Government.

NRC staff expected that Congress would provide guidance for development of disposal capacity for wastes exceeding Class C concentrations. Those wastes whose radionuclides concentrations exceeded the maximum allowed for land disposal, GTCC, were required to be stored by licensees pending further determination. This determination was provided in an amendment to 10 CFR 61 (Part 61.55, "Waste Classification") published in the Federal Register dated May 25, 1989, wherein all GTCC wastes are to be disposed of in a geologic repository, or in an approved alternative. In the LLRWPAA legislation passed by Congress in 1985, the U.S. Department of Energy (DOE) was assigned the responsibility for the disposal of GTCC wastes. Under this legislation, DOE must provide the capability for disposal of the GTCC wastes, but the waste generator must pay for the service. Thus, the costs of disposal of GTCC wastes resulting from decommissioning activities are a legitimate decommissioning expense.

Decommissioning activities do not include the removal and disposal of spent fuel, which is considered to be an operational activity, or the removal and disposal of nonradioactive structures and materials beyond that necessary to terminate the NRC license. Spent fuel disposal, although not included as a decommissioning activity, could nevertheless have an impact on the decommissioning schedule (see discussion below). The detailed schedule for development of monitored retrievable storage and geologic disposal capacity provided in the Nuclear Waste Policy Act of 1982 (NWPA, Public Law 97-245, January 7, 1983) and in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, Public Law 100-203, December 22, 1987) has been slipping. Therefore, licensees will have to assess the situation with regard to spent fuel disposal when they prepare their decommissioning plans.

Appendix D contains the background information and the rationale for the derivation of the minimum length of the SAFSTOR period at the reference PWR resulting from DOE's intent to not accept standard spent nuclear fuel (SNF)[2] from reactors until that fuel is cooled at least five years or can meet shipping cask certification requirements. This regulatory action could also result in changes in the decommissioning planning bases for DECON and ENTOMB as well. This change in the planning base requires a reassessment of decommissioning activity schedules and sequences, staff loadings, and shift schedules, to minimize the cost and radiation dose over the different decommissioning periods. Thus, the results of the analysis presented in this study are realistically anticipated to significantly affect the available choices of decommissioning alternatives for the reference plant.

It should be recognized, however, that the situation described in Appendix D with regard to spent fuel storage and final disposition and its subsequent impact on choice of decommissioning alternative is predicated on the current regulatory environment and on site-specific information associated with the reference pressurized water reactor (PWR). Therefore, the conclusions reached in this study concerning decommissioning alternatives for the reference PWR may be different for other PWR power stations, depending upon the age and burnup of the fuel in the pool, and the availability of other pool storage within a given utility system.

The NWPA of 1982 assigns to the Federal Government responsibility to provide for the permanent disposal of SNF and high-level radioactive waste (HLW).[3] The Director of DOE's Office of Civilian Radioactive Waste Management (OCRWM) is responsible for carrying out the functions of the Secretary of Energy (Secretary) under NWPA. Section 302(a) of the NWPA authorizes the Secretary to enter into contracts[4] with owners or generators[5] of commercial SNF and/or HLW. The Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste(5) 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 and/or HLW by DOE, its transportation to DOE facilities, and its subsequent disposal.

---

[2] As delineated in 10 CFR Part 961, Appendix E,(5) SNF is broadly classified into three categories - standard fuel, nonstandard fuel, and failed fuel. Most, if not all, SNF from the reference PWR is assumed to fall into the standard fuel category. One of the General Specifications for standard fuel is a minimum cooling time of five (5) years.

[3] 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 to require permanent isolation.

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

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

Concerning the issue of priority being afforded to permanently shutdown reactors, DOE has responded thusly:(6)

> "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 anticipates 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"(7) are fully implemented. Until waste acceptance begins, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel.

The decommissioning rule(1) requires that at or about five years prior to the projected end of operation, each reactor licensee submit a preliminary decommissioning plan containing a cost estimate for decommissioning and an up-to-date assessment of the actions necessary for decommissioning. This requirement would assure that consideration be given to relevant up-to-date information which could be important to adequate planning and funding for decommissioning well before decommissioning actually begins. These considerations include an assessment of the current waste disposal conditions. If, for any reason, disposal capacity for decommissioning wastes were unavailable, there are provisions in 10 CFR 50.82 that would allow delay in completion of decommissioning in order to permit temporary safe storage of decommissioning waste. In addition, Section 50.82 contains requirements to ensure that adequate funding is available for completion of delayed decommissioning. It should be noted, however, that delays would have to be based on safety considerations and not just on economic considerations.

Disposal of nonradioactive hazardous waste arising from decommissioning operations are not covered by the aforementioned regulations, but would be treated by other appropriate agencies having responsibility over these wastes.

Quality Assurance Plan

The NRC recognizes that quality assurance (QA) is important for decommissioning. The decommissioning rule(1) indicates that QA provisions during decommissioning are to be described, as appropriate, in the decommissioning plan. The decommissioning rule contains requirements that a decommissioning plan, regardless of the alternative chosen, contain a description of quality assurance provisions.

Quality assurance is enhanced and facilitated by good practices concerning record keeping by the licensee. Paragraph 50.75(g) of the decommissioning rule requires licensees to keep records of information important to safe and effective decommissioning until the license is terminated by the NRC. This section of the rule also identifies the kinds of information the NRC considers important to decommissioning. A draft regulatory guide (DG-1006)(8) has been developed in conjunction with the decommissioning rule and was published for public comment in September 1989. The purpose of the draft guide is to provide guidance concerning the specific information that should be kept and maintained in the decommissioning records required by the rule regarding the radiological conditions at the plant that could affect occupational and public health and safety during decommissioning. Knowledge of radiological conditions in and around the reactor will serve to facilitate decommissioning by minimizing occupational exposure and reducing the risk of any public exposure.

Currently, the NRC's regulatory position concerning records important for decommissioning of nuclear reactors is stated in DG-1006 as follows. The collection, safekeeping, retention, maintenance, and updating of decommissioning records should be included in the overall site quality assurance program, consistent with the coverage for other health and safety records systems. Regulatory Guide 1.88, Revision 2, "Collection, Storage, and Maintenance of Nuclear Power Plant Quality Assurance Records," should be used in particular for guidance on records administration, storage, preservation, safekeeping, and retrieval of the decommissioning records.

Draft Regulatory Guide DG-1005 provides the licensee guidance for QA program requirements to be established and executed during decommissioning. For example, the equipment, such as plasma torches, portable ventilation, and shielding, and the procedures that will be subject to the QA controls and audits should be listed. The QA program should be established at the earliest practical time consistent with the schedule for accomplishing an activity or task.[6] The staff positions and responsibilities for review and audit should be specified.

In addition, American Nuclear Insurers (ANI)[7] 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 on an engineering evaluation of the adequacy of performance in the major areas of nuclear safety, *quality assurance* (emphasis added), and documentation. The results of the engineering assessment and QA oversight can affect the level of premium assessed and the rate of change of premium during decommissioning.(9)

Security and Safeguards Plan

Security and safeguards plans should be part of the license amendment request or the decommissioning plan. Although security and safeguards during decommissioning are not specifically addressed in the regulations, the intent of the regulations for operating plants remains the same during decommissioning, insofar as they apply. These subjects are discussed in 10 CFR 50.34(c), "Physical Security Plan," Regulatory Guide 1.17, *Protection of Nuclear Power Plants Against Industrial Sabotage*, and 10 CFR Part 73, *Physical Protection of Plants and Materials.*

In addition, Supplementary Information supporting the rule states: "The existing regulations on safeguards for nuclear facilities are considered to contain criteria applicable to the decommissioning process. Therefore, it is not considered necessary to amend those regulations." However, the rule requires that safeguards provisions during decommissioning be described, as appropriate, in the decommissioning plan. Appropriate guidance documents have not yet been issued identifying which of the current operating requirements on safeguards are to apply during decommissioning.(1)

Environmental Plans

The environmental information that is supplied with the license amendment request or the decommissioning plan should satisfy the requirements of 10 CFR Part 51, *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions*, and the intent of Section 51.53, "Supplement to Environmental Report." It states in Section 51.53(b) "Post Operating License Stage," that each applicant for a license amendment authorizing the decommissioning of a production or utilization facility covered by § 51.20 and each applicant for a license or license amendment to store spent fuel at a nuclear power reactor after expiration of the operating license for the nuclear power reactor shall submit with its application a separate document, entitled "Supplement to Applicant's Environmental Report - Post Operating License Stage," as appropriate, to reflect any new information or significant environmental change associated with the applicant's proposed decommissioning activities or with the applicant's proposed activities with respect to the planned storage of spent fuel. Unless

---

[6] DG-1005 defines an "activity" as an organized unit of work for performing a function and may consist of several tasks. A "task" is defined as a specific work assignment or job.

[7] 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.

otherwise required by the Commission, in accordance with the generic determination in § 51.23(a)[8] and the provisions of § 51.23(b), the applicant shall only address the environmental impact of spent fuel storage for the term of the license applied for. The Supplement may incorporate by reference any information contained in previously submitted records, which are delineated in Section 51.53(b).

Furthermore, in Section 51.95, "Supplement to Final Environmental Impact Statement," Subsection (b), "Post Operating License Stage," the following is stated: "In connection with the amendment of an operating license to authorize the decommissioning of a production or utilization facility covered by § 51.20 or with the issuance, amendment or renewal of a license to store spent fuel at a nuclear power reactor after expiration of the operating license for the nuclear power reactor, the NRC staff will prepare a supplemental environmental impact statement for the post operating license stage or an environmental assessment, as appropriate, which will update the prior environmental review. This document may incorporate by reference any information contained in previously submitted records, which are delineated in Section 51.95(b)."

In summary, the NRC has determined that if proper consideration and implementation is given to decommissioning, whatever alternative is chosen, in comparison with the impact expected from 40 years of licensed operation, the environmental impacts from decommissioning are expected to be small. Thus, the decommissioning rule(1) allows for reduction of 10 CFR Part 51 National Environmental Policy Act (NEPA) (42 USC 4321 et seq.) requirements through elimination of the mandatory requirement for an environmental impact statement (EIS) at the time of decommissioning for 10 CFR Part 50 and 72 licenses. Environmental assessments would still be required, but these would not necessarily lead to an EIS being issued.

I.1.3 Licensing Costs

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 from the Department of Energy (DOE)-administered Nuclear Waste Fund[9] to the NRC for FYs 1991 through 1995 for purposes of licensing support to the 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 on 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.

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.

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

---

[8] As stated in 10 CFR Part 51.23, *Temporary Storage of Spent Fuel After Cessation of Reactor Operation - Generic Determination of No Significant Environmental Impact*, Subsection (a): The Commission has made a generic determination that, if necessary, spent fuel generated in any reactor 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 onsite or offsite independent spent fuel storage installations. Further, the Commission believes there is reasonable assurance that at least one mined geologic repository will be available within the first quarter of the twenty-first century, and sufficient repository capacity will be available within 30 years beyond the licensed life for operation of any reactor to dispose of the commercial high-level waste and spent fuel originating in such reactor and generated up to that time.

[9] 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.

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. It should also be noted that if a facility has a POL at the beginning of the fiscal year, a licensee is no longer assessed annual fees. Hourly fees remain, however, for plant-specific licensing actions.

In addition, holders of licenses associated with the storage of spent fuel, including a general license to receive and store spent fuel at an independent spent fuel storage installation (ISFSI), and each holder of a Certificate of Compliance for a spent fuel storage cask, will be assessed an annual fee.

Thus, the NRC will charge fees in proportion to its costs (i.e., full-cost recovery) for providing individually identifiable services to specific applicants for, and holders of, NRC licenses and approvals. These fees are deposited into the U.S. Treasury and do not augment the NRC appropriation. Congress must still pass appropriations legislation for the NRC, but because the NRC is now obligated to raise the money from users, legislators will chiefly consider the funding authorization - that is, whether the amount of money the NRC proposes to raise is reasonable.(10, 11)

The financial protection requirements during plant operation are given in 10 CFR Part 140, *Financial Protection Requirements and Indemnity Agreements*. The levels of protection required during decommissioning are not specifically defined. However, the intent of the regulations for operating plants remains the same during decommissioning, insofar as they apply, as discussed in the following subsection.

I.1.4 Financial Assurance

As previously mentioned, on June 27, 1988, the NRC published amendments to 10 CFR Part 50 (53 FR 24018) concerning general requirements for decommissioning nuclear facilities. Amended 10 CFR 50.33(k), 50.75, and 50.82(b) require operating license applicants and existing licensees to submit information on how reasonable assurance will be provided that funds will be available to decommission their facilities. Amended Section 50.75 establishes requirements for indicating how this assurance will be provided, namely the amount of funds that must be provided, including updates, and the methods to be used for assuring funds for any of the decommissioning alternatives of DECON, SAFSTOR, or ENTOMB.

Title 10 CFR Part 50.75(c)(2) requires nuclear power reactor licensees to periodically adjust the estimate of the cost of decommissioning their plants, in dollars of the current year, as part of the process to provide reasonable assurance that adequate funds for decommissioning will be available when needed. NUREG-1307, "Report on Waste Burial Charges," which is scheduled to be revised approximately annually, contains information to be used in a formula for escalating decommissioning cost estimates that is acceptable to the NRC. The sources of information to be used in the escalation formula are identified, and the values developed for the escalation of radioactive waste burial costs, by site and by year, are given. The licensees may use the formula, the coefficients, and the burial escalation factors from NUREG-1307 in their escalation analyses, or they may use an escalation rate at least equal to the escalation approach presented therein.(12)

Regulatory Guide 1.159 (Task DG-1003), "Assuring the Availability of Funds for Decommissioning Nuclear Reactors," August 1990, was developed in conjunction with the rule amendments. Its purpose is to provide guidance to applicants and licensees of nuclear power reactors and research and test reactors concerning methods acceptable to the NRC staff for complying with requirements in the amended rule regarding the amount of funds for decommissioning. It also provides guidance on the content and form of the financial assurance mechanisms indicated in the rule amendments.

Under normal circumstances, decommissioning follows the orderly shutdown of the facility at the end of its planned life. However, as discussed in the *Final Generic Environmental Impact Statement on Decommissioning Nuclear Facilities* (commonly referred to as GEIS),(13) decommissioning at a reactor which has been involved in an accident could take place following stabilization and accident cleanup activities. Thus, the availability of funds for post-accident cleanup is also related to financial assurance for decommissioning. For example, an accident and the resulting accident cleanup activities have an effect on subsequent decommissioning activities, on the decommissioning alternatives, and on the cost, safety and environmental consequences of those alternatives.

The costs of post-accident cleanup can be substantially larger than the costs of decommissioning. Assurance of funds for post-accident cleanup activities is more properly covered by use of insurance. Post-accident cleanup activities are broader in scope than decommissioning, that is, they can lead ultimately to either reuse or decommissioning. Accordingly, the funding requirements for accident cleanup are not included in the GEIS or in the rule,(1) but are contained in 10 CFR 50.54(w), which requires that utility licensees for production and utilization facilities obtain insurance to cover decontamination and cleanup costs associated with onsite property damage resulting from an accident.[10]

With regard to the funding of decommissioning activities which would occur prematurely either following an accident or if an accident did not occur, NRC has had several studies done to address this issue, including NUREG/CR-1481,(14) NUREG/CR-3899,(15) NUREG/CR-3899 Supplement 1,(16) and NUREG/CR-2370.(17) These documents address the question of assurance provided by the various funding methods, including prepayment, external reserve, internal reserve, and insurance. In particular, as discussed in Section 2.6 of the GEIS and in more detail in NUREG-1221, Section D.3.2.1.1,(18) and as noted in NUREG/CR-3899, the market value of utilities, even those involved in the most extreme financial crises, is still far in excess of decommissioning costs and that the value of the assets of a utility (both tangible and intangible) is more than adequate to cover future projected decommissioning costs. These considerations must also be viewed within the context of the Commission requirements for onsite property damage insurance in 10 CFR 50.54(w), discussed above, the proceeds from which a utility could use to decontaminate its reactor after an accident. Although these insurance proceeds would not be used directly for decommissioning, they would go a long way toward reducing the risk of a utility being subject to a tremendous demand for funds after an accident. Because most utilities are now carrying insurance in excess of $1 billion and the Commission has implemented its requirement in 10 CFR 50.54(w) for insurance at this level, a major threat to long-term utility solvency has been substantially reduced.(13)

Thus, pursuant to 10 CFR 50.54(w), a licensee is required to carry a minimum coverage limit of onsite primary property damage insurance for a reactor station site of either $1.06 billion or whatever amount of insurance is generally available from private sources, whichever is less. However, under certain conditions (e.g., a permanently shutdown, defueled reactor), and with the proper justification, an NRC exemption to reduce the amount of primary property damage insurance from the full amount of $1.06 billion to a lesser amount (with correspondingly lesser premiums) is possible. For example, in its application for exemption, the licensee must provide justification that the lesser amount of insurance provides an adequate level of coverage to stabilize, clean up, or decontaminate the reactor facility based on limited and much less severe accidents that could occur, given the defueled condition.

At a licensee's request, the NRC has the prerogative to grant exemptions from the requirements of the regulations, which pursuant to 10 CFR 50.12(a) are (1) authorized by law, will not present an undue risk to the public health and safety, and are consistent with the common defense and security, and (2) present special circumstances. Pursuant to 10 CFR 50.12(a)(2)(ii), special circumstances exist when compliance with a rule would not serve the purpose of or is not necessary to achieve the

---

[10] As a result of the efforts during accident cleanup, decommissioning can be carried out in a more stable environment than the accident cleanup. Nevertheless, there would be certain impacts on the decommissioning from the accident and the accident cleanup activities, including increased levels and spread of contamination compared to normal decommissioning still remaining after the cleanup activities, the need to decommission systems and structures built and used during accident cleanup, and the potential need to store wastes generated by the accident, and during the accident cleanup period, onsite on an interim basis for an extended time period.(13)

underlying purpose of the rule. Pursuant to 10 CFR 50.12(a)(2)(iii), special circumstances exist if compliance would result in undue hardship or costs in excess of those contemplated when the regulation was adopted, or costs that are significantly in excess of those incurred by others similarly situated.

In addition, the Commission recognized the risk that, if some reactors did not operate for their entire operating lives, those licensees might have insufficient decommissioning funds at the time of permanent shutdown. After the NRC published the decommissioning rule in 1988,(1) four power reactor facilities shut down prematurely - the Fort St. Vrain Nuclear Generating Station, the Yankee Rowe Nuclear Power Station, the Rancho Seco Nuclear Generating Station, and the Shoreham Nuclear Power Station. As a result, the NRC had to consider whether the decommissioning funding provisions in the rules were appropriate in those cases. In August 1991, the NRC decided to propose a new special-case amendment.(19)

The decommissioning rule, as it stands now, allows a licensee to build up funding steadily over the duration of the license, but intends that enough money should be in place by the time plant operations end. For a facility which has permanently ceased operation before the expiration of its operating license, the collection period for any shortfall of funds will be determined, upon application by the licensee, on a case-by-case basis taking into account the specific safety and financial situation at each nuclear power plant.(20)

In addition, although not as directly related to decommissioning activities as to 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 operating nuclear power reactors, the licensee shall, no later than 5 years before expiration of the reactor operating license, 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 upon expiration of the reactor operating license until title to the irradiated fuel and possession of the fuel is transferred to the Secretary of Energy for its ultimate disposal. Final Commission review will be undertaken as part of any proceeding for continued licensing under Part 50 or Part 72. 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 require 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."

The number of reactors that have been shut down prematurely has increased over earlier expectations. Therefore, the NRC has recently amended its regulations concerning 10 CFR 50.54(bb) to clarify the timing of notification to the NRC of spent fuel management and funding plans by licensees of those nuclear power reactors that have been shut down before the expected end of their operating lives. The rule requires that a licensee submit such notification either within 2 years after permanently ceasing operation of its licensed power reactor or no later than 5 years before the reactor operating license expires, whichever event occurs first.(21)

I.1.5 Internal Revenue Service Involvement in Decommissioning Funding

The Tax Reform Act of 1984 added section 468A, "Special Rules for Nuclear Decommissioning Costs," to the Internal Revenue Code, which sets out the rules for creating nuclear decommissioning funds by public utilities. This section defines the rate at which funds are taxed, restrictions on the funds, and types of investments that can be made by the fund. The cash contributed to these funds and the income accumulated by the funds will be used to pay future costs of decommissioning nuclear power plants and to pay the administrative costs of the funds each year. Funds are tax-deductible the year they are contributed to the fund, but the income on the investments of these funds is taxed at the highest tax rate that applies to corporations.

The Tax Reform Act of 1986 provides that nuclear decommissioning funds will be treated as corporations. This law also reduced the highest tax rate from 46% to 34% and became effective on July 1, 1987. Subsequently, the tax rate on decommissioning funds was lowered from 34% to 20% when the National Energy Policy Act (NEPA), Public Law 102-486, was signed into law on October 24, 1992.(22)

The Tax Reform Act of 1986 also requires nuclear decommissioning funds to pay estimated taxes. The method for determining estimated tax is explained in the General Instructions of Form 1120-ND (November 1986), which is used by nuclear decommissioning funds to report contributions received, income earned, the administrative expenses of operating the fund, and the tax on the income earned.

As part of the 1986 tax overhaul, the Internal Revenue Service, which must determine the "qualified" portion of every nuclear utility's decommissioning funds (i.e., the amount of the total decommissioning costs entitled to funding on a tax-deductible basis) was empowered to look at utilities' decommissioning fund contributions going back to 1984.(23)

An unqualified fund invested, for example, in stocks, could earn greater returns, but its principal is subject to risk and contributions are taxed. Contributions to a qualified fund are tax-deductible, but its earnings are taxed at the maximum federal corporate rate of 34%. The NRC decommissioning rule(1) required utilities to have external funds established by mid-1990 but does not require them to be qualified. An unqualified fund's earnings are added to the earnings of its corporate owner and taxed at the utility's overall rate.(23)

I.2 Active Decommissioning

Regulations, regulatory guides, and national standards that apply to the basic aspects of active decommissioning of the reference PWR are discussed in this section. Most of these basic aspects are similar in nature to many aspects of plant operation; and the regulatory controls and national standards that govern plant operation of these aspects also apply to active decommissioning, although some of them may not specifically mention decommissioning activities. The basic areas of active decommissioning are: licensing, occupational radiation safety, public radiation safety, special nuclear material management, radioactive waste management, industrial safety, and license termination and facility release.

I.2.1 Licensing

"Application for Termination of License" is regulated by 10 CFR Part 50.82. For a facility that permanently ceases operation after July 27, 1988, the application must be made within two years following permanent cessation of operations, and in no case later than one year prior to expiration of the operation license. Each application for termination of license must be accompanied, or preceded, by a proposed decommissioning plan (see previous discussion in Section I.1.2 for details).

Although a POL is not defined anywhere in the regulations, Regulatory Guide 1.86, *Termination of Operating Licenses for Nuclear Reactors*,[11] contains the procedures that are acceptable to NRC in amending the facility operating license to a POL and for obtaining a dismantling order. A POL is essentially an amended operating license and is one way for a licensee to obtain relief from operating requirements. Regulatory Guide 1.86 delineates the applicability of the POL and the dismantling order to the various decommissioning modes, the surveillance and security requirements if the final decommissioning status requires a POL, and the procedures for terminating the license.

---

[11] It should be recognized that Regulatory Guide 1.86 is currently being revised to be fully consistent with the recent changes to 10 CFR 50.82.

The POL allows the licensee to possess, but not to operate, the facility. It permits unloading, storing, and subsequent shipping of the spent reactor fuel, as well as the minor work associated with preparation for custodial safe storage or passive safe storage. In effect, the POL does not preclude the storage of spent fuel in the spent fuel pool, in an onsite independent spent fuel storage installation (ISFSI), shipment of spent fuel to another ISFSI offsite, or shipment to a U.S. Department of Energy facility for disposal. It is the governing license in all decommissioning modes, but a dismantling order is also required in the case of dismantlement or preparations for hardened safe storage or entombment. The POL remains in force during the continuing care period of safe storage or entombment, and must be renewed every 40 years. In addition, an updated decommissioning plan is required at the end of the SAFSTOR period when the licensee decides on how to dismantle the facility. All activities must be completed within 60 years of plant final shutdown.

The POL permits deletion of the technical specifications regarding plant operation (and associated surveillance requirements) that are not applicable to decommissioning, but maintains those that are necessary to ensure protection of the workers and the public during decommissioning. Thus, the POL would allow the licensee to immediately cut expenses by reducing testing requirements and staffing. It also contains the authority to possess and handle byproduct material, source material, and special nuclear material as governed by 10 CFR Part 30, *Rules of General Applicability to Domestic Licensing of Byproduct Material*, 10 CFR Part 40, *Domestic Licensing of Source Material*, and 10 CFR Part 70, *Domestic Licensing of Special Nuclear Material*.

Situations that exceed the limitations of the POL may arise during the course of active decommissioning. (Regulatory Guide 1.86 refers to these situations as "unrelated safety questions.") This type of situation is regulated by 10 CFR 50.59, "Changes, Tests and Experiments."

I.2.2 Occupational Radiation Safety

Because of the highly radioactive materials and contaminated work locations in the reference PWR during active decommissioning, occupational radiation exposure control is of major importance. Occupational radiation safety is regulated by 10 CFR Part 20, *Standards for Protection Against Radiation*. The maximum permissible limits for occupational radiation exposure are presented in 10 CFR 20.101, "Radiation Dose Standards for Individuals in Restricted Areas," and 10 CFR 20.103, "Exposure of Individuals to Concentrations of Radioactive Materials in Air in Restricted Areas." However, these limits are tempered by the operating philosophy of As Low As is Reasonably Achievable (ALARA) as explained in 10 CFR 20.1(c). This philosophy is described in Regulatory Guide 8.8, *Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be As Low As Reasonably Achievable*, and in Regulatory Guide 8.10, *Operating Philosophy for Maintaining Occupational Radiation Exposures as Low As is Reasonably Achievable.*

Additional information on how to comply with the ALARA concept can be found in the NRC Standard Review Plan, Section 12.1, "Assuring that Occupational Radiation Exposures Are As Low As is Reasonably Achievable."(24) Besides 10 CFR Part 20 and Regulatory Guide 8.8, some of the more relevant regulations and guidance cited in Section 12.1 are given below:

- 10 CFR Part 19, *Notices, Instructions and Reports to Workers: Inspection and Investigations*
- Regulatory Guide 1.8, *Personnel Selection and Training/Qualification and Training of Personnel for Nuclear Power Plants*
- Regulatory Guide 1.33, *Quality Assurance Program Requirements (Operations)*
- NUREG-0761, Revision 2, July 1981, "Contents of Radiation Protection Plans for Nuclear Power Reactor Licensees."

As of January 1, 1994 (with earlier compliance encouraged), the maximum permissible limits for occupational radiation exposure delineated in 10 CFR 20, Subpart C, "Occupational Dose Limits," Section 20.1201, "Occupational Dose Limits for Adults," are to be implemented. The NRC listed several objectives in revising 10 CFR 20. A primary objective was to "implement the principal current dose-limiting recommendations of the International Commission on Radiological Protection (ICRP)" by incorporating the ICRP effective dose equivalent (EDE) concept and requiring programs for "keeping radiation exposures as low as reasonably achievable (ALARA)."(25)

The following discussion of the revised 10 CFR 20, as it relates to the radiological protection of workers, has been extracted from References 26 and 27. The ICRP EDE concept essentially says that one rem from external exposure is no different from one rem due to internal exposure. In addition, with the revision of 10 CFR 20, internal dose (committed effective dose equivalent) and external whole-body dose (deep dose equivalent) must be added to obtain the total effective dose equivalent (TEDE), which is limited to 5 rem (0.05 Sv) per year. There is no quarterly limit, although the NRC fully expects that licensees will prorate the 5 rem quarterly.

The revision of 10 CFR 20 is based on the 1977 recommendations of the ICRP - which the NRC began reviewing soon after - and is "generally consistent" with 1987 recommendations of the National Council on Radiation Protection and Measurements (NCRP). The changes reflect basic changes in the philosophy of protection and update scientific information on radionuclide uptake and metabolism and the biological effects of ionizing radiation. The revision implements the 1987 Presidential guidance on occupational radiation protection. The major changes to 10 CFR 20 include the following:

- greater emphasis on numerical risks
- control of dose by use of the sum of internal and external doses
- greater equality in treatment of external and internal doses
- use of the committed effective dose equivalent for internal exposures rather than the critical organ approach
- wider selection of methods for estimating radionuclide intakes and internal doses.

The revised rule also eliminates the use of the cumulative lifetime dose limit of 5(N-18), where N is the age of the worker in years. No lifetime dose is specified because if the magnitude of the annual dose is limited, there is a de facto limitation of the lifetime dose that can be received.

I.2.3 Public Radiation Safety

Public radiation exposure that results from decommissioning the reference PWR must also comply with 10 CFR Part 20. Currently, the maximum public exposure limits for external exposure are specified in 10 CFR 20.105, "Permissible Levels of Radiation in Unrestricted Areas." Limits for internal exposure pathways are given in 10 CFR 20.106, "Radioactivity in Effluents to Unrestricted Areas." As in the case of occupational exposure, 10 CFR 20.1(c) requires application of the ALARA principle to the control of public radiation exposures and releases of radioactive materials to the environs. In addition, a plant undergoing decommissioning must meet the design requirements of Appendix I to 10 CFR Part 50.

As of January 1, 1993 (with earlier compliance encouraged), the maximum permissible limits for public radiation exposure are delineated in 10 CFR 20, Subpart D, "Radiation Dose Limits for Individual Members of the Public," Section 20.1301 "Dose Limits for Individual Members of the Public" became effective. The major changes to 10 CFR 20 concern:

- Explicit limits on public doses - 0.1 rem (1 mSv) per year [a temporary 0.5 (5 mSv) rem per year limit is available upon NRC approval]; the previous requirement was an implicit limit of 0.5 rem per year.

- The dose in any unrestricted area from external sources does not exceed 0.002 rem (0.02 mSv) in any one hour. (Note: This Part 20 dose requirement is separate from current decommissioning site release criteria discussed in Section I.1.2.1.)

The Environmental Protection Agency (EPA) public exposure limits are defined in Title 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*; specifically Subpart A, *Environmental Standards for Management and Storage*, July 1, 1990. Section 191.01 states that the EPA limits apply to the radiation doses received by members of the public as a result of the management (except transportation) and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at any facility regulated by the NRC or by Agreement States, to the extent that such management and storage operations are not subject to the provisions of Part 190 of Title 40.

It is further stated in Section 191.03, *Standards*, that management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

I.2.4 Special Nuclear Materials Management

Safeguards and security precautions must continue after plant shutdown until all special nuclear materials that come under regulatory control are removed from the plant. Regulations defining the required precautions are found in 10 CFR Part 70, *Domestic Licensing of Special Nuclear Materials* and 10 CFR Part 73, *Physical Protection of Plants and Materials*. The principal concern is to protect against acts of industrial sabotage that could endanger the safety of the work force and the public.

I.2.5 Radioactive Waste Management

Regulations that govern the packaging and transport of radioactive materials are designed to prevent the dispersal of radioactivity to the environs and to protect the public and the transportation workers during shipment. There is some overlapping of federal responsibility for regulating the safe packaging and transport of radioactive materials. This responsibility lies primarily with the Department of Transportation (DOT) and secondarily with the NRC.

The following subsections describe packaging and transportation regulations and licensing requirements for land disposal of radioactive wastes associated with decommissioning radioactive waste management.

Packaging and Transport Regulations

The DOT is responsible for safety standards governing packaging and shipping containers and for their labeling, classification, and marking. The NRC develops performance standards and reviews designs for Type B, fissile, and large-quantity packages. The DOT requires NRC approval to use these packages. The DOT also implements safety standards for the mechanical condition of carrier equipment and for the qualifications of carrier personnel. The Federal Aviation Administration (FAA), the Interstate Commerce Commission (ICC), the U.S. Coast Guard, and the U.S. Postal Service also exercise some regulatory authority over the shipment of radioactive materials.

Shipments of radioactive material utilizing NRC-approved packages must be in accordance with the provisions of 49 CFR 173.471, "Requirements for U.S. Nuclear Regulatory Commission Approved Packages," and 10 CFR Part 71, *Packaging and Transportation of Radioactive Material*, as applicable. In satisfying the requirements of Section 71.12, "General License: NRC Approved Package," it is the responsibility of the licensees to insure themselves that they have a copy of the current approval and conduct their transportation activities in accordance with an NRC-approved quality assurance program. Note that the general license of 10 CFR 71.12 does not authorize the receipt, possession, use, or transfer of byproduct, source, or special nuclear materials; such authorization must be obtained pursuant to 10 CFR Parts 30 to 36, 40, 50, or 70.

By Federal Register notice dated December 21, 1990,(28) the DOT promulgated a final rule which comprehensively revises the Hazardous Materials Regulations (HMR; 49 CFR Parts 171-180) with respect to hazard communication, classification and packaging requirements. The changes are based on the United Nations Recommendations on the Transport of Dangerous Goods (U.N. Recommendations) and DOT's Research and Special Programs Administration's (RSPA) own initiative. They are made because the existing HMR are: (1) difficult to use because of their length and complexity; (2) relatively inflexible and outdated with regard to non-bulk packaging technology; (3) deficient in terms of safety with regard to the classification and packaging of certain categories of hazardous materials; and, (4) generally not in alignment with international regulations based on the U.N. Recommendations. The changes: (1) simplify and reduce the volume of the HMR; (2) enhance safety through better classification and packaging; (3) promote flexibility and technological innovation in packaging; (4) reduce the need for exemptions from the HMR; and (5) facilitate international commerce.

In addition to complying with NRC's requirements in 10 CFR Part 71, each licensee who transports licensed material outside of the confines of its plant or other place of use, or who delivers licensed material to a carrier for transport, shall comply with the applicable DOT requirements in 49 CFR Parts 170 through 189.

Land Disposal Regulations

By Federal Register notice dated December 27, 1982,(29) the NRC promulgated a regulation governing the land disposal of low-level radioactive waste (LLW): 10 CFR 61, *Licensing Requirements for Land Disposal of Radioactive Waste*. The new regulation established three classes of LLW, based on radiological hazard, and provides minimum waste form and stability requirements and near-surface disposal requirements for the land burial of these wastes. The categories were identified as Class A, Class B, Class C, and Greater-Than-Class C (GTCC), depending upon the contained concentrations of specific short-lived and long-lived radionuclides. Class A waste contains the lowest radionuclide concentrations and must meet only minimum waste form requirements. Class B and C wastes contain higher radionuclide concentrations and must meet both the minimum waste form and the stability requirements of Section 61.56. Class C waste must be disposed of by use of methods that provide added protection against inadvertent intrusion into the burial ground. Categories A, B, and C are acceptable for land disposal.

Those wastes whose radionuclides concentrations exceeded the maximum allowed for land disposal, GTCC, were required to be stored pending further determination. This determination was provided in an amendment to 10 CFR 61 (Part 61.55, "Waste Classification") published in the Federal Register dated May 25, 1989, wherein all GTCC wastes are to be disposed of in a geologic repository, or in an approved alternative. In related legislation passed by Congress in 1985 (Low-Level Radioactive Waste Policy Amendments Act of 1985), the U.S. Department of Energy (DOE) was assigned the responsibility for the disposal of GTCC wastes. Under this legislation, DOE must provide the capability for disposal of the GTCC wastes, but the waste generator must pay for the service. Thus, the costs of disposal of GTCC wastes resulting from decommissioning activities are a legitimate decommissioning expense.

In effect, the amendments to 10 CFR 61 treat GTCC as if it were high-level waste, which is what the DOE intends to bury in its repository. However, the NRC has stated it does not consider this action to be a redefinition of GTCC as HLW. The supporting text to the most recent amendments to 10 CFR 61, published in the Federal Register on May 25, 1989, addresses the matter of considering GTCC as a separate class of intermediate-level waste as follows: "It is the Commission's view that intermediate disposal facilities may never be available....At the same time, the Commission wishes to avoid foreclosing possible use of intermediate disposal facilities," by the DOE.(30)

In the analysis of the decommissioning of the reference PWR reported previously in NUREG/CR-0130, it was assumed that the LLW from decommissioning could be disposed of by near-surface burial at a licensed shallow-land burial ground. This assumption was reevaluated by Murphy(31) in terms of the established requirements contained 10 CFR Part 61, which took effect on January 23, 1983. Based upon the 1983 regulation (10 CFR 61), Murphy's reevaluation concluded that the neutron-activated stainless steel core shroud and the lower grid plate have such high concentrations of Ni-59, Ni-63, and Nb-94 that they exceed the Class C limits of 10 CFR 61. The radioactivity of the lower core barrel and the thermal shields also exceeds Class C limits by a small amount. These materials are generally unacceptable for routine near-surface disposal. Therefore, this reevaluation of decommissioning the reference PWR now includes rough estimates for storage and geologic disposal of these materials.

Some additional requirements directed primarily at waste generators and handlers were concurrently published as a new Section 20.311, "Transfer for Disposal and Manifests," of Part 20, "Standards for Protection Against Radiation." The effective date of 10 CFR 20.311 was December 27, 1983. Subsequently, the NRC announced in January 1991, the availability of a revised Staff Technical Position entitled "Technical Position on Waste Form (Revision 1)." This technical position on waste form was initially developed in 1983 to provide guidance to both fuel-cycle and non-fuel-cycle waste generators on waste form test methods and results acceptable to the NRC staff for implementing the 10 CFR Part 61 waste form requirements. It has been used as an acceptable approach for demonstrating compliance with the 10 CFR Part 61 waste stability criteria. The Position (Revision 1) includes guidance on (1) the processing of wastes into an acceptable, stable waste form, (2) the design of acceptable high integrity containers, (3) the packaging of filter cartridges, and (4) minimization of radiation effects on organic ion-exchange resins. The regulation, 10 CFR 20.311, requires waste generators and processors to certify that their waste forms meet the requirements of Part 61 (including the requirements for structural stability). The recommendations and guidance provided in the Technical Position (Revision 1) are an acceptable method upon which to base such certification by waste generators.

Because of their subsequent potential impact on legally-disposable LLW from decommissioning, a brief historical review of U.S. LLW disposal facilities and selected regulations that impact their licensing and operation follows.

Six commercially operated LLW disposal facilities have been licensed and operated since the AEC's announcement in 1960 that regional land disposal sites for commercially generated LLW should be established and that the sites should be operated by the private sector, subject to government licensing authority. These facilities are located in Beatty, Nevada; Maxey Flats, Kentucky; West Valley, New York; Richland, Washington; Sheffield, Illinois; and Barnwell, South Carolina. The Beatty facility, which opened in 1962, was the first to begin commercial disposal operations; the Barnwell facility, which opened in 1971, was the last. Four of those facilities (Maxey Flats, West Valley, Sheffield, and Beatty) have since closed. The other two facilities (Richland and Barnwell) are still operating successfully and dispose of all the commercial LLW currently generated in the United States.

The problems experienced in the developmental years of commercial LLW disposal led to the recognition that the regulations controlling the licensing of radioactive materials did not contain sufficient technical standards or criteria for the disposal of radioactive waste.[12] More comprehensive standards, technical criteria, and licensing procedures were needed for the licensing of new disposal sites, the operation of the existing sites, and for the final closure and stabilization of all sites.

Title 10 Code of Federal Regulations, Part 61 also established a series of performance objectives and technical and financial requirements which a LLW disposal site and site operator must meet in order to ensure public health, safety, and long-term protection of the environment. The regulation established four performance objectives: a) to protect the general population from releases of radioactivity, b) to protect any individual who inadvertently enters a disposal site after the site is closed, c) to protect workers during site operations, and d) to ensure long-term stability at disposal sites to eliminate the need for ongoing active maintenance after closure.

Technical requirements were established for site selection, design, operation, and closure as well as for environmental monitoring, waste classification, and waste characteristics. Specifically, two of the technical requirements established during the regulatory reform years of 1980-1983 have the potential for impacting decommissioning costs. They are: a) sites must have characteristics which maximize long-term stability and isolation of waste and ensure that performance objectives are met (site characteristics and performance must be evaluated for at least a 500-year period) and b) to reduce subsidence or cracking of the caps or barriers covering the waste, all LLW must be placed in the disposal unit in a way that maintains the integrity of the waste package and permits voids to be filled.

Special technical requirements were also established for waste form. These requirements included: (a) waste must not be packaged for disposal in cardboard or fiberboard boxes; (b) liquid waste must be solidified or packaged in absorbent material; (c) wastes that generate toxic fumes or are spontaneously flammable or explosive are prohibited; (d) waste form or high integrity containers (HICs) used to provide structural stability must maintain gross physical properties and identity for 300 years, under the expected disposal conditions, and (e) void spaces must be reduced to the extent practicable.

Nevada, South Carolina, and Washington passed additional regulations to ensure that the transportation and packaging problems they had experienced in the earlier years of operation would not be repeated. In general, these state regulations required radioactive waste shippers to: (a) purchase transportation permits and liability insurance, (b) certify that the shipment and transport vehicle have been inspected and comply with applicable state and federal laws, and (c) notify the disposal facility prior to shipment of waste. In addition, the regulations impose penalties ranging from $1,000 to $25,000 in fines and possible suspension or revocation of the permit.

In summary, the current system for management of LLW evolved over a period of time when disposal capacity was available and costs were low. Disposal capacity currently exists at two sites: Barnwell, South Carolina and Hanford, Washington. South Carolina and Washington have decided to cut back on the amount of waste they will accept from other states. Furthermore, the volume of waste generated is on the rise despite improved volume-reduction techniques. Disposal costs have risen as well, as have costs for transporting the waste as much as 3,000 miles to accommodate current volume ceilings at the existing disposal sites.

---

[12] Inadequate waste form was one of the most significant factors leading to the difficulties experienced at the closed sites. Waste forms sent to the sites reflected general practices of the times. Licensees were encouraged to send all suspect wastes for disposal, and waste minimization and volume reduction were not required. Most of the waste that was disposed of at the sites is believed to have been either composed of very easily degradable material or packaged so that large void spaces existed within the waste or between the waste and the packaging. Some of the waste packages (such as cardboard and fiberboard boxes) were often easily degradable. Also, the wastes often contained chemical agents that enhanced waste degradation and leaching of radionuclides. Frequently, these easily degraded wastes contained little or no radioactivity. Early operating practices also contributed to rapid waste degradation, subsequent slumping of the trench covers, and influx of precipitation. Problems of this kind have not been experienced at the two sites still in operation.

When Congress enacted the Low-Level Radioactive Waste Policy Act of 1980 and subsequent amendments in 1985, it set in motion major changes in the national low-level waste disposal program:

- As of January 1, 1993, each state will be responsible for providing its own disposal facilities for low-level waste. That includes all 50 states and the District of Columbia.

- The most efficient method would be through regional compacts, which would provide a central disposal facility for several neighboring states. Congress must endorse the creation of each compact in advance and renew the approval every five years.

- After January 1, 1993, any state can refuse to accept low-level waste from other states that are not members of its regional compact. Essentially, this means that a state must enter into a regional agreement, establish its own disposal facility, or stop generating low-level waste.(32)

The lessons learned during the developmental years of commercial LLW disposal led to regulatory reform of the system under which disposal is conducted. Improvements in the form of waste that is disposed of, as well as in site selection, characterization, operations, monitoring and post-closure care, have significantly reduced the likelihood that a new LLW disposal facility will require costly remediation in the future.

In addition to the aforementioned technical improvements, many states and compacts have also imposed requirements for additional engineered barriers (generally concrete waste packages or disposal cells) to reinforce public confidence that the waste will be safely isolated from the environment while it decays to background levels. Although the long-term benefit of engineered barriers over carefully selected natural barriers is a topic of much discussion and technical analysis, the selection of multiple barrier systems illustrates the degree to which state and compact officials have responded to public concerns that disposal of LLW should pose as little risk to public health and safety as reasonably possible. However, it should be recognized that the costs of any changes/improvements will ultimately be paid for by the waste generators.

On April 30, 1991, the NRC renewed in its entirety Chem-Nuclear Systems Incorporated's license to receive, possess, store, and dispose of special nuclear material (SNM) at its commercial LLW disposal facility located near Barnwell, South Carolina. The license was renewed in its entirety for five years.(33)

I.2.6 Industrial Safety

During active decommissioning of a PWR, industrial safety and occupational work conditions are regulated by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor under 29 CFR Parts 1900 to end.

Hazardous waste operations are defined as any work within a facility, site, or area that has been deemed as a hazardous waste site. Work may include sampling, logging, drilling, excavating, monitoring, and remediation activities. Such work may be governed by a written, customized Health and Safety Plan (HSP) that meets the intent of the requirements established in 29 CFR 1910, *Occupational Safety and Health Standards*, and 29 CFR 1926, *Construction Safety and Health Standards*, with specific emphasis being applied to 29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response."

The OSHA requirements delineated in 29 CFR 1910.120 that dictate experience for team members are imposed to protect the worker. 29 CFR 1910.120 requires that all hazardous waste workers receive at least three days (24 hours) experience on a bona fide hazardous waste site under the direct supervision of an experienced hazardous waste worker with similar duties. Specific training and certification in such areas as radiological safety, asbestos removal and handling, and hearing protection may also be required. For example, if an asbestos abatement worker is to be assigned work on a hazardous waste site, that worker must either verify that he/she has the necessary hazardous waste experience, or must be assigned to a worker who has been verified as an experienced hazardous waste worker. For decommissioning workers, applicable state, local, or licensee requirements may be imposed as well. A thorough prejob analysis will help determine the level of training required. In addition, it is expected that the onsite project manager or team leader have relevant work experience, e.g., mixed waste characterization, mixed waste remediation, or soil removal.

I.2.7 Other Statutory and Regulatory Requirements

The Environmental Protection Agency (EPA) develops, promulgates, and enforces environmental protection standards and regulations as directed by statutes passed by the U.S. Congress. Environmental regulations and standards of potential relevance to decommissioning the reference PWR are those promulgated by the EPA under the Atomic Energy Act (AEA), the Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

As reported in Reference 34, regulation of mixed radioactive/hazardous waste (i.e., mixed waste) by the EPA and the NRC is largely duplicative, and that situation is not likely to change in the near future. In fact, regulations are likely to become more complex and burdensome in the future. States are authorized to promulgate mixed waste regulations under the RCRA as long as their regulations are no less stringent than applicable federal regulations. States, however, have been slow to apply for and receive authorization to regulate mixed waste under their approved RCRA programs; in fact, as of January 24, 1991, only 24 states and territories had been authorized to regulate mixed waste.

The NRC and the EPA have been working together for several years to resolve the issues associated with mixed waste. The agencies conducted a survey of generators of commercial mixed radioactive/hazardous waste and are completing two joint technical guidances on testing and storage of such wastes. Oak Ridge National Laboratory, which conducted the voluntary generator survey for the two agencies, sent out questionnaires to over 1,300 potential mixed waste generators in November 1991. The results of the survey, presented in NUREG/CR-5938,(35) have been used to develop a national profile that is expected to provide needed information to states and compact officials, private developers, and federal agencies to assist in planning and developing adequate disposal capacity for LLW, including mixed waste, as mandated by the LLRWPAA of 1985. The report also contains information on existing and potential commercial waste treatment facilities that may provide treatment for specific waste streams identified in the national survey. The report provides a reliable national database on the volumes, characteristics and treatability of commercial mixed waste in the United States. Data from the survey also may serve as a basis for possible federal actions to effectively manage and regulate the treatment and disposal of mixed waste.

The NRC and the EPA also are developing a joint guidance on safe storage of mixed waste. Given the current lack of treatment and disposal capacity for most mixed wastes, both agencies are concerned with long-term problems that could arise from storage of such wastes. The joint guidance will address issues associated with onsite storage, including inspection and surveillance of waste, waste compatibility and segregation, storage container requirements, and time limitations on storage of untreated waste. For each issue, the agencies are attempting to identify acceptable practices.(36)

The EPA has set some treatment standards for mixed waste. Incineration is an applicable technology for LLW combined with organic compounds in wastewater and non-wastewater, as well as D001 ignitable liquids (listed waste under RCRA). Vitrification is specified as an acceptable technology for transuranic and high-level wastes containing both highly radioactive compounds and hazardous components.(34)

Scientific Ecology Group, Inc. (SEG) in Oak Ridge, Tennessee, is the nation's largest LLW processor. SEG has applied for permits and a license to operate the first commercially available incinerator for solid and liquid mixed waste. The incinerator is currently licensed only for LLW. The company submitted an RCRA Part A permit application in March 1991.(34) The associated Part B permit application was submitted to the Tennessee Division of Solid Waste in early 1993. These permits, when granted, will allow SEG to store and treat characteristic hazardous wastes.

In instances where regulatory authority can be delegated, the EPA may delegate regulatory authority to the state for state programs that meet or exceed EPA requirements. Where regulatory authority is not delegated (e.g., CERCLA), the EPA is responsible for reviewing and evaluating compliance with the EPA regulations. This includes interpreting regulations and consulting with reactor owners and their contractors to aid regulation implementation and inspection of facilities at the sites.

I.2.8 License Termination and Facility Release

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.

As discussed in the Supplementary Information contained in the decommissioning rule,(1) acceptable levels of residual radioactivity for release of property for unrestricted use were not proposed as part of the rulemaking. Criteria for residual radioactive contamination are being developed by the NRC as part of a major rulemaking effort currently underway.

I.3 Continuing Care

Continuing care is a subcategory of SAFSTOR and deals with the surveillance and maintenance of the plant in a safe storage mode. The NRC staff reviews the decommissioning alternatives submitted by the licensee against the applicable regulations. Primary concerns during this period are for public and occupational safety and for licensing. Safeguards and security precautions as discussed in Section I.2.4 are required until the spent nuclear fuel inventory is reduced to zero.

I.3.1 Public and Occupational Safety

Requirements for public and occupational safety during the continuing care phase of decommissioning remain identical to those during active decommissioning (see Sections I.2.2 and I.2.3). The requirements in this area are specified by the possession-only license, which likely will not be changed for continuing care.

I.3.2 Licensing

The NRC possession-only license remains in force during SAFSTOR. Regulatory Guide 1.86 and 10 CFR 50.82, "Application for Termination of License," present the guidance and regulations, respectively, for terminating the license at the end of SAFSTOR. In most cases, some dismantlement will be required to ensure that the contamination levels in the plant are at or below acceptable residual contamination levels. The regulatory requirements discussed in Sections I.1.1 and I.2.8 of this chapter will apply in these cases.

I.4 Selected Regulatory Aspects Associated with Decommissioning Prematurely Shutdown Plants

The following information concerning the regulatory process for decommissioning prematurely shutdown plants is extracted from NUMARC 92-02 (draft report).(37) The current regulations in 10 CFR 50 focus primarily on the design, construction, and operation of nuclear facilities. Although 10 CFR § 50.82 "Application for Termination of License" allows a licensee to apply to the NRC for the authority to surrender its license voluntarily and decommission its facility, there are a myriad of regulatory issues that become ambiguous, or are undefined, when a licensee decides to shut down its facility permanently.

With the recent premature closing of several nuclear power stations, licensees, NRC, and the Nuclear Management and Resources Council, Inc. (NUMARC) have recognized the need for a uniform nuclear plant closure and decommissioning policy. The NUMARC 92-02 draft report presents:

- guidance on activities that can be accomplished after premature plant closure;
- a discussion of the regulations applicable to a plant as it proceeds from cessation of operations through preparation for decommissioning activities, including issues utilities may face with regards to supporting their permanently shutdown nuclear facility;
- a review of the current regulatory process for decommissioning, including a regulatory summary;
- a review of a number of "case histories" of prematurely shutdown facilities, including a comparison of their decommissioning approaches and common features so that facilities can use this information for early decommissioning planning.

Prematurely shutdown plants have been submitting documents to gain regulatory and economic relief and to begin the decommissioning process. Because there is no defined set of documentation to achieve these objectives, each plant has submitted its own unique series of documents to the NRC for approval. Although each facility has experienced different circumstances leading to permanent shutdown, the post-shutdown status and condition of the plants were similar in many respects.

When a plant is shut down prematurely, it is likely that the licensee has not fully prepared for permanent plant closure or decommissioning. It is also likely that the licensee has not yet submitted its application to terminate the operating license or completed its proposed decommissioning plan. To minimize the cost of supporting a prematurely shutdown nuclear reactor, it is essential that a utility act quickly to reduce the number and scope of regulatory programs applicable to its prematurely shutdown facility that are no longer applicable or needed to protect public health and safety. NUMARC 92-02 discusses a plan to provide a smooth transition through these phases and considerations as to the most effective way to address these issues. In addition, a step-by-step licensee/NRC action plan for decommissioning is included in the report.

Currently, there is no definition or criteria for a possession-only license (POL) in the Code of Federal Regulations. However, as a result of recent closures, there has been much discussion concerning what a POL is and what its implications are. The NUMARC 92-02 draft report reviews the impact of the POL on plant closure and decommissioning, including the generic issues impacting decommissioning along with the regulatory basis for relief (e.g., § 50.59 evaluation process, National Environmental Policy Act, Decommissioning Funding, Annual Operating Fees). The report also identifies the 10 CFR sections for which an exemption should be submitted to the NRC relative to a POL.

The following selected conclusions are drawn from the NUMARC 92-02 draft report:

- Decommissioning a prematurely shutdown nuclear plant involves much more than decontaminating and dismantling the facility to permit its release for unrestricted use, and allow for termination of its license.
- Future rulemaking on decommissioning is needed because the present regulations and associated guidance do not address prematurely shutdown plants and all phases of the process once a plant is prematurely shutdown. Until such rulemaking is completed, utilities must be aware of, and plan for, the cost of maintaining their prematurely shutdown facilities until they are issued a POL and gain approval of their proposed decommissioning plan.

I.5 Decommissioning After a 20-Year License Renewal Period

The NRC is proposing to amend its regulations to establish new requirements for environmental review of applications to renew operating licenses for nuclear power plants. The proposed amendments would define the number and scope of environmental impacts that would need to be addressed as part of a license renewal application.

As reported in Reference 38, the physical requirements and attendant effects of decommissioning nuclear power plants after a 20-year license renewal period are not expected to be different from those at the end of the current 40-year license period. While license renewal would not be expected to change the ultimate cost of decommissioning, it would reduce the present value of the cost. The socioeconomic effects of decommissioning will depend on the magnitude of the decommissioning effort, the size of the community, and other economic activities at the time. However, the NRC does not expect that the impacts would be increased by decommissioning at the end of a 20-year license renewal period rather that at the end of the current license term. Because the NRC can reach a generic conclusion on the acceptability of the incremental impacts of decommissioning for all plants, impacts on decommissioning need not be evaluated for each plant license renewal application.(38)

The NUREG reports and regulatory guides mentioned in this appendix are available for inspection and copying for a fee under the decommissioning file docket 43 FR 10370, at the Commission's Public Document Room, 2120 L Street NW, Washington, DC 20036. NUREG reports and final regulatory guides are available for purchase from the National Technical Information Service, Springfield, VA 22161; and from the Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7982. Free single copies of draft regulatory guides are available on request from the Division of Information Support Services, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

I.6 References

1. Federal Register. "General Requirements for Decommissioning Nuclear Facilities," Vol. 53, No. 123, pp. 24018-24056, June 27, 1988.

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

3. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

4. U.S. Nuclear Regulatory Commission Regulatory Guide 1.159 (Task DG-1003), "Assuring the Availability of Funds for Decommissioning Nuclear Reactors," August 1990.

5. U.S. Department of Energy, "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste," Code of Federal Regulations, Title 10, Part 961 (1990).

6. U.S. Department of Energy, "Annual Capacity Report," DOE/RW-0294P, Office of Civilian Radioactive Waste Management, Washington, D.C. (December 1990).

7. U.S. Department of Energy, "Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program," DOE/RW-0247, Washington, D.C. (November 1989).

8. U.S. Nuclear Regulatory Commission Draft Regulatory Guide (Task DG-1006), "Records Important for Decommissioning of Nuclear Reactors," September 1989.

9. Paul E. Fuller. 1987. "Decommissioning - An Insurance Perspective," Proceedings 1987 International Decommissioning Symposium, October 4-8, 1987, Pittsburgh, Pennsylvania.

10. *Nuclear News*. January 1990. "Proposed Amendments on Fees, Radiography," pp. 79-80.

11. *Nuclear News*. March 1991. "Advanced Reactor Reviews Boost NRC Requirements," p. 30.

12. NUREG-1307, Revision 2. July 1991. *Report on Waste Burial Charges - Escalation of Decommissioning Waste Disposal Costs at Low-Level Waste Burial Facilities.*

13. NUREG-0586. August 1988. *Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities.*

14. NUREG/CR-1481. July 1980. *Financing Strategies for Nuclear Power Plant Decommissioning*. Prepared by New England Conference of Public Utilities Commissioners, Inc., in conjunction with Temple, Barker and Sloane, Inc. for U.S. Nuclear Regulatory Commission.

15. J. J. Siegel. 1984. *Utility Financial Stability and the Availability of Funds for Decommissioning*. NUREG/CR-3899, U.S. Nuclear Regulatory Commission Report by Engineering and Economics Research, Inc.

16. J. J. Siegel. 1988. *Utility Financial Stability and the Availability of Funds for Decommissioning*. NUREG/CR-3899, Supplement 1, U.S. Nuclear Regulatory Commission Report by Engineering and Economics Research, Inc.

17. P. L. Chernick, et al. 1981. *Design, Costs and Acceptability of an Electric Utility Pool for Assuring the Adequacy of Funds for Nuclear Power Plant Decommissioning Expense*. NUREG/CR-2370, U.S. Nuclear Regulatory Commission Report by Analysis and Inference, Inc.

18. NUREG-1221. June 1988. *Summary, Analysis and Response to Public Comments on Proposed Amendments to 10 CFR Parts 30, 40, 50, 51, 70 and 72: Decommissioning Criteria for Nuclear Facilities.*

19. Federal Register. "10 CFR Part 50, Decommissioning Funding for Prematurely Shutdown Power Reactors," Vol. 56, No. 162, pp. 41493-41495, August 21, 1991.

20. Federal Register. "10 CFR Part 50, Decommissioning Funding for Prematurely Shutdown Power Reactors," Vol. 57, No. 132, pp. 30383-30387, July 9, 1992.

21. Federal Register. "10 CFR Part 50, Notification of Spent Fuel Management and Funding Plans by Licensees of Prematurely Shut Down Power Reactors," Vol. 58, No. 124, pp. 34947-34949, June 30, 1993.

22. *Nuclear News*. November 1992. "NEPA: Sweeping Changes on the Horizon ?, p. 22.

23. *Nucleonics Week*. "Utilities Face Slew of Options as Decommissioning Funds Grow," pp. 9-12, January 12, 1989.

24. NUREG-0800 (formerly issued as NUREG-75/087). June 1987. *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants - LWR Edition.*

25. Federal Register. "10 CFR Parts 19 and 20. Standards for Protection Against Radiation; Extension of Implementation Date," Vol. 57, p. 38588, August 26, 1992.

26. *Nuclear News.* March 1991. "Experts Discuss Adoption of Revised Requirements," pp. 36-38.

27. *Nuclear News.* July 1991. "Exposure Management: Lower Doses and Good Practices," pp. 43-48.

28. Federal Register. "Performance-Oriented Packaging Standards; Changes to Classification, Hazard Communication, Packaging and Handling Requirements Based on UN Standards and Agency Initiative," Vol. 55, No. 246, December 21, 1990, pp. 52402-52729.

29. Federal Register. "Licensing Requirements for the Land Disposal of Radioactive Waste," Vol. 47, No. 248, December 27, 1982, pp. 57446-57482.

30. *Nuclear News.* July 1989. "Greater-Than-Class-C Included by NRC Rule," p. 84.

31. E. S. Murphy. 1984. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station - Classification of Decommissioning Wastes.* NUREG/CR-0130, Addendum 3, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

32. DOE/NE-0085. November 1987. *Atoms to Electricity.*

33. U.S. Nuclear Regulatory Commission. 1991. "Safety Evaluation Report for Renewal of NRC License Number 12-135361-01 Issued to Chem-Nuclear Systems, Incorporated - April 1991.

34. *Hazardous Waste News*, July 1, 1991, pp. 256-257.

35. J. A. Klein, et al. December 1992. *National Profile on Commercially Generated Low-Level Radioactive Mixed Waste.* NUREG/CR-5938, U.S. Nuclear Regulatory Commission Report by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

36. *Nuclear Waste News*, August 29, 1991, pp. 342-344.

37. NUMARC 92-02 (Draft), July 1992. "Regulatory Process for Decommissioning Prematurely Shut Down Plants." Report by Nuclear Management and Resources Council, Inc., Washington, D.C.

38. Federal Register. "10 CFR Part 51, Environmental Review for Renewal of Operating Licenses," Vol. 56, No. 180, pp. 47016-47035, September 17, 1991.

Appendix J

Review of Decommissioning Experience Since 1978

Appendix J

Review of Decommissioning Experience Since 1978

A comprehensive review of the available experience in the decommissioning of nuclear facilities was presented in NUREG/CR-0130, published in 1978.(1) Since that time, additional decommissioning activities have occurred, including the total dismantlement of the Shippingport reactor. This appendix contains information on selected nuclear reactor decommissionings, both domestic and foreign, since 1978. Industrial activities with potential applications to decommissioning pressurized water reactors (PWRs) are described in Appendix K.

J.1 Domestic Experience in Decommissioning Nuclear Power Stations Since 1978

The decommissioning of nuclear reactor facilities is a relatively well-developed technology. In the United States, the term "decommission" means to remove (as a facility) 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).(2) Historically, decommissioning activities at nuclear facilities have not necessarily resulted in complete dismantlement of plant facilities for unrestricted use. In fact, the safe storage (mothballing, layaway, and entombment) approaches that have been used are now recognized as only one stage in the decommissioning process, leading to dismantlement/unrestricted release. The current NRC decommissioning regulations require that all decommissioning activities be completed within 60 years after termination of licensed power operations. Consideration will be given to an alternative that provides for completion of decommissioning beyond 60 years, only when it is necessary to protect health and safety.(3)

Previously, conventional wisdom suggested that all decommissioning methods start with removing all fuel and source material from the site. Of course, the 1978 study (NUREG/CR-0130) could not foresee the future provision delineated in the 1983 U.S. Department of Energy (DOE) contracts with utilities (10 CFR Part 961)(4) that would require spent fuel to undergo at least 5 years of radioactive decay before DOE will take possession of spent fuel. This provision impacts decommissioning activities by delaying, for up to 5 years, removal of the last core loading of spent fuel from a site and subsequent decontamination and dismantlement of the spent fuel storage facility.[1]

Information on selected nuclear reactor power stations decommissionings and/or shutdowns since 1978 is presented in Table J.1. Discussions of some of the significant reactor decommissionings follow, based on information excerpted from a United States General Accounting Office report,(5) unless indicated otherwise.

J.1.1 Shippingport Reactor, Shippingport, Pennsylvania

Over its 25-year life, Shippingport operated for about 80,324 hours, produced about 7.4 billion kilowatt-hours of electricity, and operated at varying power levels of 68, 150, and 72 megawatts-electric. The plant was shut down by its owner,

---

[1] The impact of the temporary storage of spent fuel at the reference PWR, until DOE takes possession, is addressed in Appendix D. A small staff would be required to provide security operations, maintenance, and radiation protection support. Some low-level radioactive wastes would also be generated due to operation of the water purification system for the spent fuel storage facility. Storage operations would continue to be under an NRC license.

Table J.1 Information on selected nuclear reactor decommissioning and shutdowns(a)

Facility name and location	Reactor type	Power rating, MWe	Type of decommissioning	License status	Monitoring system	Safe storage measures	Year decommissioned	Other information
Dresden 1, Morris, IL	BWR	200	SAFSTOR	POL(b)	-(c)	-	-	-
Fort St. Vrain, Platteville, CO	HTGR	330	DECON	POL	-	-	-	Onsite ISFSI Constructed
Hanford-N, Richland, WA	LGR	860	-	None; gov't owned	-	-	-	Defueled; dry lay-up since 1988
Humboldt Bay 3, Eureka, CA	BWR	63	SAFSTOR	POL	Continuous security force	Locked doors, security fence	-	Wet Storage of spent fuel onsite; Decommissioning Plan approved by NRC
Indian Point 1, Buchanan, NY	PWR	257	-	POL	-	-	-	Decommissioning Plan under review
LaCrosse, Genoa, WI	BWR	50	SAFSTOR	POL	-	-	-	Decommissioning Plan approved; SNF onsite
Pathfinder, Sioux Falls, SD	BWR	66	Dismantled(d)	Byproduct NRC	-	-	1992	Estimated dismantling cost $13M
Rancho Seco, Clay Station, CA	PWR	913	TBD(e)	POL(f)	Continuous security force	Locked doors, security fence	-	Spent nuclear fuel stored onsite
Shippingport, Shippingport, PA	LWBR(g)	72	Dismantled	Not NRC licensed	-	-	1989	Decommissioning cost $91.3M; took 4 years
Shoreham, Brookhaven, NY	BWR	809	DECON	POL(h)	-	-	-	See footnote (i)
Three Mile Island 2, Londonderry Twp., PA	PWR	792	-(j)	-	-	-	-	-

(a) With the exceptions of Pathfinder (closed in October 1967), Indian Point 1 (closed in October 1974), Humboldt Bay 3 (closed in July 1976), and Dresden 1 (closed in October 1978), the remaining reactors shown in the table were shut down permanently in the post-1978 time frame.
(b) POL = Possession-Only License (10 CFR Part 50).
(c) Dash indicates information is unavailable from the literature or is not applicable.
(d) The Pathfinder reactor was shut down in 1967 and placed in safe storage until dismantlement began in 1990.
(e) TBD = To Be Determined.
(f) In accordance with the results of a public referendum on June 6, 1989, the owner of the Rancho Seco unit decided to shut it down and notified the NRC of its intent to decommission the plant. A decommissioning plan was submitted to the NRC in May 1991.
(g) Converted to a light water breeder reactor on October 1, 1977.
(h) The POL was issued for Shoreham on June 14, 1991, but may not be effective because of possible lawsuits. The decommissioning plan is under review by the NRC.
(i) The Shoreham unit achieved criticality and produced power, but closed before it could begin commercial operation.
(j) The TMI-2 reactor is defueled and in a Post-Defueling Monitored Storage (PDMS) condition, similar to SAFSTOR. The licensee's application for a POL is currently under review.

Duquesne Light Company, in October 1982. In 1983, The Energy Daily reported that the $60- to $70-million job of decommissioning the reactor was expected to start in March 1984.[6] However, actual decommissioning activities began in September 1985. At the time of shutdown, the radioactivity in the pressure vessel was about 30,000 curies; at the outset of decommissioning, it was about 17,000 curies.

DOE generally met the goals it had established for Shippingport. It completed all decommissioning activities in December 1989 - 4 months ahead of schedule - at a cost of $91.3 million, $7 million under its 1986 estimated cost. The most significant benefit of Shippingport was that DOE demonstrated that technology existed to decommission a plant within the costs and time frame established. One objective of the Shippingport project was to demonstrate that a nuclear power plant could be safely and economically decommissioned using existing technology, such as manually dismantling radioactive piping systems and components. Thus, DOE did not design the project to increase the basic research and development knowledge on methods or equipment needed to decommission a large plant. It relied on technology that the nuclear industry had used for the last 30 years to construct, maintain, or demolish plant systems and components. As a result, DOE did not need, nor was it required, to develop new technology, such as robotics, to decommission Shippingport.

Very few utilities will be able to decommission their plants the way DOE decommissioned Shippingport, and it is possible that newer technology may be available by the time utilities do so. To illustrate, Shippingport was much smaller and less radioactively contaminated than other plants, and DOE removed the most highly radioactive component, the reactor pressure vessel, in one piece. Utilities operating commercial plants will probably have to disassemble (cut-up) the reactor pressure vessels, because of their much larger sizes, in a manner similar to the disassembly procedure used for the Elk River Reactor pressure vessel in the early 1970s. For the Elk River Reactor disassembly, a full test development program was carried out on the cutting processes and a manipulator for remote handling of the cutting torches was developed. Also, DOE disposed of all the low-level radioactive waste from the Shippingport decommissioning activities at its Hanford, Washington, facility. Utilities will have to dispose of waste at commercial sites at substantially higher costs.

Because of the demonstration nature of the Shippingport decommissioning project, DOE used a relatively elaborate management structure. To extend decommissioning experience and knowledge to the private sector, DOE used over eight contractors to conduct the physical activities, and three management contractors to oversee those activities. Only about 30% of DOE's costs related to the actual physical decommissioning activities; the remaining 70% included engineering, oversight, management, and other activities, such as waste disposal (see Table J.2).

Shippingport was not licensed by the NRC; therefore, DOE did not have to obtain NRC's approval for the decommissioning activities conducted at the plant. However, DOE established a formal site release criteria that limited the radiation exposure from the decommissioned site to less than 100 mrem/yr and as low as reasonably achievable for the maximum-exposed individual. The decommissioned site fully met the criteria, with a calculated maximum exposure of 2 mrem/yr for the worst-case plausible scenario. A site release certification was prepared for each of the 75 subdivisions of the Shippingport site. It contained the data that confirmed the conformance to the release criteria. The decommissioning operations contractor issued a Post Remedial Action Report that was used by DOE as a summary document, distilling key information of site history, decontamination reports, limiting conditions for release criteria and radiological status.

The following conclusions pertaining to the Shippingport decommissioning project are drawn directly from Reference 5:

- Utility executives that the GAO investigators contacted said the lessons learned from DOE's planning efforts at Shippingport could facilitate their planning for future decommissioning projects.

- Shippingport provided only limited information to reduce worker exposures on future projects where the pressure vessel would be cut-up. (In the decommissioning plan, DOE's contractor proposed a worker exposure limit of about 1,010 person rem for the project; the actual exposure was 155 person rem.)

Table J.2 Summary of Shippingport decommissioning costs[a]

Cost category	Approximate cost ($ millions)	Approximate percent of total
Phase I Engineering	6.1	7
Operations Project Management (DOE)	10.5	11
Decommissioning Operations Contractor (DOC)	16.6	18
Site Management and Support	38.9	42
Home Office Support	1.6	2
Physical Decommissioning Activities	28.6	31
Fee	5.4	6
Total DOC Costs	74.5	81
Other	0.2	<1
	0.2	
Total, Decommissioning Costs	91.3	100

(a) Costs shown in the table are derived from information contained in Reference 7.

- With the exception of Northern States Power, which has removed the pressure vessel from Pathfinder in one piece, there is little evidence that Shippingport influenced other decommissioning projects. DOE developed extensive information on Shippingport, but the usefulness of the data will diminish as the utilities defer decommissioning of their plants.

- DOE did not develop any new technology, such as remotely operated equipment or robotics, to decommission Shippingport because one of the project's objectives was to demonstrate that a nuclear plant could be safely and economically decommissioned using existing technology.

- Lastly, DOE had predetermined sites to dispose of the spent (used) fuel from Shippingport as well as the low-level and mixed waste generated from decommissioning activities. DOE sent the spent fuel to its Idaho National Engineering Laboratory and the low-level waste to a government disposal facility at Hanford. Currently, no disposal site exists for the spent fuel from commercial plants; DOE expects that the earliest a permanent disposal site would be available is 2010.

J.1.2 Pathfinder Reactor, Sioux Falls, South Dakota

Pathfinder, a 66-MWe boiling water reactor (BWR), was placed in passive safe storage by its owner, Northern States Power Company (NSPC). The reactor was shut down in 1967, and the plant was converted to fossil-fueled operation. NSPC started to decontaminate the plant in 1968 after removing the spent fuel and shipping it offsite. The modification of the turbine cycle equipment, at a cost of about $3.6 million, was the major activity. This equipment still has 0.041 curies of residual radioactivity, and thus requires an NRC Part 30 license.(8)

Pathfinder's piping and turbine components were decontaminated during the plant conversion process. Decontaminating fluids were placed in barrels, solidified, and shipped for burial. Over 300 0.2-m^3 barrels of solidified waste were removed from the site. The utility removed all contaminated pipe outside the reactor and fuel handling buildings, drained and filled the reactor pressure vessel with gravel and grouted it in place. The utility did not decontaminate the piping system inside the reactor building and left it in place. After partially decontaminating the reactor and fuel handling buildings, NSPC sealed the areas in 1971 to prevent unauthorized access. The cost of this Phase 1 decommissioning work was $1.87 million.(9)

In 1990, NSPC began to decontaminate the previously sealed areas. The onsite decommissioning staff averaged only 30-35 full-time employees, occasionally supplemented with outside contract personnel, such as for the reactor pressure vessel (RPV) lift. The utility disposed of most of the low-level radioactive waste at a commercial site operated by U.S. Ecology in Richland, Washington. Because of the weight (290 tons) and size (12 feet x 32 feet) of the RPV (in one piece) and the shipping package, the utility rented a special railcar and train to transport it.(9) The RPV was buried at the U.S. Ecology-Richland site in August 1991.

Pathfinder's decommissioning cost, through July 1992, was $12.31 million. Cost projections were reevaluated in August 1992 based on accomplishments to date and forecasts for future expenditures. The revised projections reflect a total project cost estimate of about $13.0 million, down from a June 1991 cost estimate of $13.38 million, and an original cost estimate of $16.0 million (to green field condition). The reduction in the August 1992 cost estimate resulted from costs for RPV shipment and burial being less than anticipated.(10)

J.1.3 Fort St. Vrain Reactor, Platteville, Colorado

Fort St. Vrain, a 330-MWe high-temperature gas-cooled reactor (HTGR), is owned by the Public Service Company (PSC) of Colorado. The plant began commercial operation in 1979. In August 1989, the utility shut the plant down after years of operating problems. During its lifetime, Fort St. Vrain operated for about 21,360 hours, generating about 4.3-billion kilowatt-hours of electricity. At the time the plant was shut down, company officials estimate that the reactor contained about 900,000 curies of radioactive contamination.

Fort St. Vrain is physically quite different from Shippingport and the other 112 domestic nuclear power plants. For example, the plant used graphite as the moderator and helium as the coolant, whereas Shippingport and the other commercial power reactor plants generally use water for both functions. Also, the fuel used in Fort St. Vrain differed from that used in Shippingport and other plants. In November 1989, the utility began removing the spent fuel and planned to send it to DOE's Idaho National Engineering Laboratory, but shipment was halted by state of Idaho court action. As an interim measure, the company is now storing the spent fuel in an independent spent fuel storage installation (ISFSI) at the site.

PSC selected DECON as its decommissioning option for Fort St. Vrain, and is now proceeding with that option following approval of the plan by the NRC in November 1992. PSC estimates the costs for dismantlement at $157 million.

J.1.4 Rancho Seco Nuclear Generating Station, Clay Station, California

Rancho Seco Nuclear Generating Station (RSNGS), a 913-MWe PWR, is owned and operated by the Sacramento Municipal Utility District (SMUD). On June 7, 1989, SMUD shut down the plant in response to a voter referendum to close the plant. During its lifetime, RSNGS operated for about 51,595 hours and generated about 44-billion kilowatt-hours of electricity. Company officials estimate that the amount of radioactivity in the plant at shutdown exceeded 9 million curies.(5)

In May 1991, SMUD submitted a decommissioning plan to NRC. The decommissioning plan outlines SMUD's intent to store spent fuel in the spent fuel pool during the initial phase of decommissioning (Custodial-SAFSTOR). The Hardened-SAFSTOR phase of decommissioning will follow Custodial-SAFSTOR, after the fuel has been placed in dry storage at an onsite ISFSI. Deferred-DECON (decontamination and dismantlement) will commence thereafter. An estimated $280.8 million will be required to decommission the plant, including site restoration.(11)

J.1.5 Three Mile Island 2, Londonderry Township, Pennsylvania

Three Mile Island Unit 2 (TMI-2), a 792-MWe PWR operated by GPU Nuclear Corporation, was closed in March 1979 due to a nuclear accident. The information base is extensive concerning the TMI-2-related cleanup, research, and development activities following the accident. Many contributions of potential benefit to future nuclear power plants decommissioning programs have resulted from the overall accident cleanup program at TMI-2. The brief summaries of a few such contributions of the TMI-2 research and development (R&D) program that follow were extracted from Reference 12. Other potential decommissioning-related contributions from TMI-2 are further described in References 13-17.

One important contribution of the TMI-2 R&D program has been the high-level radioactive waste technology developed at the national laboratories. From the standpoint of volume reduction, the use of the EPICOR II system[2] reduced the radioactive waste volume by a factor of 10, and the submerged demineralizer system (SDS) reduced the volume by a factor of 500 over conventional waste processing systems.

Another accomplishment has been the development of the high-integrity containers (HICs). The concrete HIC is durable, tested, licensed, and equipped with a one-way vent system for exhausting the gases produced inside. The HIC's design and scale could be adapted according to industry needs.

In addition, the knowledge gained from the handling of large radioactive components at TMI-2, and their subsequent disposal, should assist operating nuclear power plants in formulating and carrying out plans for decommissioning their own plants.

J.1.6 La Crosse Reactor, Genoa, Wisconsin

La Crosse, a 50-MWe BWR, was placed in safe storage (SAFSTOR) by its owner, Dairyland Power Cooperative (DPC), in May 1987. All fuel was removed from the reactor vessel, and DPC plans to monitor the reactor and the stored fuel until such time as the fuel can be sent away to a federal high-level waste or spent fuel facility. Decommissioning of the reactor facility would take place only after the fuel has left.(18) The possession-only license for La Crosse has been approved to March 2031.

J.1.7 Peach Bottom 1, York County, Pennsylvania

Peach Bottom Unit 1, a 40-MWe prototype high-temperature gas-cooled reactor (HTGR), is owned by the Philadelphia Electric Company. The plant operated from June 1967 until October 1974. During this 7-year period, the plant operated for about 32,375 hours, generating about 1.4-billion kilowatt-hours of electricity. At the time the plant was shut down, the radioactivity in the pressure vessel was more than 3 million curies.

Philadelphia Electric decided to place the facility in SAFSTOR and started to decontaminate the site in January 1976. The company completed these activities in February 1978, using about 179 man-months of labor, at a cost of about $3.5 million. The utility removed all radioactive liquids, drained refrigerants and cooling water, and sent the spent fuel to DOE's Idaho

---

[2] the contaminated water at TMI-2, approximately 2,120,000 liters, was decontaminated using the three-stage EPICOR II demineralization system, which contained organic and inorganic ion exchange media.

National Engineering Laboratory. The company left the reactor vessel, piping systems, and steam generators in the plant, and officials estimate that they will not start to remove these components or otherwise decommission the plant for about 20 more years.(5)

J.1.8 Saxton Nuclear Experimental Reactor, Saxton, Pennsylvania

The Saxton Nuclear Experimental Reactor, a 3-MWe prototype PWR, is owned by the Saxton Nuclear Experimental Corporation (SNEC). The reactor was placed in SAFSTOR following its shutdown in 1972. Work on decommissioning the reactor and site started in 1986. To date, decontamination activities have been completed in the control room and radwaste building. The reactor containment building is not scheduled for dismantling until the mid-1990s.(19)

J.2 Foreign Experience in Decommissioning Nuclear Reactors Since 1978

According to an October 1991 Nucleonics Week article,(20) "the OECD Nuclear Energy Agency (NEA) has solved the puzzle of why estimates of nuclear facility decommissioning costs have varied so widely: it's not the size of the facility that counts, nor even the scope of the planned decommissioning, but rather the amount of waste the job is projected to generate that makes the difference. The finding is significant not only because it will help nuclear facility owners better project their own decommissioning costs, but also because the wide variation in decommissioning cost estimates worldwide has undermined the credibility of all those estimates, essentially with the cheaper ones being disbelieved by the public."

An assessment of foreign decommissioning technology with potential application to U.S. decommissioning needs is presented in Appendix K. Discussions of some of the significant foreign reactor decommissionings follow, based on information extracted from References 21 and 22. When cited in the references, the decommissioning costs and reactor power levels are given.

J.2.1 Decommissioning Projects in Canada

Gentilly-1 is a 296-MWe CANDU (Canadian Deuterium Uranium Reactor), moderated with heavy water and cooled with boiling light water. It has been mothballed since 1979. Canadian strategy calls for keeping the facility in a "static state,"[3] monitor it for 50-80 years, then dismantle the facility. Extensive use was made of an electrically driven water blaster (hydrolaser) for decontamination of fuel bundles, equipment, and spent fuel pool surfaces. The decommissioning to the "static state" was completed in 1986 at a cost of $13 million (Canadian); surveillance cost is about $1 million (Canadian) per year.

Douglas Point is a 216-MWe CANDU pressurized heavy-water reactor that operated from 1968 to 1984 and was permanently shut down in 1984. All 23,000 spent fuel assemblies (300 MTU) were moved into 47 above-ground concrete canisters (completed in 1987) for storage until a permanent repository is available. The reactor facility was sealed and kept intact in "static state," pending a decision on possible future use.

J.2.2 Decommissioning Projects in France

France is relying on the nuclear industry to make decisions based upon economics and applicable regulations; numerous decommissioning projects have been completed or are under way following this policy. Like most countries, France adheres to the IAEA's three-stage decommissioning pattern in planning its decommissioning projects:(23)

---

[3] A "static state" was achieved by sealing the reactor building and consolidating the contaminated wastes (including spent fuel) in the turbine building. This work was completed in the spring of 1986.

- Stage 1 decommissioning relates to the period immediately following final shutdown of the nuclear power plant, usually assumed to be a planned operation rather than the result of an accident or major breakdown. In this stage the reactor is defueled and made safe, the work essentially being an extension of normal operations.

- Stage 2 decommissioning has the objective of dismantling all plant external to the biological shield. This stage is characterized by the ability to dismantle the plant using built-in facilities or readily available brought-in engineering equipment.

- Stage 3 is the removal of the reactor itself together with its biological shield, or pre-stressed concrete vessel, and final clearance of the site rendering it safe for further use.

Past and current reactor decommissioning projects in France include the following:

- Cesar GCR (gas-cooled reactor) at Cadarache has been decommissioned to Stage 3, i.e., complete dismantlement and removal of radioactive facilities and equipment.

- Chinon A1 (70 MWe), A2 (180 MWe), and A3 (360 MWe) GCRs have been shut down since 1973, 1985, and 1990, respectively. A1 has been decommissioned through Stage 1. Decommissioning of Chinon A2 to Stage 2 is expected to take 5 years and cost 100 million FF ($17 million U.S.).

- EL2, EL3, Zoe HWRs at Fontenay-aux-Roses have been shut down. EL2 was decommissioned to Stage 2 in 1968 and EL3 was decommissioned through Stage 3 in 1984. Zoe has been decommissioned through Stage 2.

- The EL4 (70 MWe) GCHWR at Monts d'Arree has been shut down since 1985 and decommissioning is underway.

- G1 (3 MWe), G2 (40 MWe), and G3 (40 MWe) GCRs at Marcoule have been shut down. G1 has been decommissioned through Stage 2; G2 decommissioning is underway; and G3 decommissioning is planned to be complete by 1993. Decommissioning of the G2 and G3 reactors to Stage 2 is estimated to cost 20 million FF ($3.3 million U.S.).

- Minerve, Nereide, and Triton experimental LWRs at Fontenay-aux-Roses are being decommissioned. Minerve and Triton have been decommissioned through Stage 3. The Nereide reactor decommissioning is underway.

- The Pegase and Peggy experimental LWRs, along with the 40-MWt Rapsodie experimental LMFR (Liquid Metal Fast Reactor) at Cadarache, have been shut down. Pegase and Peggy have been decommissioned to Stage 3 and decommissioning of Rapsodie is just starting.

J.2.3 Decommissioning Projects in Federal Republic of Germany

The Federal Republic of Germany (FRG), having a large nuclear program, has undertaken numerous decommissioning projects. Major projects include the following:

- FR-2 research reactor at Karlsruhe: This 44-MWt, tank-type HWR operated between 1961 and 1981. The fuel has been removed and non-radioactive structures are being removed (Stage 2). The core structure and bioshield will be dismantled in 30 years.

- MZFR research reactor at Karlsruhe: This 58-MW PWR operated between 1965 and 1984. The facility, except for the fuel storage building, is out of operation and in safe enclosure.

- Niedereichbach nuclear power plant: This heavy-water-moderated, gas-cooled, 100-MWe reactor operated from 1972-1974. Decommissioning started in 1987. The site is to be restored to "green field" condition. The estimated cost for the program is 100 million DM. Contaminated steel (about 1700 tons) from the project is to be melted after size reduction in an induction-melting furnace installed in the decontaminated and decommissioned building of the FR-2 reactor (facility name "EIRAM").

- KRB-A power plant at Gundremmingen: This 250-MWe BWR operated between 1966 and 1977. Fuel has been removed and all systems but the biological shield and reactor vessel are expected to be dismantled by 1992.

- KWL Lingen power plant: This 268-MWe BWR operated between 1968 and 1977. The facility has been placed in safe enclosure (Stage 1). Dismantlement will start after 25 years.

- AVR and THTR-300 reactors:. The first stage of decommissioning and dismantling of the 296-MWe THTR-300 high-temperature, gas-cooled reactor will be completed in 1992. The FRG's other HTR, the 15-MWe AVR pilot HTR at Julich, was shut down in 1988 and is awaiting decommissioning licenses from the state regulators. Spent fuel from the two units will be disposed at Gorleben.

- Nuclear Ship "Otto Hahn": This nuclear-powered ship, built in 1963, was shut down in 1979. All activated and contaminated components were removed and the rooms were decontaminated. The ship is used for non-nuclear purposes. The decommissioning and dismantling cost 21.7 million DM ($11 million U.S.).

J.2.4 Decommissioning Projects in Italy

Major decommissioning projects in Italy include the following:

- Garigliano nuclear power plant: This 160-MWe BWR operated from 1964-1978. The nuclear steam supply system is to be placed in protective storage for 30 years.

- Decommissioning of the Latina GCR (153 MWe) has begun. The fuel unloading is expected to take three years (fuel shipments are suspended during summer). The possible reuse of the plant's turbines for non-nuclear combined-cycle power generation is under investigation. Approximately 270 MT of the reactor's fuel will be shipped to the United Kingdom for reprocessing.

J.2.5 Decommissioning Projects in Japan

The Japanese policy on decommissioning of closed nuclear power plants is to mothball them for 5-10 years, and then dismantle them completely so that the land can be reused. Current estimates are 30 billion yen ($220 million) for complete dismantling of a 1000-MWe reactor unit. JAERI (Japan Atomic Energy Research Institute) is at an advanced stage of decommissioning the Japan Power Demonstration Reactor (JPDR). This was a 12.5-MWe BWR at Tokai. Dismantling was started in 1986, with project completion scheduled in late 1993.

J.2.6 Decommissioning Projects in Spain

It has been assumed for calculation and planning purposes that once the useful life of Spain's nuclear power plants (estimated at 30 years) comes to an end and after a "cooling" period of about 5 years, total dismantling would begin, lasting approximately another 5 years, leaving the site ready for other unrestricted uses. Spain's main efforts and expenditures on decommissioning nuclear facilities are predicted to be in 2000-2025. Furthermore, Spain does not deem it advisable to undertake specific research and development projects on decommissioning; rather, it plans to follow the R&D programs in other countries, especially those in the European Community. However, it may undertake direct collaboration/participation in some foreign projects.

The 20-year old Jen-1, a 3-kW experimental reactor, is being dismantled. The shutdown Vandellos 1, a 480-MWe GCR whose turbo-generator was severely damaged in a fire in 1989, is also to be decommissioned. The Spanish government has estimated the cost of dismantling the Vandellos 1 reactor at 15 billion pesetas (about $146 million U.S.).

J.2.7 Decommissioning Projects in the United Kingdom

The United Kingdom's plans for R&D of nuclear power reactors covers three phases: (1) removing spent fuel and bulk wastes; (2) dismantling and removing the non-radioactive equipment/facilities around the reactor; and (3) removing the radioactive portions of the reactor after a 100-year delay to allow decay of the radioactivity. Past and planned decommissioning projects include:

- Four nuclear power stations, the 13-MWe Dounreay Fast Reactor (DFR), the Berkeley Magnox units 1 (138 MWe) and 2 (138 MWe), and the prototype 28-MWe Windscale Advanced Gas-Cooled Reactor (WAGR), have been shut down. Decommissioning of the Berkeley units is just starting with Stage 2 decommissioning expected to be complete in about 10 years. Phase 1 decommissioning of the DFR has been completed with no plans for further work, while Phase 3 decommissioning of the WAGR is expected to be completed in the mid/late-1990s. The cost of decommissioning the U.K.'s outdated Magnox power stations and reprocessing their wastes was estimated at $2.4 billion U.S., as reported in a 1988/89 annual report of the Central Electricity Generating Board (CEGB). The total for CEGB was estimated at $18.5 billion U.S. (13 Magnox reactors) and at $2.9 billion U.S. for the South of Scotland Electricity Board (3 Magnox reactors). Recent studies indicate substantial savings can be realized by "mounding over" obsolete Magnox reactors instead of completely decommissioning them.

- Decommissioning of the Windscale Piles, shut down after a serious fire in 1957, is just beginning.

J.3 References

1. R. I. Smith, G. J. Konzek, and W. E. Kennedy, Jr. 1978. *Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.* NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. Title 10, Code of Federal Regulations, Part 50 - *Domestic Licensing of Production and Utilization Facilities*, January 1, 1989.

3. Federal Register. "General Requirements for Decommissioning Nuclear Facilities," Vol. 53, No. 123, pp. 24018-24056, June 27, 1988.

4. Title 10, Code of Federal Regulations, Part 961 - *Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste*, January 1, 1989.

5. GAO/RCED-90-208. *NUCLEAR RESEARCH AND DEVELOPMENT: Shippingport Decommissioning - How Applicable Are the Lessons Learned?* U.S. General Accounting Office Report to Congressional Requesters, Washington, D.C., September 1990.

6. *The Energy Daily.* October 26, 1983. "GE to Decommission Shippingport Station," p. 3.

7. DOE/SSDP-0081. December 2, 1989. *Final Project Report - Shippingport Station Decommissioning Project.* U.S. Department of Energy Report by Westinghouse Hanford Company, Richland, Washington.

8. Title 10, Code of Federal Regulations, Part 30 - *Rules of General Applicability to Domestic Licensing of Byproduct Material*, January 1, 1990.

9. *Nuclear News.* July 1991. "Reactor Vessel Removed from Pathfinder Plant," p. 31.

10. Quarterly Status Report - Pathfinder Decommissioning Project (E89N030). October 1981.

11. NRC Docket No. 50-312, "Rancho Seco Decommissioning Plan," May 1991.

12. "U.S. Department of Energy and GPU Nuclear Corporation Research and Development Activities Report on Three Mile Island Unit Two: January - June 1989." October 1989. U.S. Department of Energy Report by GPU Nuclear Corporation, Middletown, Pennsylvania and EG&G Idaho, Inc., Idaho Falls, Idaho.

13. GEND-064. "U.S. Department of Energy Three Mile Island Research and Development Program 1988 Annual Report." April 1989. U.S. Department of Energy Report by EG&G Idaho, Inc., Idaho Falls, Idaho.

14. GEND-INF-073. "TMI-2 Defueling Tools Engineering Report." February 1986. U.S. Department of Energy and EG&G Idaho, Inc. Report by Bechtel North American Power Corporation, Gaithersburg, Maryland.

15. GEND-039. "TMI-2 Technical Information and Examination Program 1983 Annual Report." April 1984. U.S. Department of Energy Report by EG&G Idaho, Inc., Idaho Falls, Idaho.

16. "Data Report TPO/TMI-107: Evaluation of Concrete Core Borings from Reactor Building." February 1984. Prepared by TMI-2 Technical Planning Department GPU Nuclear Corporation - Bechtel National, Inc.

17. "Data Report TPO/TMI-053: Part A Dose Reduction." January 1984. Prepared by TMI-2 Technical Planning Department GPU Nuclear Corporation - Bechtel National, Inc.

18. *Nuclear News.* June 1987. "Dairyland Announces Permanent Shutdown," pp. 31-32.

19. DOE/RW-006, Rev. 7. October 1991. *Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics.* U.S. Department of Energy Report by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

20. *Nucleonics Week.* October 17, 1991. "NEA Study Finds Waste Weight is Key to Decommissioning Costs," pp. 1-9.

21. K. J. Schneider, et al. April 1991. *National Briefing Summaries: Nuclear Fuel Cycle and Waste Management.* U.S. Department of Energy Report prepared by Pacific Northwest Laboratory, Richland, Washington.

22. *Nuclear News.* August 1991. "World List of Nuclear Power Plants."

23. *Nuclear Engineering International.* August 1984. "Five Years of Research Into Decommissioning," pp. 15-18.

Appendix K

Review of Decommissioning Technical Developments Since 1978

Appendix K

Review of Decommissioning Technical Developments Since 1978

Because of finite resources and the wide range of topics researched during the course of this reevaluation study, it was not possible to obtain information on decommissioning-related equipment/processes from all vendors or suppliers. However, the selected equipment/processes and suppliers described in this appendix are believed to be representative of state-of-the-art in those areas. It should be recognized, however, that the identification of specific vendors, processes, and/or equipment does *not* constitute an endorsement of those entities.

K.1 Domestic and Foreign Technical Developments Since 1978

Both domestic and foreign technical developments were reviewed for potential direct applications to decommissioning pressurized water reactors (PWRs). The results of that review are described in the following sections.

K.1.1 Domestic Technical Developments

Perhaps the most significant ongoing industrial activities with potential direct applications to decommissioning PWRs that have occurred since 1978 concern steam generator replacement projects. These programs have yielded significant information on decommissioning (e.g., steam generator removal technology and associated exposure reduction techniques). In turn, this information on removal activities has been incorporated into this reexamination of the decommissioning of the reference PWR.

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 Pacific Nuclear Services (PNS), located in Richland, Washington. 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) since no commercial PWR has yet undergone a full-system chemical decontamination in the United States, a first-of-a-kind (FOAK) full-system chemical decontamination of a PWR could cost in the range of $20-25 million. However, when such decontaminations of PWRs become "routine" (defined for purposes of this reevaluation study as after at least three such campaigns have been successfully completed), a cost in the range of $10-$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.

In addition, Pacific Nuclear 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 PWR analyzed in this report is not postulated to be chemically decontaminated before disassembly.

In summary, primary system chemical decontamination programs for both PWRs and BWRs have become major contributors to ALARA programs at operating sites.(1-3) Practical and proven reactor coolant system chemical decontamination technology is a major dose reduction procedure being used by U.S. nuclear utilities today. Primary system decontamination as a precursor to decommissioning (especially the base scenario analyzed in Appendix D of this report, where maximum benefits could be achieved) will undoubtedly be seriously considered in future decommissionings.

According to an Electric Power Research Institute (EPRI) survey,(4) nuclear power plants have increased the use of industrial video cameras as support tools for a variety of plant operations and outage tasks. It was found that many plants are using video cameras as surveillance and monitoring tools to significantly reduce personnel radiation exposure during both routine and specialized tasks. Typical uses include remote health physics support, observation of workers to ensure that they position themselves to minimize exposure, job planning prior to entry into a radiation zone, and videotaping jobs for training purposes. Video cameras are also used as communication tools so that supervisors and task engineers can provide technical direction from outside the work zone. Area surveillance, such as fire watch during welding, leak detection, and general observation during plant operations, is another common application.

Robots are yet another application of closed-circuit television (CCTV) at nuclear power plants. Though still considered developmental at many utilities, they have performed a broad range of productive tasks (e.g., surface decontamination, sludge removal, waste handling and packaging, area radiation surveys, transporting shielding, sample acquisition, concrete scabbling, concrete coring, fire watch, and component inspections). This is particularly true at TMI-2, where extensive contamination made robots the only option for some plant recovery tasks.(5) In recent years, many plants have used underwater surveillance vehicles for inspection, cleaning, object retrieval, and monitoring divers. These submersibles are equipped with cameras and lights; thus they are another nuclear plant application of CCTV.(4)

Although special radiation-hardened cameras have for many years been used for tasks such as in-vessel inspections and fuel-assembly examinations, a new generation of industrial video cameras is finding many new plant applications. These cameras are versatile, relatively inexpensive, and easy to install and operate. In summary, the EPRI survey concluded that video cameras are important tools for reducing radiation exposure and improving productivity through more efficient use of personnel.

Many plants are using advanced image retrieval and processing systems to store, search, display, and print visual information. Using microcomputer hardware and proprietary software, these systems can access images stored on videotape, microfilm, laser disc, or in computer memory. The most common application is for surrogate walk-throughs. That is, thousands of photographs of the nuclear power plant are stored on laser disc, and a joy-stick control is used to "walk" through areas visually for orientation, job planning, etc.(4)

K.1.2 Foreign Technical Developments

In 1987, the Pacific Northwest Laboratory (PNL) conducted a study(6) for the U.S. Department of Energy to identify and technically assess foreign decommissioning technology developments that may represent significant improvements over decommissioning technology currently available or under development in the United States. Technology need areas for nuclear power reactor decommissioning operations were identified and prioritized using the results of past light water reactor (LWR) decommissioning studies to quantitatively evaluate the potential for reducing cost and decommissioning worker radiation dose for each major decommissioning activity.

Based on these identified needs, current foreign decommissioning technologies of potential interest to the U.S. were identified through personal contacts and the collection and review of an extensive body of decommissioning literature. These technologies were then assessed qualitatively to evaluate their uniqueness, potential for a significant reduction in decommissioning costs and/or worker radiation dose, development status, and other factors affecting their value and applicability to U.S. needs.

The results of that study show that the major cost elements in LWR decommissioning, and thus the activities with the greatest potential for cost savings through improved technology, are: (1) management of radioactive decommissioning wastes, (2) the demolition of heavily reinforced nonradioactive structures, and (3) the detachment, removal and segmentation of fluid systems and components. Similarly, decommissioning worker radiation dose data show clearly that improved technology for the last category represents the major opportunity for worker dose reduction.

The technology assessment in that study indicates that no specific decommissioning technology needs were identified that are not addressed to some degree either by the foreign technology development work or by existing U.S. technology development programs. In addition, there are no presently identified, fully developed foreign technologies directly applicable to major U.S. decommissioning needs that are not currently available in the U.S. There are, however, several promising technologies in the conceptual or R&D/demonstration stage that should be monitored and periodically reassessed as further development and demonstration studies are conducted. Based on the outcome of the ongoing R&D work, the technology need areas that potentially could benefit most from additional R&D emphasis would include improved monitoring methods for metallic waste to assure compliance with release criteria, better survey/sampling methods for contaminated concrete surfaces to guide operations on the extent of concrete removal, and cost-effective treatment processes for secondary decontamination wastes.

K.2 Facilitation Techniques for Decommissioning Light Water Power Reactors

NUREG/CR-3587(7) contains a comprehensive review of the available experience in the identification and evaluation of practical techniques to facilitate the decommissioning of nuclear power generating facilities. The objectives of the "facilitation techniques" evaluated in that report were to reduce public/occupational exposure and/or reduce volumes of radioactive waste generated during the decommissioning process.[1]

The report presents the possible facilitation techniques identified during the study (circa 1986) and discusses the corresponding facilitation of the decommissioning process. Techniques are categorized by their applicability of being implemented during three stages of reactor life: design/construction, operation, or decommissioning. Detailed cost-benefit analyses were performed for each technique to determine the anticipated exposure and/or radioactive waste reduction; the estimated cost for implementing each technique was then calculated. Finally, these techniques were ranked by their effectiveness to facilitate the decommissioning process.

K.3 Conclusions

Concerning technology development for nuclear power reactor decommissioning, most experience and development has been in such areas as training, developing specialized tools, physical decontamination, lifting and removing heavy objects in high radiation fields, remote visual inspection techniques, and demolition of nonradioactive components. These areas are fairly well-developed and radical new developments that will affect decommissioning costs significantly are not expected. Areas where technology development is likely to occur and may have significant cost effects include chemical decontamination, remote disassembly, waste reduction and recycling, and waste disposal.(8)

---

[1] This study is part of the NRC's evaluation of decommissioning policy and modification of regulations pertaining to the decommissioning process. The findings can be used by utilities in the planning and establishment of the activities to ensure that all objectives of decommissioning will be achieved.

K.4 References

1. *Nuclear News*. October 1988. "Chemical Decontamination Experience at Northeast Utilities," pp. 42-46.
2. EPRI NP-6023, Final Report, September 1988. *Chemical Decontamination Experience at Commonwealth Edison Nuclear Power Plants.* Electric Power Research Institute Report by Niagara Technical Consultants, Niagara Falls, New York.
3. R. A. Shaw and C. J. Wood. *Nuclear News*, "Chemical Decontamination: An Overview," pp. 107-111, June 1985.
4. EPRI NP-6882, Final Report, August 1990. *Video Camera Use at Nuclear Power Plants - Tools for Increasing Productivity and Reducing Radiation Exposure*. Electric Power Research Institute Report by ENCORE Technical Resources, Inc., Middletown, Pennsylvania.
5. EPRI NP-6521, September 1989. *Robotics Program Development: Applicable Lessons Learned from TMI-2.* Electric Power Research Institute Report, Palo Alto, California.
6. R. P. Allen, G. J. Konzek, K. J. Schneider, and R. I. Smith. 1987. *Assessment of Foreign Decommissioning Technology with Potential Application to U.S. Decommissioning Needs.* PNL-6335, U.S. Department of Energy Report by Pacific Northwest Laboratory, Richland, Washington.
7. T. S. LaGuardia and J. F. Risley. *Identification and Evaluation of Facilitation Techniques for Decommissioning Light Water Power Stations.* NUREG/CR-3587, U.S. Nuclear Regulatory Commission Report by TLG Engineering, Inc., Brookfield, Connecticut, June 1986.
8. P. M. Strauss and J. Kelsey. 1991. "State Regulation of Decommissioning Costs," *The Energy Journal*, Volume 12, Special Issue.

Appendix L

Estimated Non-Radioactive Demolition and Site Restoration Costs for the Reference PWR Power Station

John M. McFarland, Sr.
Thomas S. McFarland

McFarland Wrecking Corporation
Seattle, Washington

Appendix L

Estimated Non-Radioactive Demolition and Site Restoration Costs for the Reference PWR Power Station

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 pressurized water reactor (PWR), Trojan power station, and to upgrade NUREG/CR-0130.(1) This study addresses changes in demolition costs, technology, and regulations to date and subsequent to the original decommissioning cost studies of the reference PWR in 1978.

Once all radioactive materials in a PWR 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 the 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.

L.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 remains a strong consideration in all demolition operations. 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, lead, and other designated materials have been greatly increased. Costs of disposal of demolition debris have far exceeded general inflation.

The total estimated cost of demolition for the reference PWR, $38,142,000, is summarized in Table L.1.

L.2 General Methodology for Demolition Cost Estimates

Basic structural characteristics that are relevant to demolition techniques were examined for the major plant structures, including:

- Physical arrangement of the plant

- Structure seismic classifications

- General degree of steel reinforcing

Table L.1 Summary of estimated demolition and site restoration costs for Trojan

Building name, description	Estimated demolition costs (1993 dollars)
Cooling Tower	$9,474,200
Reactor Containment Building	8,215,700
Turbine Generator Building	4,131,200
Auxiliary Building	2,242,600
Control Building	1,554,500
Fuel Building	1,499,400
Turbine Auxiliary Building	506,100
Condensate Demineralizer Building	78,400
Intake Structure	125,500
Miscellaneous Light Structures	1,332,600
Site Restoration	1,453,400
Copper Salvage Allowance	(100,000)
Subtotal	30,513,600
25% Contingency	7,628,400
Total	$38,142,000

- 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-0130, and generated from information furnished by Portland General Electric. 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 PGE 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 unforeseeable changes of conditions and/or costs.

L.2.1 Assumptions for the Development of Cost Estimates

The analyses of the effort and costs involved in demolishing the reference PWR 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 as required; 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 0.85 m earth and 0.15 m 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 concrete rubble may be disposed onsite, 1 m below grade level.
- Other debris is to be disposed of at the regional landfill at Roosevelt, Washington, some 300 km from the site.
- Costs associated with cement asbestos board (CAB) cooling fins and other CAB in the cooling tower 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.

L.2.2 Factors Affecting Estimation of Demolition Costs

Changes in cost estimates for demolition of the reference PWR 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.

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 tubes 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 costs of future regulatory requirements must be added to future inflationary considerations.

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 hydraulic 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.

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 add to decommissioning costs. They would represent a changed condition and would be covered by the contingency allowance.

L.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 concrete structures of the reference PWR. The Shippingport reactor is the closest example, but its walls were substantially less than the thickness and reinforcement of the PWR. 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 Satsop, Washington, indicated that such hammers were ineffective. The estimates presented in this appendix result from comparisons of the reference PWR 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 PWR 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 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 they are not designed to drill through massive steel. Assigning dollar values to these factors relies heavily on subjective judgment.

L.3 Demolition Considerations

All above-ground structures on the plant site will be demolished and removed down to 1 m below grade, and all site features restored, by grading and planting, to "native" condition.

Decommissioning activities do not include the removal and disposal of spent fuel, which is considered to be an operational activity, or the removal and disposal of nonradioactive structures and materials beyond that necessary to terminate the NRC license. Spent fuel disposal, although not included as a decommissioning activity, could nevertheless have an impact on the decommissioning schedule (see discussion below). The detailed schedule for development of monitored retrievable storage and geologic disposal capacity provided in the Nuclear Waste Policy Act of 1982 (NWPA, Public Law 97-245, January 7, 1983) and in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, Public Law 100-203, December 22, 1987) has been slipping. Therefore, licensees will have to assess the situation with regard to spent fuel disposal when they prepare their decommissioning plans.

Appendix D contains the background information and the rationale for the derivation of the minimum length of the SAFSTOR period at the reference PWR resulting from DOE's intent to not accept standard spent nuclear fuel (SNF)[2] from reactors until that fuel is cooled at least five years or can meet shipping cask certification requirements. This regulatory action could also result in changes in the decommissioning planning bases for DECON and ENTOMB as well. This change in the planning base requires a reassessment of decommissioning activity schedules and sequences, staff loadings, and shift schedules, to minimize the cost and radiation dose over the different decommissioning periods. Thus, the results of the analysis presented in this study are realistically anticipated to significantly affect the available choices of decommissioning alternatives for the reference plant.

It should be recognized, however, that the situation described in Appendix D with regard to spent fuel storage and final disposition and its subsequent impact on choice of decommissioning alternative is predicated on the current regulatory environment and on site-specific information associated with the reference pressurized water reactor (PWR). Therefore, the conclusions reached in this study concerning decommissioning alternatives for the reference PWR may be different for other PWR power stations, depending upon the age and burnup of the fuel in the pool, and the availability of other pool storage within a given utility system.

The NWPA of 1982 assigns to the Federal Government responsibility to provide for the permanent disposal of SNF and high-level radioactive waste (HLW).[3] The Director of DOE's Office of Civilian Radioactive Waste Management (OCRWM) is responsible for carrying out the functions of the Secretary of Energy (Secretary) under NWPA. Section 302(a) of the NWPA authorizes the Secretary to enter into contracts[4] with owners or generators[5] of commercial SNF and/or HLW. The Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste(5) 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 and/or HLW by DOE, its transportation to DOE facilities, and its subsequent disposal.

---

[2] As delineated in 10 CFR Part 961, Appendix E,(5) SNF is broadly classified into three categories - standard fuel, nonstandard fuel, and failed fuel. Most, if not all, SNF from the reference PWR is assumed to fall into the standard fuel category. One of the General Specifications for standard fuel is a minimum cooling time of five (5) years.

[3] 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 to require permanent isolation.

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

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

Concerning the issue of priority being afforded to permanently shutdown reactors, DOE has responded thusly:[6]

> "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 anticipates 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"[7] are fully implemented. Until waste acceptance begins, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel.

The decommissioning rule[1] requires that at or about five years prior to the projected end of operation, each reactor licensee submit a preliminary decommissioning plan containing a cost estimate for decommissioning and an up-to-date assessment of the actions necessary for decommissioning. This requirement would assure that consideration be given to relevant up-to-date information which could be important to adequate planning and funding for decommissioning well before decommissioning actually begins. These considerations include an assessment of the current waste disposal conditions. If, for any reason, disposal capacity for decommissioning wastes were unavailable, there are provisions in 10 CFR 50.82 that would allow delay in completion of decommissioning in order to permit temporary safe storage of decommissioning waste. In addition, Section 50.82 contains requirements to ensure that adequate funding is available for completion of delayed decommissioning. It should be noted, however, that delays would have to be based on safety considerations and not just on economic considerations.

Disposal of nonradioactive hazardous waste arising from decommissioning operations are not covered by the aforementioned regulations, but would be treated by other appropriate agencies having responsibility over these wastes.

Quality Assurance Plan

The NRC recognizes that quality assurance (QA) is important for decommissioning. The decommissioning rule[1] indicates that QA provisions during decommissioning are to be described, as appropriate, in the decommissioning plan. The decommissioning rule contains requirements that a decommissioning plan, regardless of the alternative chosen, contain a description of quality assurance provisions.

Quality assurance is enhanced and facilitated by good practices concerning record keeping by the licensee. Paragraph 50.75(g) of the decommissioning rule requires licensees to keep records of information important to safe and effective decommissioning until the license is terminated by the NRC. This section of the rule also identifies the kinds of information the NRC considers important to decommissioning. A draft regulatory guide (DG-1006)(8) has been developed in conjunction with the decommissioning rule and was published for public comment in September 1989. The purpose of the draft guide is to provide guidance concerning the specific information that should be kept and maintained in the decommissioning records required by the rule regarding the radiological conditions at the plant that could affect occupational and public health and safety during decommissioning. Knowledge of radiological conditions in and around the reactor will serve to facilitate decommissioning by minimizing occupational exposure and reducing the risk of any public exposure.

Currently, the NRC's regulatory position concerning records important for decommissioning of nuclear reactors is stated in DG-1006 as follows. The collection, safekeeping, retention, maintenance, and updating of decommissioning records should be included in the overall site quality assurance program, consistent with the coverage for other health and safety records systems. Regulatory Guide 1.88, Revision 2, "Collection, Storage, and Maintenance of Nuclear Power Plant Quality Assurance Records," should be used in particular for guidance on records administration, storage, preservation, safekeeping, and retrieval of the decommissioning records.

Draft Regulatory Guide DG-1005 provides the licensee guidance for QA program requirements to be established and executed during decommissioning. For example, the equipment, such as plasma torches, portable ventilation, and shielding, and the procedures that will be subject to the QA controls and audits should be listed. The QA program should be established at the earliest practical time consistent with the schedule for accomplishing an activity or task.[6] The staff positions and responsibilities for review and audit should be specified.

In addition, American Nuclear Insurers (ANI)[7] 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 on an engineering evaluation of the adequacy of performance in the major areas of nuclear safety, *quality assurance* (emphasis added), and documentation. The results of the engineering assessment and QA oversight can affect the level of premium assessed and the rate of change of premium during decommissioning.(9)

Security and Safeguards Plan

Security and safeguards plans should be part of the license amendment request or the decommissioning plan. Although security and safeguards during decommissioning are not specifically addressed in the regulations, the intent of the regulations for operating plants remains the same during decommissioning, insofar as they apply. These subjects are discussed in 10 CFR 50.34(c), "Physical Security Plan," Regulatory Guide 1.17, *Protection of Nuclear Power Plants Against Industrial Sabotage*, and 10 CFR Part 73, *Physical Protection of Plants and Materials.*

In addition, Supplementary Information supporting the rule states: "The existing regulations on safeguards for nuclear facilities are considered to contain criteria applicable to the decommissioning process. Therefore, it is not considered necessary to amend those regulations." However, the rule requires that safeguards provisions during decommissioning be described, as appropriate, in the decommissioning plan. Appropriate guidance documents have not yet been issued identifying which of the current operating requirements on safeguards are to apply during decommissioning.(1)

Environmental Plans

The environmental information that is supplied with the license amendment request or the decommissioning plan should satisfy the requirements of 10 CFR Part 51, *Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions*, and the intent of Section 51.53, "Supplement to Environmental Report." It states in Section 51.53(b) "Post Operating License Stage," that each applicant for a license amendment authorizing the decommissioning of a production or utilization facility covered by § 51.20 and each applicant for a license or license amendment to store spent fuel at a nuclear power reactor after expiration of the operating license for the nuclear power reactor shall submit with its application a separate document, entitled "Supplement to Applicant's Environmental Report - Post Operating License Stage," as appropriate, to reflect any new information or significant environmental change associated with the applicant's proposed decommissioning activities or with the applicant's proposed activities with respect to the planned storage of spent fuel. Unless

---

[6] DG-1005 defines an "activity" as an organized unit of work for performing a function and may consist of several tasks. A "task" is defined as a specific work assignment or job.

[7] 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.

otherwise required by the Commission, in accordance with the generic determination in § 51.23(a)[8] and the provisions of § 51.23(b), the applicant shall only address the environmental impact of spent fuel storage for the term of the license applied for. The Supplement may incorporate by reference any information contained in previously submitted records, which are delineated in Section 51.53(b).

Furthermore, in Section 51.95, "Supplement to Final Environmental Impact Statement," Subsection (b), "Post Operating License Stage," the following is stated: "In connection with the amendment of an operating license to authorize the decommissioning of a production or utilization facility covered by § 51.20 or with the issuance, amendment or renewal of a license to store spent fuel at a nuclear power reactor after expiration of the operating license for the nuclear power reactor, the NRC staff will prepare a supplemental environmental impact statement for the post operating license stage or an environmental assessment, as appropriate, which will update the prior environmental review. This document may incorporate by reference any information contained in previously submitted records, which are delineated in Section 51.95(b)."

In summary, the NRC has determined that if proper consideration and implementation is given to decommissioning, whatever alternative is chosen, in comparison with the impact expected from 40 years of licensed operation, the environmental impacts from decommissioning are expected to be small. Thus, the decommissioning rule(1) allows for reduction of 10 CFR Part 51 National Environmental Policy Act (NEPA) (42 USC 4321 et seq.) requirements through elimination of the mandatory requirement for an environmental impact statement (EIS) at the time of decommissioning for 10 CFR Part 50 and 72 licenses. Environmental assessments would still be required, but these would not necessarily lead to an EIS being issued.

I.1.3 Licensing Costs

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 from the Department of Energy (DOE)-administered Nuclear Waste Fund[9] to the NRC for FYs 1991 through 1995 for purposes of licensing support to the 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 on 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.

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.

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

---

[8] As stated in 10 CFR Part 51.23, *Temporary Storage of Spent Fuel After Cessation of Reactor Operation - Generic Determination of No Significant Environmental Impact*, Subsection (a): The Commission has made a generic determination that, if necessary, spent fuel generated in any reactor 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 onsite or offsite independent spent fuel storage installations. Further, the Commission believes there is reasonable assurance that at least one mined geologic repository will be available within the first quarter of the twenty-first century, and sufficient repository capacity will be available within 30 years beyond the licensed life for operation of any reactor to dispose of the commercial high-level waste and spent fuel originating in such reactor and generated up to that time.

[9] 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.

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. It should also be noted that if a facility has a POL at the beginning of the fiscal year, a licensee is no longer assessed annual fees. Hourly fees remain, however, for plant-specific licensing actions.

In addition, holders of licenses associated with the storage of spent fuel, including a general license to receive and store spent fuel at an independent spent fuel storage installation (ISFSI), and each holder of a Certificate of Compliance for a spent fuel storage cask, will be assessed an annual fee.

Thus, the NRC will charge fees in proportion to its costs (i.e., full-cost recovery) for providing individually identifiable services to specific applicants for, and holders of, NRC licenses and approvals. These fees are deposited into the U.S. Treasury and do not augment the NRC appropriation. Congress must still pass appropriations legislation for the NRC, but because the NRC is now obligated to raise the money from users, legislators will chiefly consider the funding authorization - that is, whether the amount of money the NRC proposes to raise is reasonable.(10, 11)

The financial protection requirements during plant operation are given in 10 CFR Part 140, *Financial Protection Requirements and Indemnity Agreements*. The levels of protection required during decommissioning are not specifically defined. However, the intent of the regulations for operating plants remains the same during decommissioning, insofar as they apply, as discussed in the following subsection.

I.1.4 Financial Assurance

As previously mentioned, on June 27, 1988, the NRC published amendments to 10 CFR Part 50 (53 FR 24018) concerning general requirements for decommissioning nuclear facilities. Amended 10 CFR 50.33(k), 50.75, and 50.82(b) require operating license applicants and existing licensees to submit information on how reasonable assurance will be provided that funds will be available to decommission their facilities. Amended Section 50.75 establishes requirements for indicating how this assurance will be provided, namely the amount of funds that must be provided, including updates, and the methods to be used for assuring funds for any of the decommissioning alternatives of DECON, SAFSTOR, or ENTOMB.

Title 10 CFR Part 50.75(c)(2) requires nuclear power reactor licensees to periodically adjust the estimate of the cost of decommissioning their plants, in dollars of the current year, as part of the process to provide reasonable assurance that adequate funds for decommissioning will be available when needed. NUREG-1307, "Report on Waste Burial Charges," which is scheduled to be revised approximately annually, contains information to be used in a formula for escalating decommissioning cost estimates that is acceptable to the NRC. The sources of information to be used in the escalation formula are identified, and the values developed for the escalation of radioactive waste burial costs, by site and by year, are given. The licensees may use the formula, the coefficients, and the burial escalation factors from NUREG-1307 in their escalation analyses, or they may use an escalation rate at least equal to the escalation approach presented therein.(12)

Regulatory Guide 1.159 (Task DG-1003), "Assuring the Availability of Funds for Decommissioning Nuclear Reactors," August 1990, was developed in conjunction with the rule amendments. Its purpose is to provide guidance to applicants and licensees of nuclear power reactors and research and test reactors concerning methods acceptable to the NRC staff for complying with requirements in the amended rule regarding the amount of funds for decommissioning. It also provides guidance on the content and form of the financial assurance mechanisms indicated in the rule amendments.

Under normal circumstances, decommissioning follows the orderly shutdown of the facility at the end of its planned life. However, as discussed in the *Final Generic Environmental Impact Statement on Decommissioning Nuclear Facilities* (commonly referred to as GEIS),(13) decommissioning at a reactor which has been involved in an accident could take place following stabilization and accident cleanup activities. Thus, the availability of funds for post-accident cleanup is also related to financial assurance for decommissioning. For example, an accident and the resulting accident cleanup activities have an effect on subsequent decommissioning activities, on the decommissioning alternatives, and on the cost, safety and environmental consequences of those alternatives.

The costs of post-accident cleanup can be substantially larger than the costs of decommissioning. Assurance of funds for post-accident cleanup activities is more properly covered by use of insurance. Post-accident cleanup activities are broader in scope than decommissioning, that is, they can lead ultimately to either reuse or decommissioning. Accordingly, the funding requirements for accident cleanup are not included in the GEIS or in the rule,(1) but are contained in 10 CFR 50.54(w), which requires that utility licensees for production and utilization facilities obtain insurance to cover decontamination and cleanup costs associated with onsite property damage resulting from an accident.[10]

With regard to the funding of decommissioning activities which would occur prematurely either following an accident or if an accident did not occur, NRC has had several studies done to address this issue, including NUREG/CR-1481,(14) NUREG/CR-3899,(15) NUREG/CR-3899 Supplement 1,(16) and NUREG/CR-2370.(17) These documents address the question of assurance provided by the various funding methods, including prepayment, external reserve, internal reserve, and insurance. In particular, as discussed in Section 2.6 of the GEIS and in more detail in NUREG-1221, Section D.3.2.1.1,(18) and as noted in NUREG/CR-3899, the market value of utilities, even those involved in the most extreme financial crises, is still far in excess of decommissioning costs and that the value of the assets of a utility (both tangible and intangible) is more than adequate to cover future projected decommissioning costs. These considerations must also be viewed within the context of the Commission requirements for onsite property damage insurance in 10 CFR 50.54(w), discussed above, the proceeds from which a utility could use to decontaminate its reactor after an accident. Although these insurance proceeds would not be used directly for decommissioning, they would go a long way toward reducing the risk of a utility being subject to a tremendous demand for funds after an accident. Because most utilities are now carrying insurance in excess of $1 billion and the Commission has implemented its requirement in 10 CFR 50.54(w) for insurance at this level, a major threat to long-term utility solvency has been substantially reduced.(13)

Thus, pursuant to 10 CFR 50.54(w), a licensee is required to carry a minimum coverage limit of onsite primary property damage insurance for a reactor station site of either $1.06 billion or whatever amount of insurance is generally available from private sources, whichever is less. However, under certain conditions (e.g., a permanently shutdown, defueled reactor), and with the proper justification, an NRC exemption to reduce the amount of primary property damage insurance from the full amount of $1.06 billion to a lesser amount (with correspondingly lesser premiums) is possible. For example, in its application for exemption, the licensee must provide justification that the lesser amount of insurance provides an adequate level of coverage to stabilize, clean up, or decontaminate the reactor facility based on limited and much less severe accidents that could occur, given the defueled condition.

At a licensee's request, the NRC has the prerogative to grant exemptions from the requirements of the regulations, which pursuant to 10 CFR 50.12(a) are (1) authorized by law, will not present an undue risk to the public health and safety, and are consistent with the common defense and security, and (2) present special circumstances. Pursuant to 10 CFR 50.12(a)(2)(ii), special circumstances exist when compliance with a rule would not serve the purpose of or is not necessary to achieve the

---

[10] As a result of the efforts during accident cleanup, decommissioning can be carried out in a more stable environment than the accident cleanup. Nevertheless, there would be certain impacts on the decommissioning from the accident and the accident cleanup activities, including increased levels and spread of contamination compared to normal decommissioning still remaining after the cleanup activities, the need to decommission systems and structures built and used during accident cleanup, and the potential need to store wastes generated by the accident, and during the accident cleanup period, onsite on an interim basis for an extended time period.(13)

underlying purpose of the rule. Pursuant to 10 CFR 50.12(a)(2)(iii), special circumstances exist if compliance would result in undue hardship or costs in excess of those contemplated when the regulation was adopted, or costs that are significantly in excess of those incurred by others similarly situated.

In addition, the Commission recognized the risk that, if some reactors did not operate for their entire operating lives, those licensees might have insufficient decommissioning funds at the time of permanent shutdown. After the NRC published the decommissioning rule in 1988,(1) four power reactor facilities shut down prematurely - the Fort St. Vrain Nuclear Generating Station, the Yankee Rowe Nuclear Power Station, the Rancho Seco Nuclear Generating Station, and the Shoreham Nuclear Power Station. As a result, the NRC had to consider whether the decommissioning funding provisions in the rules were appropriate in those cases. In August 1991, the NRC decided to propose a new special-case amendment.(19)

The decommissioning rule, as it stands now, allows a licensee to build up funding steadily over the duration of the license, but intends that enough money should be in place by the time plant operations end. For a facility which has permanently ceased operation before the expiration of its operating license, the collection period for any shortfall of funds will be determined, upon application by the licensee, on a case-by-case basis taking into account the specific safety and financial situation at each nuclear power plant.(20)

In addition, although not as directly related to decommissioning activities as to 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 operating nuclear power reactors, the licensee shall, no later than 5 years before expiration of the reactor operating license, 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 upon expiration of the reactor operating license until title to the irradiated fuel and possession of the fuel is transferred to the Secretary of Energy for its ultimate disposal. Final Commission review will be undertaken as part of any proceeding for continued licensing under Part 50 or Part 72. 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 require 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."

The number of reactors that have been shut down prematurely has increased over earlier expectations. Therefore, the NRC has recently amended its regulations concerning 10 CFR 50.54(bb) to clarify the timing of notification to the NRC of spent fuel management and funding plans by licensees of those nuclear power reactors that have been shut down before the expected end of their operating lives. The rule requires that a licensee submit such notification either within 2 years after permanently ceasing operation of its licensed power reactor or no later than 5 years before the reactor operating license expires, whichever event occurs first.(21)

I.1.5 Internal Revenue Service Involvement in Decommissioning Funding

The Tax Reform Act of 1984 added section 468A, "Special Rules for Nuclear Decommissioning Costs," to the Internal Revenue Code, which sets out the rules for creating nuclear decommissioning funds by public utilities. This section defines the rate at which funds are taxed, restrictions on the funds, and types of investments that can be made by the fund. The cash contributed to these funds and the income accumulated by the funds will be used to pay future costs of decommissioning nuclear power plants and to pay the administrative costs of the funds each year. Funds are tax-deductible the year they are contributed to the fund, but the income on the investments of these funds is taxed at the highest tax rate that applies to corporations.

The Tax Reform Act of 1986 provides that nuclear decommissioning funds will be treated as corporations. This law also reduced the highest tax rate from 46% to 34% and became effective on July 1, 1987. Subsequently, the tax rate on decommissioning funds was lowered from 34% to 20% when the National Energy Policy Act (NEPA), Public Law 102-486, was signed into law on October 24, 1992.(22)

The Tax Reform Act of 1986 also requires nuclear decommissioning funds to pay estimated taxes. The method for determining estimated tax is explained in the General Instructions of Form 1120-ND (November 1986), which is used by nuclear decommissioning funds to report contributions received, income earned, the administrative expenses of operating the fund, and the tax on the income earned.

As part of the 1986 tax overhaul, the Internal Revenue Service, which must determine the "qualified" portion of every nuclear utility's decommissioning funds (i.e., the amount of the total decommissioning costs entitled to funding on a tax-deductible basis) was empowered to look at utilities' decommissioning fund contributions going back to 1984.(23)

An unqualified fund invested, for example, in stocks, could earn greater returns, but its principal is subject to risk and contributions are taxed. Contributions to a qualified fund are tax-deductible, but its earnings are taxed at the maximum federal corporate rate of 34%. The NRC decommissioning rule(1) required utilities to have external funds established by mid-1990 but does not require them to be qualified. An unqualified fund's earnings are added to the earnings of its corporate owner and taxed at the utility's overall rate.(23)

I.2 Active Decommissioning

Regulations, regulatory guides, and national standards that apply to the basic aspects of active decommissioning of the reference PWR are discussed in this section. Most of these basic aspects are similar in nature to many aspects of plant operation; and the regulatory controls and national standards that govern plant operation of these aspects also apply to active decommissioning, although some of them may not specifically mention decommissioning activities. The basic areas of active decommissioning are: licensing, occupational radiation safety, public radiation safety, special nuclear material management, radioactive waste management, industrial safety, and license termination and facility release.

I.2.1 Licensing

"Application for Termination of License" is regulated by 10 CFR Part 50.82. For a facility that permanently ceases operation after July 27, 1988, the application must be made within two years following permanent cessation of operations, and in no case later than one year prior to expiration of the operation license. Each application for termination of license must be accompanied, or preceded, by a proposed decommissioning plan (see previous discussion in Section I.1.2 for details).

Although a POL is not defined anywhere in the regulations, Regulatory Guide 1.86, *Termination of Operating Licenses for Nuclear Reactors*,[11] contains the procedures that are acceptable to NRC in amending the facility operating license to a POL and for obtaining a dismantling order. A POL is essentially an amended operating license and is one way for a licensee to obtain relief from operating requirements. Regulatory Guide 1.86 delineates the applicability of the POL and the dismantling order to the various decommissioning modes, the surveillance and security requirements if the final decommissioning status requires a POL, and the procedures for terminating the license.

---

[11] It should be recognized that Regulatory Guide 1.86 is currently being revised to be fully consistent with the recent changes to 10 CFR 50.82.

The POL allows the licensee to possess, but not to operate, the facility. It permits unloading, storing, and subsequent shipping of the spent reactor fuel, as well as the minor work associated with preparation for custodial safe storage or passive safe storage. In effect, the POL does not preclude the storage of spent fuel in the spent fuel pool, in an onsite independent spent fuel storage installation (ISFSI), shipment of spent fuel to another ISFSI offsite, or shipment to a U.S. Department of Energy facility for disposal. It is the governing license in all decommissioning modes, but a dismantling order is also required in the case of dismantlement or preparations for hardened safe storage or entombment. The POL remains in force during the continuing care period of safe storage or entombment, and must be renewed every 40 years. In addition, an updated decommissioning plan is required at the end of the SAFSTOR period when the licensee decides on how to dismantle the facility. All activities must be completed within 60 years of plant final shutdown.

The POL permits deletion of the technical specifications regarding plant operation (and associated surveillance requirements) that are not applicable to decommissioning, but maintains those that are necessary to ensure protection of the workers and the public during decommissioning. Thus, the POL would allow the licensee to immediately cut expenses by reducing testing requirements and staffing. It also contains the authority to possess and handle byproduct material, source material, and special nuclear material as governed by 10 CFR Part 30, *Rules of General Applicability to Domestic Licensing of Byproduct Material*, 10 CFR Part 40, *Domestic Licensing of Source Material*, and 10 CFR Part 70, *Domestic Licensing of Special Nuclear Material.*

Situations that exceed the limitations of the POL may arise during the course of active decommissioning. (Regulatory Guide 1.86 refers to these situations as "unrelated safety questions.") This type of situation is regulated by 10 CFR 50.59, "Changes, Tests and Experiments."

I.2.2 Occupational Radiation Safety

Because of the highly radioactive materials and contaminated work locations in the reference PWR during active decommissioning, occupational radiation exposure control is of major importance. Occupational radiation safety is regulated by 10 CFR Part 20, *Standards for Protection Against Radiation.* The maximum permissible limits for occupational radiation exposure are presented in 10 CFR 20.101, "Radiation Dose Standards for Individuals in Restricted Areas," and 10 CFR 20.103, "Exposure of Individuals to Concentrations of Radioactive Materials in Air in Restricted Areas." However, these limits are tempered by the operating philosophy of As Low As is Reasonably Achievable (ALARA) as explained in 10 CFR 20.1(c). This philosophy is described in Regulatory Guide 8.8, *Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be As Low As Reasonably Achievable*, and in Regulatory Guide 8.10, *Operating Philosophy for Maintaining Occupational Radiation Exposures as Low As is Reasonably Achievable.*

Additional information on how to comply with the ALARA concept can be found in the NRC Standard Review Plan, Section 12.1, "Assuring that Occupational Radiation Exposures Are As Low As is Reasonably Achievable."(24) Besides 10 CFR Part 20 and Regulatory Guide 8.8, some of the more relevant regulations and guidance cited in Section 12.1 are given below:

- 10 CFR Part 19, *Notices, Instructions and Reports to Workers: Inspection and Investigations*
- Regulatory Guide 1.8, *Personnel Selection and Training/Qualification and Training of Personnel for Nuclear Power Plants*
- Regulatory Guide 1.33, *Quality Assurance Program Requirements (Operations)*
- NUREG-0761, Revision 2, July 1981, "Contents of Radiation Protection Plans for Nuclear Power Reactor Licensees."

As of January 1, 1994 (with earlier compliance encouraged), the maximum permissible limits for occupational radiation exposure delineated in 10 CFR 20, Subpart C, "Occupational Dose Limits," Section 20.1201, "Occupational Dose Limits for Adults," are to be implemented. The NRC listed several objectives in revising 10 CFR 20. A primary objective was to "implement the principal current dose-limiting recommendations of the International Commission on Radiological Protection (ICRP)" by incorporating the ICRP effective dose equivalent (EDE) concept and requiring programs for "keeping radiation exposures as low as reasonably achievable (ALARA)."(25)

The following discussion of the revised 10 CFR 20, as it relates to the radiological protection of workers, has been extracted from References 26 and 27. The ICRP EDE concept essentially says that one rem from external exposure is no different from one rem due to internal exposure. In addition, with the revision of 10 CFR 20, internal dose (committed effective dose equivalent) and external whole-body dose (deep dose equivalent) must be added to obtain the total effective dose equivalent (TEDE), which is limited to 5 rem (0.05 Sv) per year. There is no quarterly limit, although the NRC fully expects that licensees will prorate the 5 rem quarterly.

The revision of 10 CFR 20 is based on the 1977 recommendations of the ICRP - which the NRC began reviewing soon after - and is "generally consistent" with 1987 recommendations of the National Council on Radiation Protection and Measurements (NCRP). The changes reflect basic changes in the philosophy of protection and update scientific information on radionuclide uptake and metabolism and the biological effects of ionizing radiation. The revision implements the 1987 Presidential guidance on occupational radiation protection. The major changes to 10 CFR 20 include the following:

- greater emphasis on numerical risks
- control of dose by use of the sum of internal and external doses
- greater equality in treatment of external and internal doses
- use of the committed effective dose equivalent for internal exposures rather than the critical organ approach
- wider selection of methods for estimating radionuclide intakes and internal doses.

The revised rule also eliminates the use of the cumulative lifetime dose limit of 5(N-18), where N is the age of the worker in years. No lifetime dose is specified because if the magnitude of the annual dose is limited, there is a de facto limitation of the lifetime dose that can be received.

I.2.3 Public Radiation Safety

Public radiation exposure that results from decommissioning the reference PWR must also comply with 10 CFR Part 20. Currently, the maximum public exposure limits for external exposure are specified in 10 CFR 20.105, "Permissible Levels of Radiation in Unrestricted Areas." Limits for internal exposure pathways are given in 10 CFR 20.106, "Radioactivity in Effluents to Unrestricted Areas." As in the case of occupational exposure, 10 CFR 20.1(c) requires application of the ALARA principle to the control of public radiation exposures and releases of radioactive materials to the environs. In addition, a plant undergoing decommissioning must meet the design requirements of Appendix I to 10 CFR Part 50.

As of January 1, 1993 (with earlier compliance encouraged), the maximum permissible limits for public radiation exposure are delineated in 10 CFR 20, Subpart D, "Radiation Dose Limits for Individual Members of the Public," Section 20.1301 "Dose Limits for Individual Members of the Public" became effective. The major changes to 10 CFR 20 concern:

- Explicit limits on public doses - 0.1 rem (1 mSv) per year [a temporary 0.5 (5 mSv) rem per year limit is available upon NRC approval]; the previous requirement was an implicit limit of 0.5 rem per year.
- The dose in any unrestricted area from external sources does not exceed 0.002 rem (0.02 mSv) in any one hour. (Note: This Part 20 dose requirement is separate from current decommissioning site release criteria discussed in Section I.1.2.1.)

The Environmental Protection Agency (EPA) public exposure limits are defined in Title 40 CFR Part 191, *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*; specifically Subpart A, *Environmental Standards for Management and Storage*, July 1, 1990. Section 191.01 states that the EPA limits apply to the radiation doses received by members of the public as a result of the management (except transportation) and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at any facility regulated by the NRC or by Agreement States, to the extent that such management and storage operations are not subject to the provisions of Part 190 of Title 40.

It is further stated in Section 191.03, *Standards*, that management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) discharges of radioactive material and direct radiation from such management and storage and (2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

I.2.4 Special Nuclear Materials Management

Safeguards and security precautions must continue after plant shutdown until all special nuclear materials that come under regulatory control are removed from the plant. Regulations defining the required precautions are found in 10 CFR Part 70, *Domestic Licensing of Special Nuclear Materials* and 10 CFR Part 73, *Physical Protection of Plants and Materials*. The principal concern is to protect against acts of industrial sabotage that could endanger the safety of the work force and the public.

I.2.5 Radioactive Waste Management

Regulations that govern the packaging and transport of radioactive materials are designed to prevent the dispersal of radioactivity to the environs and to protect the public and the transportation workers during shipment. There is some overlapping of federal responsibility for regulating the safe packaging and transport of radioactive materials. This responsibility lies primarily with the Department of Transportation (DOT) and secondarily with the NRC.

The following subsections describe packaging and transportation regulations and licensing requirements for land disposal of radioactive wastes associated with decommissioning radioactive waste management.

Packaging and Transport Regulations

The DOT is responsible for safety standards governing packaging and shipping containers and for their labeling, classification, and marking. The NRC develops performance standards and reviews designs for Type B, fissile, and large-quantity packages. The DOT requires NRC approval to use these packages. The DOT also implements safety standards for the mechanical condition of carrier equipment and for the qualifications of carrier personnel. The Federal Aviation Administration (FAA), the Interstate Commerce Commission (ICC), the U.S. Coast Guard, and the U.S. Postal Service also exercise some regulatory authority over the shipment of radioactive materials.

Shipments of radioactive material utilizing NRC-approved packages must be in accordance with the provisions of 49 CFR 173.471, "Requirements for U.S. Nuclear Regulatory Commission Approved Packages," and 10 CFR Part 71, *Packaging and Transportation of Radioactive Material*, as applicable. In satisfying the requirements of Section 71.12, "General License: NRC Approved Package," it is the responsibility of the licensees to insure themselves that they have a copy of the current approval and conduct their transportation activities in accordance with an NRC-approved quality assurance program. Note that the general license of 10 CFR 71.12 does not authorize the receipt, possession, use, or transfer of byproduct, source, or special nuclear materials; such authorization must be obtained pursuant to 10 CFR Parts 30 to 36, 40, 50, or 70.

By Federal Register notice dated December 21, 1990,(28) the DOT promulgated a final rule which comprehensively revises the Hazardous Materials Regulations (HMR; 49 CFR Parts 171-180) with respect to hazard communication, classification and packaging requirements. The changes are based on the United Nations Recommendations on the Transport of Dangerous Goods (U.N. Recommendations) and DOT's Research and Special Programs Administration's (RSPA) own initiative. They are made because the existing HMR are: (1) difficult to use because of their length and complexity; (2) relatively inflexible and outdated with regard to non-bulk packaging technology; (3) deficient in terms of safety with regard to the classification and packaging of certain categories of hazardous materials; and, (4) generally not in alignment with international regulations based on the U.N. Recommendations. The changes: (1) simplify and reduce the volume of the HMR; (2) enhance safety through better classification and packaging; (3) promote flexibility and technological innovation in packaging; (4) reduce the need for exemptions from the HMR; and (5) facilitate international commerce.

In addition to complying with NRC's requirements in 10 CFR Part 71, each licensee who transports licensed material outside of the confines of its plant or other place of use, or who delivers licensed material to a carrier for transport, shall comply with the applicable DOT requirements in 49 CFR Parts 170 through 189.

Land Disposal Regulations

By Federal Register notice dated December 27, 1982,(29) the NRC promulgated a regulation governing the land disposal of low-level radioactive waste (LLW): 10 CFR 61, *Licensing Requirements for Land Disposal of Radioactive Waste*. The new regulation established three classes of LLW, based on radiological hazard, and provides minimum waste form and stability requirements and near-surface disposal requirements for the land burial of these wastes. The categories were identified as Class A, Class B, Class C, and Greater-Than-Class C (GTCC), depending upon the contained concentrations of specific short-lived and long-lived radionuclides. Class A waste contains the lowest radionuclide concentrations and must meet only minimum waste form requirements. Class B and C wastes contain higher radionuclide concentrations and must meet both the minimum waste form and the stability requirements of Section 61.56. Class C waste must be disposed of by use of methods that provide added protection against inadvertent intrusion into the burial ground. Categories A, B, and C are acceptable for land disposal.

Those wastes whose radionuclides concentrations exceeded the maximum allowed for land disposal, GTCC, were required to be stored pending further determination. This determination was provided in an amendment to 10 CFR 61 (Part 61.55, "Waste Classification") published in the Federal Register dated May 25, 1989, wherein all GTCC wastes are to be disposed of in a geologic repository, or in an approved alternative. In related legislation passed by Congress in 1985 (Low-Level Radioactive Waste Policy Amendments Act of 1985), the U.S. Department of Energy (DOE) was assigned the responsibility for the disposal of GTCC wastes. Under this legislation, DOE must provide the capability for disposal of the GTCC wastes, but the waste generator must pay for the service. Thus, the costs of disposal of GTCC wastes resulting from decommissioning activities are a legitimate decommissioning expense.

In effect, the amendments to 10 CFR 61 treat GTCC as if it were high-level waste, which is what the DOE intends to bury in its repository. However, the NRC has stated it does not consider this action to be a redefinition of GTCC as HLW. The supporting text to the most recent amendments to 10 CFR 61, published in the Federal Register on May 25, 1989, addresses the matter of considering GTCC as a separate class of intermediate-level waste as follows: "It is the Commission's view that intermediate disposal facilities may never be available....At the same time, the Commission wishes to avoid foreclosing possible use of intermediate disposal facilities," by the DOE.(30)

In the analysis of the decommissioning of the reference PWR reported previously in NUREG/CR-0130, it was assumed that the LLW from decommissioning could be disposed of by near-surface burial at a licensed shallow-land burial ground. This assumption was reevaluated by Murphy(31) in terms of the established requirements contained 10 CFR Part 61, which took effect on January 23, 1983. Based upon the 1983 regulation (10 CFR 61), Murphy's reevaluation concluded that the neutron-activated stainless steel core shroud and the lower grid plate have such high concentrations of Ni-59, Ni-63, and Nb-94 that they exceed the Class C limits of 10 CFR 61. The radioactivity of the lower core barrel and the thermal shields also exceeds Class C limits by a small amount. These materials are generally unacceptable for routine near-surface disposal. Therefore, this reevaluation of decommissioning the reference PWR now includes rough estimates for storage and geologic disposal of these materials.

Some additional requirements directed primarily at waste generators and handlers were concurrently published as a new Section 20.311, "Transfer for Disposal and Manifests," of Part 20, "Standards for Protection Against Radiation." The effective date of 10 CFR 20.311 was December 27, 1983. Subsequently, the NRC announced in January 1991, the availability of a revised Staff Technical Position entitled "Technical Position on Waste Form (Revision 1)." This technical position on waste form was initially developed in 1983 to provide guidance to both fuel-cycle and non-fuel-cycle waste generators on waste form test methods and results acceptable to the NRC staff for implementing the 10 CFR Part 61 waste form requirements. It has been used as an acceptable approach for demonstrating compliance with the 10 CFR Part 61 waste stability criteria. The Position (Revision 1) includes guidance on (1) the processing of wastes into an acceptable, stable waste form, (2) the design of acceptable high integrity containers, (3) the packaging of filter cartridges, and (4) minimization of radiation effects on organic ion-exchange resins. The regulation, 10 CFR 20.311, requires waste generators and processors to certify that their waste forms meet the requirements of Part 61 (including the requirements for structural stability). The recommendations and guidance provided in the Technical Position (Revision 1) are an acceptable method upon which to base such certification by waste generators.

Because of their subsequent potential impact on legally-disposable LLW from decommissioning, a brief historical review of U.S. LLW disposal facilities and selected regulations that impact their licensing and operation follows.

Six commercially operated LLW disposal facilities have been licensed and operated since the AEC's announcement in 1960 that regional land disposal sites for commercially generated LLW should be established and that the sites should be operated by the private sector, subject to government licensing authority. These facilities are located in Beatty, Nevada; Maxey Flats, Kentucky; West Valley, New York; Richland, Washington; Sheffield, Illinois; and Barnwell, South Carolina. The Beatty facility, which opened in 1962, was the first to begin commercial disposal operations; the Barnwell facility, which opened in 1971, was the last. Four of those facilities (Maxey Flats, West Valley, Sheffield, and Beatty) have since closed. The other two facilities (Richland and Barnwell) are still operating successfully and dispose of all the commercial LLW currently generated in the United States.

The problems experienced in the developmental years of commercial LLW disposal led to the recognition that the regulations controlling the licensing of radioactive materials did not contain sufficient technical standards or criteria for the disposal of radioactive waste.[12] More comprehensive standards, technical criteria, and licensing procedures were needed for the licensing of new disposal sites, the operation of the existing sites, and for the final closure and stabilization of all sites.

Title 10 Code of Federal Regulations, Part 61 also established a series of performance objectives and technical and financial requirements which a LLW disposal site and site operator must meet in order to ensure public health, safety, and long-term protection of the environment. The regulation established four performance objectives: a) to protect the general population from releases of radioactivity, b) to protect any individual who inadvertently enters a disposal site after the site is closed, c) to protect workers during site operations, and d) to ensure long-term stability at disposal sites to eliminate the need for ongoing active maintenance after closure.

Technical requirements were established for site selection, design, operation, and closure as well as for environmental monitoring, waste classification, and waste characteristics. Specifically, two of the technical requirements established during the regulatory reform years of 1980-1983 have the potential for impacting decommissioning costs. They are: a) sites must have characteristics which maximize long-term stability and isolation of waste and ensure that performance objectives are met (site characteristics and performance must be evaluated for at least a 500-year period) and b) to reduce subsidence or cracking of the caps or barriers covering the waste, all LLW must be placed in the disposal unit in a way that maintains the integrity of the waste package and permits voids to be filled.

Special technical requirements were also established for waste form. These requirements included: (a) waste must not be packaged for disposal in cardboard or fiberboard boxes; (b) liquid waste must be solidified or packaged in absorbent material; (c) wastes that generate toxic fumes or are spontaneously flammable or explosive are prohibited; (d) waste form or high integrity containers (HICs) used to provide structural stability must maintain gross physical properties and identity for 300 years, under the expected disposal conditions, and (e) void spaces must be reduced to the extent practicable.

Nevada, South Carolina, and Washington passed additional regulations to ensure that the transportation and packaging problems they had experienced in the earlier years of operation would not be repeated. In general, these state regulations required radioactive waste shippers to: (a) purchase transportation permits and liability insurance, (b) certify that the shipment and transport vehicle have been inspected and comply with applicable state and federal laws, and (c) notify the disposal facility prior to shipment of waste. In addition, the regulations impose penalties ranging from $1,000 to $25,000 in fines and possible suspension or revocation of the permit.

In summary, the current system for management of LLW evolved over a period of time when disposal capacity was available and costs were low. Disposal capacity currently exists at two sites: Barnwell, South Carolina and Hanford, Washington. South Carolina and Washington have decided to cut back on the amount of waste they will accept from other states. Furthermore, the volume of waste generated is on the rise despite improved volume-reduction techniques. Disposal costs have risen as well, as have costs for transporting the waste as much as 3,000 miles to accommodate current volume ceilings at the existing disposal sites.

---

[12] Inadequate waste form was one of the most significant factors leading to the difficulties experienced at the closed sites. Waste forms sent to the sites reflected general practices of the times. Licensees were encouraged to send all suspect wastes for disposal, and waste minimization and volume reduction were not required. Most of the waste that was disposed of at the sites is believed to have been either composed of very easily degradable material or packaged so that large void spaces existed within the waste or between the waste and the packaging. Some of the waste packages (such as cardboard and fiberboard boxes) were often easily degradable. Also, the wastes often contained chemical agents that enhanced waste degradation and leaching of radionuclides. Frequently, these easily degraded wastes contained little or no radioactivity. Early operating practices also contributed to rapid waste degradation, subsequent slumping of the trench covers, and influx of precipitation. Problems of this kind have not been experienced at the two sites still in operation.

When Congress enacted the Low-Level Radioactive Waste Policy Act of 1980 and subsequent amendments in 1985, it set in motion major changes in the national low-level waste disposal program:

- As of January 1, 1993, each state will be responsible for providing its own disposal facilities for low-level waste. That includes all 50 states and the District of Columbia.
- The most efficient method would be through regional compacts, which would provide a central disposal facility for several neighboring states. Congress must endorse the creation of each compact in advance and renew the approval every five years.
- After January 1, 1993, any state can refuse to accept low-level waste from other states that are not members of its regional compact. Essentially, this means that a state must enter into a regional agreement, establish its own disposal facility, or stop generating low-level waste.(32)

The lessons learned during the developmental years of commercial LLW disposal led to regulatory reform of the system under which disposal is conducted. Improvements in the form of waste that is disposed of, as well as in site selection, characterization, operations, monitoring and post-closure care, have significantly reduced the likelihood that a new LLW disposal facility will require costly remediation in the future.

In addition to the aforementioned technical improvements, many states and compacts have also imposed requirements for additional engineered barriers (generally concrete waste packages or disposal cells) to reinforce public confidence that the waste will be safely isolated from the environment while it decays to background levels. Although the long-term benefit of engineered barriers over carefully selected natural barriers is a topic of much discussion and technical analysis, the selection of multiple barrier systems illustrates the degree to which state and compact officials have responded to public concerns that disposal of LLW should pose as little risk to public health and safety as reasonably possible. However, it should be recognized that the costs of any changes/improvements will ultimately be paid for by the waste generators.

On April 30, 1991, the NRC renewed in its entirety Chem-Nuclear Systems Incorporated's license to receive, possess, store, and dispose of special nuclear material (SNM) at its commercial LLW disposal facility located near Barnwell, South Carolina. The license was renewed in its entirety for five years.(33)

I.2.6 Industrial Safety

During active decommissioning of a PWR, industrial safety and occupational work conditions are regulated by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor under 29 CFR Parts 1900 to end.

Hazardous waste operations are defined as any work within a facility, site, or area that has been deemed as a hazardous waste site. Work may include sampling, logging, drilling, excavating, monitoring, and remediation activities. Such work may be governed by a written, customized Health and Safety Plan (HSP) that meets the intent of the requirements established in 29 CFR 1910, *Occupational Safety and Health Standards*, and 29 CFR 1926, *Construction Safety and Health Standards*, with specific emphasis being applied to 29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response."

The OSHA requirements delineated in 29 CFR 1910.120 that dictate experience for team members are imposed to protect the worker. 29 CFR 1910.120 requires that all hazardous waste workers receive at least three days (24 hours) experience on a bona fide hazardous waste site under the direct supervision of an experienced hazardous waste worker with similar duties. Specific training and certification in such areas as radiological safety, asbestos removal and handling, and hearing protection may also be required. For example, if an asbestos abatement worker is to be assigned work on a hazardous waste site, that worker must either verify that he/she has the necessary hazardous waste experience, or must be assigned to a worker who has been verified as an experienced hazardous waste worker. For decommissioning workers, applicable state, local, or licensee requirements may be imposed as well. A thorough prejob analysis will help determine the level of training required. In addition, it is expected that the onsite project manager or team leader have relevant work experience, e.g., mixed waste characterization, mixed waste remediation, or soil removal.

I.2.7 Other Statutory and Regulatory Requirements

The Environmental Protection Agency (EPA) develops, promulgates, and enforces environmental protection standards and regulations as directed by statutes passed by the U.S. Congress. Environmental regulations and standards of potential relevance to decommissioning the reference PWR are those promulgated by the EPA under the Atomic Energy Act (AEA), the Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

As reported in Reference 34, regulation of mixed radioactive/hazardous waste (i.e., mixed waste) by the EPA and the NRC is largely duplicative, and that situation is not likely to change in the near future. In fact, regulations are likely to become more complex and burdensome in the future. States are authorized to promulgate mixed waste regulations under the RCRA as long as their regulations are no less stringent than applicable federal regulations. States, however, have been slow to apply for and receive authorization to regulate mixed waste under their approved RCRA programs; in fact, as of January 24, 1991, only 24 states and territories had been authorized to regulate mixed waste.

The NRC and the EPA have been working together for several years to resolve the issues associated with mixed waste. The agencies conducted a survey of generators of commercial mixed radioactive/hazardous waste and are completing two joint technical guidances on testing and storage of such wastes. Oak Ridge National Laboratory, which conducted the voluntary generator survey for the two agencies, sent out questionnaires to over 1,300 potential mixed waste generators in November 1991. The results of the survey, presented in NUREG/CR-5938,(35) have been used to develop a national profile that is expected to provide needed information to states and compact officials, private developers, and federal agencies to assist in planning and developing adequate disposal capacity for LLW, including mixed waste, as mandated by the LLRWPAA of 1985. The report also contains information on existing and potential commercial waste treatment facilities that may provide treatment for specific waste streams identified in the national survey. The report provides a reliable national database on the volumes, characteristics and treatability of commercial mixed waste in the United States. Data from the survey also may serve as a basis for possible federal actions to effectively manage and regulate the treatment and disposal of mixed waste.

The NRC and the EPA also are developing a joint guidance on safe storage of mixed waste. Given the current lack of treatment and disposal capacity for most mixed wastes, both agencies are concerned with long-term problems that could arise from storage of such wastes. The joint guidance will address issues associated with onsite storage, including inspection and surveillance of waste, waste compatibility and segregation, storage container requirements, and time limitations on storage of untreated waste. For each issue, the agencies are attempting to identify acceptable practices.(36)

The EPA has set some treatment standards for mixed waste. Incineration is an applicable technology for LLW combined with organic compounds in wastewater and non-wastewater, as well as D001 ignitable liquids (listed waste under RCRA). Vitrification is specified as an acceptable technology for transuranic and high-level wastes containing both highly radioactive compounds and hazardous components.(34)

Scientific Ecology Group, Inc. (SEG) in Oak Ridge, Tennessee, is the nation's largest LLW processor. SEG has applied for permits and a license to operate the first commercially available incinerator for solid and liquid mixed waste. The incinerator is currently licensed only for LLW. The company submitted an RCRA Part A permit application in March 1991.(34) The associated Part B permit application was submitted to the Tennessee Division of Solid Waste in early 1993. These permits, when granted, will allow SEG to store and treat characteristic hazardous wastes.

Appendix M

Comments and Responses on Draft PWR Report

Appendix M

Comments and Responses on Draft PWR 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.

Nineteen letters were received by the NRC in response to their request for comments on the draft PWR study report prepared by Battelle Pacific Northwest Laboratories (PNL). Of those 19 letters, 14 contained specific comments and 5 merely indicated support for the comments prepared and submitted by an umbrella utility group (NUMARC). The number of comments per letter ranged from 1 to 106. As would be expected, many of the commentors made the same or similar comments on some of the topics in the report.

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 will be absent from the set of comments and responses.

001	Nuclear Management and Resources Council (NUMARC) requested an extension of the comment period to permit more thorough review and comment. No comments at that time.
002	Fawn Shillinglow, private citizen. Forty-one comments.
003	TLG Services, Inc. Forty-seven comments.
004	Southern Nuclear Operating Company. Supported NUMARC comments.
005	Georgia Power Company. Supported NUMARC comments.
006	Union Electric Company. Eight comments. Supported NUMARC comments.
007	Southern California Edison Company. Eight comments.
008	The Utility Decommissioning Group (UDG). Six comments. Submitted by Winston & Strawn.
008a	The Nuclear Management and Resources Council. Forty-three comments.
009	Virginia Electric and Power Company. Supported NUMARC and UDG comments.
010	Yankee Atomic Electric Company. Twenty comments.

011 No letter assigned this number.

012 Westinghouse Electric Corporation. Nine comments. Supported NUMARC comments.

013 Public Service Company of Colorado. Eleven comments.

014 Public Service Electric and Gas Company. Five comments. Supported TLG Services, Inc. comments.

015 Florida Power Corporation. Twenty comments.

016 Consolidated Edison Company. Five comments. Supported NUMARC comments.

017 Corrine Carey, private citizen. One comment.

018 Barry C. Mingst, META. One-hundred and seven comments.

RESPONSES TO COMMENTOR 002

002-1 Comment: (p. xvii) Assumed that an acceptable dry transfer system will be available to remove the SNF from the pool to a dry storage facility on the reactor site. Why should we assume this when use of the VSC-24 cask necessitating wet storage and purchase of a MTC transfer cask for the pool is now being advocated?

Response: The stated assumption was that there would be an acceptable dry transfer system for moving spent fuel from a failed storage device to a new storage device, not for dry transfer from the spent fuel pool. Such a system is currently under development by jointly by DOE/EPRI/SMUD.

002-2 Comment: (p. xxi) "yet-to-be-developed LLW disposal facilities"--(p. xxii) unforeseeable event which will increase cost are likely to occur" an unforeseeable event which is very "seeable" is that the low-level sites will never be developed--what is the plan in that case? You can't assume the state will develop these sites--ever.

Response: The statement was intended merely to identify a potential source of cost escalation for D&D costs.

002-3 Comment: (p. xxix) "300 yr. entomb scenario would eliminate future concerns about LLW disposal altogether"--Is this a true statement? Will the public accept a high level and low-level waste dump at these reactor sites along our nations waterways for 300 years? That is an assumption.

Response: Given the nature of the entombed radioactivity, the contaminants should decay to unrestricted release levels within 300 years. No high level radioactive wastes would be contained within the entombment structure.

002-4 Comment: (p. 1.2) You do not evaluate leaving the fuel in the pool until taken away. Why not? Why close the pools and put the fuel in casks unless there is something less safe about the pools for extended time. What is the safety factor of long term pool storage v.s. dry cask? Our SNF at LaCrosse at Genoa has been sitting there in the pool at a shut down reactor for many years. Are there problems? And what casks are to be used? The MPC has not been developed and won't be until repository final criteria is decided.

Response: Use of the spent fuel pool for SNF storage until DOE has taken possession of all of the contained SNF is considered in Appendix D, under the Present Value analyses. Pool storage is considered safe for at least 30 years, assuming the fuel rods are intact.

002-5 Comment: (p. 2.5) The Trojan EIA of 2015 for shut down is used even though it shut down January 1993. You say at the top of this page that the foundation of this study is "realistic" and "up-to-date" results. Is this being realistic? Up-to-date? Too many assumptions in the study are not realistic and out-of-date. You assume the reactors, aging as they are with reactor vessels getting brittle, steam generators needing replacement way ahead of when expected, etc., will run to full term.

Response: The Trojan reactor is used as a surrogate for all large PWRs in these analyses. Thus, the EIA bases for spent fuel acceptance was followed. The specific situation at any given reactor may well be different, and the owner should adjust his analyses accordingly.

002-6 Comment: (p. 2.6) You assume a repository "even though such a repository does not currently exist" Is this realistic? "Mixed wastes are not estimated as no estimates for disposal costs at some future mixed waste facility are available" Is this realistic?

Response: Current law and regulations presume the eventual availability of a geologic repository for disposal of spent fuel and high level waste. The quantities of mixed waste arising from a reactor decommissioning is judged to be small, with an insignificant impact on the total cost of D&D.

002-7 Comment: (p. 2.7) You assume only "insignificant" amounts of asbestos, yet quantities are unknown and why do you think they all will be removed by decommissioning time? Is there a study covering each reactor on this issue? What are costs?

Response: Information from Trojan suggests that less than 500 lb. of radioactively contaminated asbestos might be present on-site.

002-8 Comment: (p.2.7) You assume fuel to fall into the "standard" category. Has a study been done as to how much nonstandard and failed fuel is at each reactor? Where will it go?

Response: Current data suggests that non-standard fuel comprises only a few percent of the total inventory. Eventually, all of the spent fuel, standard and non-standard, will be placed into the repository.

002-9 Comment: (p. 3.2) You actually assume first SNF pickup from Trojan to be 2002 and last in 2029? How realistic is this? What is this based on?

Response: Based on Trojan's place in the queue for SNF pickup by DOE, and the DOE's schedule for initiating SNF pickup in 1998. Obviously, slippages in the DOE schedule will delay emptying the pool at Trojan, if that mechanism is relied on to empty the pool.

002-10 Comment: (p. B.37) "Nuclear insurance premium projections are based upon the assumption that the reference PWR's "retirement" is due to the expiration of the usual 40-year operating license and not due to an "incident" of any kind." How does this assumption relate to the real situation. Trojan itself was shut down early as was Yankee Rowe. Many other reactors are "aging" ahead of schedule with steam generator problems etc. Why not plan for costs of early shutdown as it well may be the case?

Response: Nuclear insurance premiums are based on the presumed risks involved. Early shutdown of a reactor for economic or equipment reasons should not affect the premiums during decommissioning.

002-11 Comment: (p. xvii) Since dry storage "may" (and most likely will) be necessitated after reactors are dismantled, why are these considered "operation" costs? If the license is to be terminated, shouldn't spent fuel be off-site 1st? Moving the SNF from the pool to casks isn't considered off-site when its within plant boundaries is it?

Response: Current NRC policy is that dry storage of SNF following reactor shutdown is NOT a decommissioning cost for the reactor. Moving the SNF into an on-site ISFSI places the SNF under a different nuclear license, thus allowing the reactor license to be terminated following decommissioning.

002-12 Comment: (p. xx) It is not prudent to eliminate costs of fuel storage, dry casks, or demolition and restoration from the amount of funds to be placed in the public decommissioning fund. These are all part of decommissioning. If they aren't required ahead, once again we are planning for an unrealistic scenario.

Response: Same answer as for 002-11.

002-13 Comment: (p. 1.3) Removal of retired steam generators is not figured in--could add $100 million more. It certainly will at Pt. Beach. Operation of pool would cost $4 million more -- is this a realistic estimate? Over what time period? -- we don't know?

Response: Trojan has no retired steam generators, thus no costs were assigned to their removal and disposal. Based on the estimated costs for transport and disposal of the original steam generators during decommissioning, an additional cost of <$5 million would be experienced for 4 retired steam generators.
Spent fuel pool operation costs are not presently included in decommissioning costs. The estimate given in Appendix D is based on an earlier study that considered information from a number of reactor sites (PNL-7778).

002-14 Comment: (p. 1.5) Transport of waste rates, increased disposal rates, cutting pipe to 5 ft. lengths (why?), removing concrete, multiple reactors-etc., etc., -all are available - so how accurate can this estimate be for a real reactor?

Response: These sensitivity analyses were performed to determine likely upper and lower bounds on the costs for these activities, and to show the impacts on the base cost estimate from these changes in assumptions. These analyses are based on the Trojan reactor, which is certainly a real reactor.

002-15 Comment: (p.1.5) All costs given in constant dollars of early 1993 regardless of when expenditures occur - this is already outdated - will figures be updated each year?

Response: The costs are presented in 1993 dollars, to provide a standard base year for a set of decommissioning analyses being performed for NRC. The escalation formula in the Decommissioning Rule should be utilized to escalate to future years as data for those years becomes available.

002-16 Comment: (p. 2.2) Original PWR study (1978) used - "no additional safety analyses need be performed for this study." That was 16 years ago just as was the EIS for (1979) storage of spend fuel. Certainly dry cask storage was not completely considered, if at all, in these old documents. The VSC-24 SAR is still not even finalized as I write this, and the Palisades plant had to change its FSAR when it used casks. Certainly new safety analysis to this plan is also needed.

Response: The safety analyses presented in NUREG/CR-0130 represented possible accidents during decommissioning. Because the basic operations have not changes significantly since that time, the original analyses still apply.

Accidents occurring in ISFSI operations are a subject of consideration during the licensing of an ISFSI.

002-17 Comment:	(p. 2.6) Costs in the study are based on location within the Northwest Compact. These costs could be increased 3 or 4 time depending on location of reactors. This is a big variable. How is it figured site specific?
Response:	The effects on cost of having to transport the wastes from Trojan to Barnwell and dispose of them there were examined as a sensitivity case. Compared to disposal at the U.S. Ecology facility at Hanford, the costs increased about $94 million. The CECP (computer program for estimating D&D costs) contains mileages between all commercial power reactors and both commercial waste disposal sites, for use in performing site-specific transportation analyses.
002-18 Comment:	(p. 3.8) Do I understand you plan to put the reactor vessel parts in dry casks in storage on the pad along with the spent fuel? What canisters have been developed for this. Tested for this?
Response:	The reactor vessel internal parts are very similar in nature to the hardware associated with spent fuel assemblies. Many casks licensed for spent fuel are also licensed to contain the highly radioactive metals from spent fuel assemblies or their equivalents. The basic assumption, given in Appendix E, is that the vessel internals are cut into pieces that will fit within a square canister whose size is equivalent to the envelope of a spent fuel assembly, and can be handled and stored as if it were a spent fuel assembly.
002-19 Comment:	(p 3.12) Reduced Staff. This is a real concern. It is addressed quite well in the report of the MRS Commission 1989 Gov Doc Y3.M74/2-2N91 page 37 number 2 "Storage at Shutdown Reactors". It states: "Maintenance of spent fuel on-site after reactor shutdown is not without consequences"... "Following reactor shutdown, trained reactor personnel would probably seek employment where their skills would be more useful. Monitoring the stored fuel and maintaining security would probably be routine and monotonous and could be carried out as a part-time responsibility by persons whose principal duties were elsewhere. Under such conditions, these operations might not be performed as well as expected, so there could be some risk that spent fuel storage and subsequent handling to prepare it for shipment to the repository would be performed under less than ideal conditions." Remember the worker at Hanford that dutifully recorded the levels of waste in the tanks, yet neglected to <u>calculate</u> that they were leaking for a long time. Will a worker, for example, recording the temperature at VSC-24 casks be able to interpret what they mean immediately, or will he just record them, and not immediately know what to do in an emergency? And will the necessary emergency equipment and manpower be available to transfer fuel to from a defective cask in an emergency at a shutdown reactor? The casks are a new development and monitoring them is a new development. Certainly new safety concerns need to be addressed concerning situations at a shutdown plant. What if 2 casks became defective at the same time for example? We had 30° <u>below</u> 0° in Wisconsin this winter for several days. If several VSC-24 casks cracked, or vents got clogged with ice and snow, the loaded MSB's couldn't be moved below 0°. What then? Does a maintenance man stop to make an analysis at that point?

Response: Concerns regarding operations and accidents at an ISFSI are considered during the licensing of the ISFSI, and are not a consideration for decommissioning of reactors.

002-20 Comment: (p. 3.29) You never explain <u>why</u> the cutting of the pipe into 5 instead of 15 ft. lengths might be necessary. Why?

Response: As discussed in the response to comment 002-14, the analysis of cutting piping into 5-ft lengths was done for a sensitivity analysis. Obviously, not every length of pipe can be cut into exactly a 5-ft or a 15-ft length, depending upon the physical layout of the piping and its attachment to other equipment. However, the 5-ft length seems a reasonable lower bound and the 15-ft length seems a reasonable upper bound.

002-21 Comment: (p. 3.24) You estimate 4 steam generators for disposal. How does a reactor like Pt. beach figure in, which will have replaced all the steam generators already, and stored old ones in a building (contaminated) on site? How does the extra storage facility figure into the costs? With so many steam generator problems, this will happen at many reactors.

Response: See response to comment 002-13.

002-22 Comment: (p4.13) "However, shouldn't it be determined at the end of the extended safe storage period that the radioactivity on this contaminated material had not decayed to levels permitting unrestricted use, then all of the removal and disposal activities of DECON Period 4 would be necessary, and the cost would be increased by about 46 million, without contingency. So is the utility required to have this 46 extra million set aside in case of this scenario?

Response: Obviously, if the Utility chooses to use the SAFSTOR alternative, it would be prudent to assume the worst, i.e., SAFSTOR2, wherein all of the radioactive materials removed during DECON would still have to be removed and disposed as LLW.

002-23 Comment: (p. 5.1) You list ENTOMB as "least likely" yet say the unavailability of waste disposal capacity would be an acceptable reason for entombment beyond 60 years. This, is looking at reality, could quite likely be the <u>most</u> common method used I would think. The waste has never been removed yet, why should we think it ever will be? Nobody else wants it. Your definition of decommissioning says 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." I have problems with this definition. Where does an ISFSI fit in? Is it part of the facility or not? Is it a disposal site or not? Is it part of the utility property or not? Is it radioactive or not? Is it open to unrestricted use - of course not? So how can the site be called "decommissioned" with casks of radioactive waste in a restricted area on the property. Please explain. To put spent fuel from pools into casks down the road on-site is not <u>removing</u> it.

Response: An on-site ISFSI is a separately licensed facility co-located on the same site with the reactor. Termination of the reactor license via any decommissioning alternative has no effect on the license for the ISFSI. With proper security and monitoring, the ISFSI facility would continue operation on the site after the reactor facility had been totally decommissioned and those areas of the site associated with the reactor had been released for unrestricted use.

002-24 Comment: (p. 5.2) You say a type of "entry" into the entombment would be necessary and so it is not a particularly viable decommissioning alternative." Yet is appears the one that most likely will take place. How do you plan this "entry"? Is there a study on this?

Response: The statement was made that it was possible that an entry might be necessary to assure that the contained radioactive materials had decayed sufficiently to meet unrestricted release limits, particularly if the entombment license was to be terminated at the end of 60 years. No analyses were made of the costs associated with such a delayed entry.

002-25 Comment: (p. 5.9) "only industrial security (2 persons onsite around the clock) will be necessary to assure no one obtains access to the entombment portion of the building." Is there a study on this?

Response: This level of security, coupled with the strong, thick closures on the entombment structure, is considered more than adequate to protect the public from the consequences of its own actions.

002-26 Comment: (p. 5.11) Frankly I'm surprised that you admit here that 60 years may be unrealistic. But of course the 380 million for the safe 300 years is out of the questions unless, as you suggest here, costs are cut on safety and "electronic security systems are tied to local law enforcement agency" for less and then insurance cuts from $600,000 to $20,000 sound better too. And this is <u>for public safety</u>, of course, as if once its sealed up, as you say, it presents "little or no risks to the general public." This is totally acceptable.

Response: No response. Comment is a statement.

002-27 Comment: (p.6.1) "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 overhead costs."
(p.6.3) "Doses are not large" -- "range from 315 person-rem to 931 person-rem roughly equivalent to a <u>few years</u> of normal reactor operation." I find these statements above hard to accept. Get the work done as fast as possible to cut costs, you appear to be saying. That means different workers on different shifts--not one man finishing a job he starts -- it means overworked people which causes accidents -- it means not taking the time to the job in the best way possible. And considering there is no safe dose of radiation, I want to know just what is told to these workers as to their expected exposures of only a <u>few years</u> of "normal" reactor operation. Are all risks explained to them? How is this to be done? Decommissioning workers are not "super people." Radiation affects them just as anybody else in the public and they should be completely aware of what the affects might be to them. Are they?

Response: D&D worker exposures are limited by the same regulations that apply to reactor operations personnel.
Continuing operations on successive shifts are generally more safe than stopping at the end of a day and starting again in the morning.

002-28 Comment: (p. 7.10) I find your definition of ISFSI surprising, Independent Spent <u>Fuel Storage</u> Installation. You say here it is designed and constructed to for the interim storage spent fuel <u>and other radiation materials</u> associated with spent fuel storage. We have been trying to get this clarified. Please explain precisely what other materials can be stored at an ISFSI. The public needs to know just what is, and is not, allowed in dry cask storage. There were many questions and "grey areas" in the DOE contract with utilities on this. Can control rods be kept in casks with spent fuel rods? What else? How does this affect repository capacity and acceptance?

Response: As discussed in Response 002-18, the other materials likely to be stored in an on-site ISFSI would include the highly activated GTCC reactor vessel internals, packaged in square canisters and handled just like spent fuel assemblies. Control rods that are an integral part of a fuel assembly can certainly be stored in an ISFSI. The GTCC materials must be disposed in an acceptable repository, and the SNF repository is likely to be the only one available.

002-29 Comment: (p. B.24) "The cost presented here is quite speculative since a geologic repository....does not presently exist" Even if one did exist, it won't hold all the military waste and spent fuel existing now. Where is the study showing Yucca Mountain would hold decommissioned reactors? How may more repositories would be needed to hold all the waste from all nuclear facilities that exist now when they are all shut down? Where is a study showing that the volume, and heat, and dose rates, are acceptable? Where is a study showing the containers to be used for all this? A container cannot be developed for a repository that does not exist. Also no cost estimates for mixed waste were even done as that facility for disposal doesn't exist either so it says on this page.

Response: The estimate is based on available data from the DOE's Office of Civilian Radioactive Waste Management program, who is charged with constructing and operating the national SNF and HLW repository. The volume of GTCC material is quite small for each reactor, about 46 canisters equivalent in volume to 46 spent PWR assemblies. If packaged within one of the proposed Multi-Purpose Canisters presently being considered by DOE for SNF, about 2 MPCs would be required. The thermal heat emission rate from the activated metals is lower than an equivalent volume of spent fuel and decays much more rapidly, so heat emission would not be a problem. As discussed in Response 002-6, the anticipated volume of mixed waste is very small and would have an insignificant impact on the total decommissioning cost.

002-30 Comment: (p. B40-41) An independent analysis subject to public input on a reactor site should be done before it is open to unrestricted use. The public needs to know just exactly what radiation levels are where on the property and what was buried or spilled where etc. For example -- where the dry cask pad was, when radioactive sludge was spread or filled (as it was at Pt. Beach) when steam generators that were replace were stored. Can people really trust the licensee to clean its own house well enough to allow their children to have a park on this land? to build public trust, an independent 2nd survey should be required before opening land to unrestricted use.

Response: The licensee must survey the entire facility and site and demonstrate that everything is sufficiently clean to satisfy unrestricted release limits. The NRC then performs a confirmatory survey of the facility and site to demonstrate that the licensee's survey is accurate, before terminating the nuclear license.

002-31 Comment: (p. D.2-D.3) You refer to "reliance on DOE's acceptance of the SNF under this 10 CFR Part 961 Contractual Agreement to empty the fuel pool." Please clarify this. If a plant shuts down prematurely and does not have an ISFSI, would it be moved up on the contract queue, and have its SNF removed from the pool before other plants that have their SNF in ISFSI's? What constitutes an "emergency" situation with one plant to cause a change in queue place? How is this decided?

The question is whether, when a repository or MRS did ever open, which plants will be stuck monitoring ISFSI's, while other plants have fuel taken directly from their pools? Could a plant shut-down early if it had steam generator problems (or what ever) and, be moved up on the queue to avoid paying for day casks?

The fact that DOE stated shut down reactors "may" get priority does just what you say here --- "invites questions of equity among all owners and generators of SNF". Have there been any recent decision on this?

Response: These questions are not within the scope of the NRC's authority, and should be directed to DOE.

002-32 Comment: (p. D.9) I object strongly to the 1979 Generic Environmental Impact Statement used (ref"). This statement is not an adequate EIS for present day dry cask storage in ISFSI's. It is 15 years old. These casks weren't even developed until the past few years. NUREG-0575 was used as the basis of an EIA on the VSC-24 we are to get at our Pt. Beach Reactor. On September 5, 1992 I sent in comments on this 1979 EIS. I will repeat a few of them here. Vol 3 (NUREG-0408) was the draft for 0575. In that volume was a comment on the draft from the attorney generals of 4 states including Wisconsin. On page 2-106 this says "The DGEIS assumes that dry storage is a viable alternative but provides no analysis to support this statement". NRC response there was "Dry Storage is not analyzed in detail because it is not under strong consideration". Well there you have it --- dry cask was not even under strong consideration in 1978-79 yet in 1994 this EIS is used for dry cask. Please defend this use of 1979 EIS.

I also want to quote an NRC response to another concern of Wisconsin (on pg 2-103 of NUREG 0575 in 1979) Wisconsin expresses concerns about decommissioning. NRC response is that "it is a relatively trivial and cheap operation" (in reference to an ISFSI). If it is so trivial and cheap, I want to see plans for decommissioning ISFSI's at nuclear plants defending this statement. In 300 years at an entombed reactor, what condition will spent fuel inside casks be? How many times will the casks be changed? Is this even feasible?

Response: The paragraph in the report makes reference to reactor pool storage. Nureg-1140, titled "A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees" analyzed potential onsite and offsite consequences of accidental releases associated with the operation of an ISFSI. A list of NRC approved spent fuel storage casks is identified in 10 CFR 72.214. VCS-24 is included.

002-33 Comment: (p. D.10) No dual casks exist that are licensed for use at US reactors, much less a MPC. You say here "Metal Canisters containing the fuel may be able to fit inside a transportable cask." This is a reference directly to the VSC-24 vertical concrete cask and the NUHOMs horizontal concrete vault. We are all eagerly awaiting to hear how these inner canisters of these systems fit into a standardized transport system of DOE. What if they don't? The present plan is for the MPC to hold 21 assemblies, so how does that relate to 24 in the VSC-24? Since the VSC-24 presently requires a MTC and pool transfer, why is NRC allowing one of these cask when it necessitates keeping pools open and hinders decommissioning plants? Is there a dry method available now? Even so, as you say here, there could be a cask seal failure or "abnormal condition" --- then what?

Response: A dual-purpose (transport and storage) cask has recently been licensed. The VSC-24 canister is loaded in the spent fuel pool, but subsequent dry transfer of the canister from the storage cask to a transport cask is not precluded. The compatibility of the VSC-24 and the NUHOMS-24 canisters with the DOE's yet to be developed transport cask remains to be determined. The utility makes it's selection of a storage device based on a number of considerations, with economics being a major factor, and must include consideration of the costs of maintaining the availability of a pool or some other appropriate device to provide recovery capability in the event of a problem with the stored fuel or the storage canister.

002-34 Comment: (p. D.10) You refer here to dry cask as "widely demonstrated". What is the longest it has been used in the US? You say fuel has been in pools for "up to 18 years". We are to get a cask in Wisconsin that has been used and tested at a reactor since last year. The public questions this as acceptable. By allowing exemptions to pre-fabricate the VSC-24 cask, all sorts of problems arose at the vendors site creating the inner canisters and at the Palisades Plant creating the concrete outer casks before NRC even gave the design a Certificate of Compliance (to the point the whole fabrication of the cask had to be stopped for evaluation). This sort of thing does not encourage public acceptance of dry cask storage. We find having casks like this sit on concrete pads along the shores of Lake Michigan a real threat to our waterways. Decommissioning of ISFSI's should be part of decommissioning of the plant. They should be a part of the on-site facility. It they aren't, then they are a disposal facility really and should be considered permanent. Why should the Spent fuel pool be an integral part of the plant and, when the fuel is shoved out the back door it's something else, and becomes "independent"?

Response: A dry cask storage demonstration has been underway at the Surry Station in Virginia for a number years. All of the storage casks presently licensed were first tested and demonstrated at the Idaho National Engineering Laboratory. A dual-purpose (transport and storage) cask has been recently licensed. The VSC-24 cask is licensed for storage. An ISFSI is licensed under 10 CFR 72, not 10 CFR 50, as in the case of the reactor, and is separate from the reactor facility. The requirements for safe operation of a power reactor are much more stringent than for the passively cooled dry storage units in an ISFSI.

002-35 Comment: (p. H.1) Mixed wastes not considered --- disposal "is presently very difficult, if not impossible". There aren't any disposal sites for this waste. How are these stored on site?

Response: Because no mixed waste disposal sites are presently available, the utility must provide a properly permitted facility on-site for storage of these materials. In most instances, such a facility already exists on-site, to accommodate mixed wastes generated during normal plant operations.

002-36 Comment: (p. H.8) EPA decided not to enforce RCRA land disposal restrictions for mixed LLW for 2 years. This policy was to terminate December 31, 1993. It is now January 1994. What is the situation now? What are utilities doing with this waste? Is there any place for it to be disposed?

Response: The wastes are being stored on-site by licensees.

002-37 Comment: (p. I.11 I.12) It says here that security and safeguards during decommissioning are not specifically addressed in the regulations. Why not? Decommissioning is a specific process bringing all kinds of new machinery and new people to work. New processes will be aired. Certainly all of these procedures need a carefully developed safety and security system evaluated specifically for this whole operation. Certainly appropriate guidance documents, (you say have not yet been issued) should now be made available to plant owners now.

Response: With the spent fuel removed from the storage pool, no requirement remain regarding safeguards of special nuclear materials (SNM). The physical security requirements are just those of industrial security, assuring that unauthorized persons are not wandering around the facilities. In other words, protecting the health and safety of the public by not admitting them onto the premises where they might be injured.

002-38 Comment: (P I.13) "The decommissioning rule allows for reduction of the NEPA requirements through elimination of the mandatory requirement for an EIS at the time of decommissioning for 10 CFR Part 50 and 72 licenses". This is wrong. An EIS should be required. An assessment is not enough. If you really expect the public to feel this is to protect their environment, a full evaluation is needed.

Response: An environmental assessment (EA) is always performed for a rule change and when there is a positive declaration of impact, an environmental impact statement (EIS) would be required.

002-39 Comment: (p I.26) Explicit limits on public doses are here stated as of January 1993 as .1 REM per year "yet temporary .05 REM per year limit is available upon NRC approval". What is the time limit considered temporary? Why is this allowed? Where is it presently allowed? I find this a "loop hole" dangerous to the public. We don't know there is any safe level of radiation at all.

Response: This issue was addressed in the Supplementary Information to the final rule published in the Federal Register Vol. 56, No. 98, dated May 21,1991, on page FR23375.

002-40 Comment: (p. I.37) What now is the acceptable level of residual radioactivity for release of property for unrestricted use? Criteria was being developed. Is it finalized now?

Response: Regulatory Guide 1.86 is presently the bases for release of materials for unrestricted use. NRC has a rulemaking in progress to define new bases, as discussed in the draft Generic Environmental Impact Statement in support of Rulemaking on Radiological Criteria for Decommissioning of NRC-Licensed Nuclear Facilities, NUREG-1496, issued for comment in August, 1994.

002-41 Comment: (p. I.38) With the premature shut-down of so many plants and more expected, I find your statement that "there are a myriad of regulatory issues that become ambiguous or are undefined" in such cases seems to me that more concern has to be given to this area. In fact, I would find allowing plants to wait for only a 5-yr time period before end of license to start planning very risky. Plants are aging ahead of expectations, steam generators need replacing, problems are occurring, yet this whole decommissioning plan remains committed to the idea that they will run full term anyway. Is this realistic? Also, POL needs a very carefully considered definition and this needs to be done now. Rulemaking is needed with full public involvement on this issue of POL.

Response: **NRC has published a proposed rule entitled "Decommissioning of Nuclear Power Reactors" in 60FR37374, July 20, 1995 to take these concerns into account.**

RESPONSES TO COMMENTOR 003

003-1 Comment: Page xvi: PNL has adopted a specific scenario for Entombment whereby all the reactor vessel internals are removed shortly after shutdown, and the remainder of the radioactive wastes relocated into the reactor containment building for long term storage (up to 300 years). This scenario had been proposed by Maine Yankee only a few years ago, and was rejected out-of-hand by the NRC. The reason given was that the Maine Yankee facility had not been designed or licensed as a long term waste disposal facility. The licensee had not performed extensive analyses to determine the long-term effects of building and structure degradation, and the total environmental effects of waste storage. In addition, the NRC did not want to create a series of low-level waste storage sites all across the nation that would increase NRC's difficulty to monitor them. It is not clear whether this PNL proposal represents a shift in NRC policy, or whether it is offered as "new alternative" which must be evaluated under the NRC's LLW storage facility criteria. In either case, PNL has not provided sufficient evidence that such an evaluation was performed and that the results favored the 300 year storage scenario.

Response: The entombment scenarios were included at the direction of the NRC to match the scenarios of the previous study (NUREG/CR-0130). The NRC does not favor this option under current regulatory requirements but will consider it under extenuating circumstances if health and safety is a consideration.

003-2 Comment: Page xxii: The discussion of increasing LLW disposal costs driving the waste volumes down by means of volume reduction and recycling techniques has been evaluated at length in the industry. The burial cost basis depends on the size of the burial facility (capital and operating costs), region of the country (in terms of labor costs), and when in the burial facility life cycle decommissioning wastes are expected to be received. The later in burial facility life that the decommissioning wastes are received, the lower the unit cost for burial as all initial development costs have been borne by operating reactor wastes. Unless, the delay is long enough that a second host burial facility must be constructed, in which case the decommissioned reactor will bear most of the development cost.

As waste volumes decrease the burial facility operators have smaller quantities of volume upon which to cover their fixed and variable operating costs. In return, they must increase the unit costs of waste burial. This may drive volumes down even further, causing an upward spiral of burial rates. The equilibrium burial cost has not been identified at this time. The economic forces at the time of decommissioning will determine these costs.

Response: The comment statement is true. No attempt was made in the study to evaluate the effects of the various possibilities described in the comment.

003-3 Comment: Page xxv: Present Value calculations are often helpful when evaluating one or more alternatives for capital equipment expenditure, such as the purchase of a new piece of machinery for a manufacturing facility. These Present Value (PV) calculations escalate current costs of a piece of machinery to future dollars using an assumed inflation rate, then discount those dollars back to their present value by assuming an appropriate interest rate. The lower PV of the alternatives is usually selected for purchase of that equipment.

While the PV of future cash expenditures is useful for evaluating alternative actions, PV is used with considerable care by regulated entities for the following reasons:

> Utility regulatory proceedings make use of nominal amounts, not real amounts, for determining electricity prices;
>
> Discount rates used in regulatory proceedings may be based on achieving a settlement amount rather than on historical data;
>
> Utility regulators deal with the impact on customers through evaluating revenue requirements; and
>
> PV's of the revenue requirements generated from cash expenditure alternatives may be significantly different from PV's of the cash expenditures.

This care is particularly important for decommissioning costs, because the patterns of the cash expenditures are very different from the patterns of the revenue requirements the expenditures will cause.

The range of available decommissioning alternatives produces a range of technical financial and regulatory risks that must be evaluated. The regulatory risk is particularly significant for delayed decommissioning alternatives, because:

> decommissioning costs are sensitive to changes to NRC and environmental regulations (such as residual radioactivity release criteria) and to technical requirements;
>
> fund contribution requirements are sensitive to changes to decommissioning costs, inflation rates, fund earnings levels and income tax rates;
>
> delayed decommissioning for up to 300 years presents considerable uncertainties with respect to public utility commission rulings for lower revenue requirements for the external trust fund; and,
>
> under electric utility deregulation, the business focus may change from generation to transmission and distribution, such that license transfers to another utility may occur whereby the new licensee may not be financially equipped to handle the risks of decommissioning.

Therefore, fund contributions (and the resulting revenue requirements) for delayed decommissioning alternatives could change long after a nuclear generating unit has ceased to operate. The risk of future regulators precluding customers from being further charged may keep delayed decommissioning alternatives from being viable, no matter what PV calculations for either cash expenditures or revenue requirements show.

These same comments apply to PNL's use of PV calculations relating the spent fuel storage alternatives of wet versus dry storage, as discussed in Volume 1, Summary, Page xxvi, and in Volume 2, Appendix D, Section D.4.3.

The inclusion of PV calculations in the PNL Revised Analysis based on cash expenditures is misleading at best and is an open invitation for criticism. PV calculations should be left to the readers, who will then be responsible for defending the PV validity.

Response: The purpose of the PV analyses is to illustrate the possible effect on funding requirements for the delayed D&D alternatives, showing that postponing expenditures for a number of years could reduce the amount of money needed in the decommissioning fund at reactor shutdown. Application of this type of analyses by the licensee and/or the public utility commissions would be a matter to be resolved between those parties.

003-4 Comment: Page 3.12: PNL has assumed all work will be done on an 8-hour per day basis, two shifts per day. The utility and DOC staff shown in Figure 3.6 for Dismantlement does not indicate how many management personnel are dedicated for second shift operations. It is not reasonable to assume dismantling activities can be performed on second shift with no, or minimal second shift management.

Response: Upon review, the number of DOC D&D Supervisors was increased from 3 to 6.

003-5 Comment: Page 3.16 - 3.18: The number of craft personnel does not appear to be reasonable. Based on 35,357 crew hours in the Reactor, Fuel and Auxiliary Buildings for the 80 week period shown in Figure 3.9, the total number of craft personnel is about:

35,357 crew hrs/(80 wks x 5days/wk x 8 hrs/day) = 11 crews

If the average crew size is 5 workers, there are about 55 total workers on day and night shifts, or about 27 workers per shift. This number of workers per shift seems very low. It is not clear how PNL calculated the number of crews to be employed. TLG employed an average of 35 workers for one-shift operations at Shippingport, just to remove piping and components. This was exclusive of vessel and internals, or building structures.

Please refer to comments on Volume 2, which are directed at the detailed estimate assumptions and bases

Response: The average staff size computed as in the comment is misleading, since it does not consider the growth and reduction of staff size over time, and neglects the fact that the crew sizes vary from as few as 3 persons to as many as 60 persons. The nominal peak staff size for direct labor operations is about 75 persons per shift.

003-6 Comment: With respect to on-site spent fuel storage, PNL assumes an ISFSI is constructed on site so that decommissioning can proceed with "minimum impact," but no costs are included for the ISFSI or its operation and maintenance PNL assumes these costs are assumed to be operating costs.

Current ISFSI designs cannot accommodate fuel cooled less than five years (the last core discharge). Accordingly, PNL should include the wet storage costs as part of the decommissioning cost.

Response: The NRC current position is that SNF storage costs are NOT decommissioning costs.

003-7 Comment: The utility staff overhead rate assumed at 42% seems very low. In general, employee fringe benefits (vacation and holidays), insurance (life, health and accidental death and dismemberment, and worker's compensation) and taxes (FICA, FUTA and SUTA) are a minimum of 32 to 35%. Comprehensive general liability insurance, building overhead (rent or capital depreciation), utilities, furniture and fixtures, and consumables add a substantial cost to the utility burden. TLG has typically seen values in the range of 80 to 90%.

Similarly, the DOC staff overhead rate varies for "home office staff" assigned to the site temporarily, and permanently assigned site management personnel. TLG has seen values ranging from 110 to 150% It is presumed that the DOC overhead rates include per diem and travel expenses.

PNL should consider separating the overhead costs into fixed and variable portions, to account for the changes in staffing levels throughout the different phases of the project.

Response: The rather low 42% overhead rate for utility staff were provided by Portland General Electric Company. The DOC overhead rate is inclusive of all adders except for mobilization/demobilization costs.

Staff overhead costs are generated based on the numbers of persons utilized in each category during each decommissioning period, as illustrated in Table 3.2.

003-8 Comment: In addition to the Reactor Coolant System, PNL has listed only eleven contaminated systems. Portland General Electric Company identified at least eighteen systems that are completely or partially contaminated at the Trojan plant. The PNL inventory is approximately 50% to 60% of the TLG inventory. This represents a considerable difference in removal and waste disposal costs.

PNL has not included any contaminated electrical systems, nor conduit or cable tray. These electrical systems and components in the Radiological Controlled Areas of the Reactor Building, Fuel Building, Auxiliary Building and the Radwaste Facilities represent a large portion of the contaminated equipment inventory. The Attachments to these TLG review comments include the Trojan contaminated electrical inventory developed by TLG with Portland General Electric Company.

Response: The systems suggested by the commentor were added to the inventory of contaminated systems. Their addition increased the direct costs by about $570,000.

003-9 Comment: PNL has not included the use of waste recycling vendors to volume reduce wastes prior to burial. These vendors can achieve 80 to 90 percent volume reduction for metallic components.

Response: By direction of NRC, no consideration was given to waste volume and cost reductions that might be realized by utilizing waste reduction and recycling contractors.

003-10 Comment: PNL assumes 8-hour shifts, two 15-minute breaks per shift and multiple shifts (two for most activities). Two shift operations may not be realistic for an extended, multi-year project. Second shift work in construction or decommissioning is generally used to correct for schedule slippages over a short period of time. Two shift operation will undoubtedly shorten the overall schedule, and will appear to reduce overall costs substantially unless second shift management costs and equipment rental surcharges are included (see below).

The estimate should address how multiple shift operations will provide for one-of-a-kind tool breakdown and repair. Adequate replacement parts and backup equipment must be provided such that second shift productivity is not affected. Vendor and supplier support is not available on second shifts. If the damaged equipment is a key to critical path activities, first shift operations will also be affected.

Response: Down-time for critical equipment, such as plasma torches, is included in the development of the Unit Cost Factors for activities utilizing that equipment. Second shift maintenance would be available on a call-in basis.

003-11 Comment: PNL has assumed all work will be performed on multiple shifts. Yet Table B. 1 lists only a single utility and DOC staff with no mention of second-shift management coverage. Clearly, if the first shift requires a management organization, the second shift also requires management coverage (even if somewhat reduced in staff). From TLG's experience, the same problems that can occur on first shift will also occur on second shift and adequate coverage i& required. If PNL has shortened the overall schedule taking credit for two shift operations without adjusting the management staff size, the overall costs will be low.

In general, rental equipment suppliers charge a surcharge of approximately 50% of the daily rate for equipment is used more than eight hours per day. This charge covers the cost of wear and tear on the equipment and replacement.

Response: See response to Comment 003-4 regarding management coverage on second shift. Equipment rental rates were derived from R. S. Means, and included in the development of the Unit Cost Factors utilizing the equipment.

003-12 Comment: Development of the overall project schedule is a difficult process. Determination of the critical path of major activities is often used as a starting point. PNL has not provided any detail on this very important part of the Revised Analysis cost estimate.

Response: The schedules, shown as bar charts in chapters 3, 4, and 5, were developed manually, by sequencing critical activities and adding parallel activities where practicable to maintain relatively uniform staff loadings over time.

003-13 Comment: B.1: PNL states an ISFSI is constructed on site so that decommissioning can proceed with "minimum impact," but no costs are included for the ISFSI, or its operation and maintenance. PNL assumes these costs are assumed to be operating costs. While it was planned that a federal repository would be available to accept this spent fuel on a timely basis during plant operations, such is not the case. No cost provision has been made to store this spent fuel until the US DOE is ready to accept shipments. DOE's fuel receipt queue now extends well into the next century, and the cost for wet or dry storage on site needs to be included.

Recent examples of the effect of spent fuel storage on decommissioning include Rancho Seco, Yankee Rowe, Trojan and Fort St. Vrain. These plants are required to delay total decommissioning until fuel can be removed from the site.

The monies to store and maintain spent fuel on site should be an identified and allowable cost of decommissioning, since decommissioning can not be completed (license termination) until the fuel is removed from the site. Also, PNL has not included any costs for decommissioning of the ISFSI storage containers, as these containers will become activated from the fuel stored within them. It is not clear whether NRC or the public utility commissions will allow utilities to fund spent fuel storage after final shutdown unless it is considered a decommissioning expense.

Response: Current NRC policy is that SNF storage is NOT a decommissioning cost.
With the SNF stored in an on-site ISFSI, under a different nuclear license, decommissioning of the reactor plant can proceed.
Decommissioning of the ISFSI falls under the ISFSI license, and is not a reactor decommissioning cost.

003-14 Comment: B.2 Manpower Costs: The utility and DOC staff cost represent the largest single element of cost of the PNL estimate. Based on Volume 1, Tables 3.2 and 3.3, the total cost of the Utility staff for Periods 1 through 4 is $30,628,745 (including Pool operations during Period 3 and ISFSI operations during Period 4) . This $30.6 million is before the authors 90% allocation of such cost to spent nuclear fuel storage costs, charged to plant operations. There is no justification provided by PNL for this 90%/10% allocation (or 88%/12% for security allocation). Applying these percentages for Periods 1 through 4 of the PNL estimate gives $13.1 million for decommissioning and $17.5 million for spent fuel storage. The specific responsibilities for the personnel identified as part of the spent fuel storage costs should be explained. Any arbitrary assignment of these percentages can result in many millions of dollars difference in the total decommissioning cost.

Response: The commentor has misunderstood the analysis. The 90%/10% split of plant cost into SNF storage operations and SAFSTOR operations applies only during the short SAFSTOR period of DECON (Period 3), when the same staff are performing both functions. All SNF storage costs during Periods 1 and 2 are operations costs, not decommissioning costs. By Period 4, the SNF is out of the pool, and the ISFSI costs are not decommissioning costs.

Comment: The DOC portion of the decommissioning cost for Periods 1 through 4 is $16,440,363. With the $13.1 million utility staff for these periods, the total cost is $29.5 million. This represents 24% of the PNL total decommissioning cost. This large portion of the cost should be reviewed in considerable detail by PNL, and supporting documentation provided to substantiate all estimates.

Response: These costs are displayed explicitly in Tables C.1 and C.2, and are based solely on the staffing structures, salary rates, and period durations presented in Chapters 3 and 4.

Comment: The utility staff overhead rate assumed at 42% seems very low. In general, employee fringe benefits (vacation and holidays), insurance (life, health and accidental death and dismemberment, and worker's compensation) and taxes (FICA, FUTA and SUTA) are a minimum of 32 to 35%. Comprehensive general liability insurance, building overhead (rent or capital depreciation), furniture and fixtures, computers, copiers, telephone systems, postage, memberships and dues, contract lawn/landscaping services, and consumables add a substantial cost to the utility burden. TLG has typically seen values in the range of 80 to 90%.

Response: As stated in the response to Comment 003-7, these rates were supplied by the Portland General Electric Company as typical for their staff at Trojan.

Comment: Similarly, the DOC staff overhead rate varies for "home office staff" assigned to the site temporarily, and permanently assigned site management personnel. TLG has seen values ranging from 110 to 150%. It is presumed that the DOC overhead rates include per diem and travel expenses.The PNL list of utility and DOC staff management personnel shows few engineering positions (licensing, QA, planning/scheduling, training and plant engineers). Experience at Shippingport, Shoreham, Ft. St. Vrain and Yankee indicate more engineers should be included (mechanical, electrical, nuclear, and civil/structural). The number of administrative personnel, clerks, secretaries and warehousemen/tool crib persons seems low. The total utility and DOC staff at Shoreham was in excess of 650 persons for decommissioning.

Response: The 141.5% overhead rate for DOC staff was selected as a reasonable value. The 650-person staff appears excessive, considering that the total DOE, DOE support contractor, and DOC staff at Shippingport was about 150 persons.

Comment: The DOC staff shows few field supervision personnel and no waste processing personnel, e. g., field superintendents (one or more for each building), radwaste processing crews, waste packaging and handling crews, etc. The crews cannot work under the minimal direction of a foreman. Experienced decommissioning supervisory personnel must oversee all field work.

Response: As stated in the response to Comments 003-4 and 003-11, upon review, the DOE D&D Supervisor staff was increased from 3 persons to 6 persons for Period 4.

Comment: It would be helpful if Table B.1 indicated the number of personnel in each job function. Since staff cost are one of the major cost components of decommissioning, the number and salaries for these personnel would be a valuable aid to establishing the credibility of the estimate.

Response: The numbers of staff in each classification are given in the staffing diagrams, Figures 3.2, 3.4, 3.5, and 3.6. The numbers of person-years for each classification in each period are given in Table 3.2.

003-15 Comment: B.3 Mobilization and Demobilization Costs: The DOC mobilization and demobilization costs previously estimated in NUREG/CR 0130 were based on a substantially smaller DOC staff size. Applying an escalation factor to this older basis may not be justified. Accordingly, PNL should re-estimate these costs for the larger staff size used in the Revised Analysis.

Response: The original mobilization/demobilization cost estimate was based on a large construction project, which had at least as many staff as are postulated for these analyses. No change was made to the estimated Mobilization/Demobilization costs.

003-16 Comment: B.6 Transportation Costs: It is not clear whether "front-end" cost and "dead-end" costs are zeroed out for multiple cask shipments. Usually, cask shipping campaigns are performed on a continuous basis and there is only one front-end and dead-end cost per cask. The PNL approach may result in duplication of cask costs.

Response: Shipment of empty casks from the owner's location to the reactor site, and from the disposal site back to the owner's location are included in the shipping algorithms in the CECP.

Comment: If the transportation scenario is specific to the Trojan Reference plant, are there other credible transportation scenarios included in the PNL computer code to handle heavy components by rail, multi-modal transport, special routing for bridges, overpasses, etc.?

Response: The CECP algorithm does not consider any special routing requirements due to bridges, etc. The user can supply additional information to the cost calculation as appropriate.

003-17 Comment: B.8 Costs of Services, Supplies and Special Equipment: The special tools needed for decommissioning are identified in Table B.6. Appendix E discusses removal of over 3,200 bolts under water to disassemble the vessel internals for further sectioning by the plasma arc torch. Such a tool would be a highly specialized, costly tool to perform its functions remotely under water at depths of 20 to 30 ft. No mention is made of this tool in Table B.6.

Response: The special tools for bolt removal have been added to the equipment list.

Comment: The small tool allowance cost of 2% of the direct labor cost is consistent with the R. S. Means recommendation.

However, PNL's example of $ 10 million for direct labor costs may be misleading. For example, for the $124 million total cost (Hanford burial site) Table C.1 on Page c.17 shows the labor and materials cost to be $86 million. Assuming half of this is labor cost (conservative assumption), the labor cost would be $43 million. This would mean a small tool cost of $860,000. At $1,100 per tool, this would require 782 small tools. If there are only 27 workers per shift based on TLG's review of Volume 1 of the Revised Assessment (Page 3.16 - 3.18), this means each worker will have 29 hand tools to use. This sounds high, and warrants a closer look.

Response: The direct labor costs are computed within the CECP, summed over all activities per period, and multiplied by 2% to obtain the small tools allowance. The commentor's assumptions in his calculation are incorrect. The actual small tools allowance over the entire project is $215,389, not $860,000 as suggested above, and the nominal staff per shift is about 75 persons. Thus, the number of tools per person would be reduced by about a factor of 12, or about 2 per person.

003-18 Comment: B.9 Property Taxation: PNL assumes local property taxes will be assessed only on the land value at the time of plant shutdown, not the value of the capital equipment installed at the site. While fully depreciated assets have no book value, local tax assessors don't always treat the assets this way. In most localities, taxes are assessed on the full value of the land, and a declining value of capital equipment at the site as the equipment is removed for disposal. This approach provides for a graded phaseout of the tax base without adversely affecting the local community. PNL should provide the land and real estate property tax assessments for the reader to evaluate the potential impact for another site.

Also, PNL assumes all the land is available for use, except the exclusion area (about 34 acres). From a local community's standpoint, the land inside the exclusion area has value to the utility (for decommissioning purposes) and would be included in the tax base.

Response: Property taxes are a very site-specific situation. For the Trojan plant, the costs were developed through discussions with PGE staff and staff of the local and state taxing authorities.

003-19 Comment: B.10 Nuclear Insurance Costs: PNL has assumed that the spent nuclear fuel storage insurance costs are not charged to decommissioning. This would be a reasonable assumption if the US DOE had provided a federal repository to dispose of the spent fuel. However, since the fuel must remain on site until a repository is available, and the 10 CFR Part 901 contract requires fuel to remain on site for at least five years, this cost should be considered a decommissioning cost.

Response: The NRC does not currently consider SNF storage costs as a decommission cost.

003-20 Comment: B.11 License Termination Survey Costs: PNL's postulated crew size and duration appears low. The Shoreham Nuclear Power Station used a team of approximately 35 workers to perform the characterization work in a period of about four months (exclusive of the NRC independent verification contractor for the final termination survey work). PNL should consider doubling the survey crew size and lengthening the survey duration.

Response: The survey costs were developed using the methodology provided in NUREG/CR-5849, and reflects the knowledge of personnel active in that area of endeavor. No change was made to the survey cost estimate.

003-21 Comment: B.12 Cascading Costs: PNL has apparently and rightly included cascading costs in its Revised Analysis, but no guidance as to the methodology used is included. As this is a relatively new approach for PNL, it would be instructive to evaluate how such costs are calculated by PNL.

Response: Development of cascading costs are discussed in the text where appropriate, calculated in the CECP, and identified on the CECP output.

003-22 Comment: B.13 Regulatory Costs: PNL has assumed that 10 CFR Part 171 fees are not applicable for decommissioning. It would be helpful if an NRC citation or reference were provided.

Response: The assumption is discussed in the text, and is based upon numerous discussions with NRC staff.

003-23 Comment: B.14 Contingency: PNL has retained the 25% overall contingency percentage for use in this Revised Analysis. They acknowledge that a single contingency value is not appropriate for all situations. It would be helpful for PNL to show the varying levels of contingency and their application to decommissioning activities. The AIF Guidelines (AIF/NESP - 036) provides several examples of varying contingency percentages for the various aspects of a decommissioning process. The contingency values used should reflect the utility licensee's confidence in various elements of cost.

Response: Most of the costs are not sufficiently well known to warrant assigning different contingencies. The blanket 25% represents a reasonable value across the board.

003-24 Comment: C.1 Inventory: In the following inventory and removal cost estimates, PNL has not identified the use of recycling centers to volume reduce the waste prior to burial. This volume reduction can account for up to 80 to 90 percent reduction of metallic components (valves, pipe, small heat exchangers, etc.), at considerable reduction in burial cost.

Response: By NRC direction, the use of waste volume reduction and recycling contractors was not considered in the study.

Comment: PNL assumes valves 3 in. and smaller are removed with the piping to which they are attached. TLG assumes valves 2 in. and smaller are removed with the pipe.

Response: Analyst's choice. Has essentially no impact on study results.

Comment: PNL does not include pipe hangers in its estimates because they "are sufficiently small that they can be placed in the piping containers without further consideration." This is not so. Pipe hangers, seismic supports and pipe whip restraints for large piping and valves weigh thousands of pounds and will require their own containers for disposal. There are literally thousands of them in the radioactive portions of the plant.

Response: There may be "literally thousands" of pipe hangers in the plant, the vast majority are of the simple strap-hanger variety which can be placed into the containers of pipe without special consideration. There is a limited number of the large snubber variety, and because adequate information regarding the volume and weight of these items was not available, they were neglected in the analyses.

Comment: PNL does not break down piping by system. The assumption is made that all stainless steel piping is contaminated and will be removed. Any carbon steel piping connected to the main steam system in the reactor building is contaminated and removed. The remaining piping remains in place for a "demolition contractor" to remove. No allowance is made for the difficulty in performing final site license termination surveys with all that pipe in place.

Response: For all practical purposes, all piping within contaminated areas is removed during dismantlement. Most of the non-contaminated carbon steel piping is located in non-contaminated areas and should not present a significant problem during the termination survey.

Comment: In addition to the Reactor Coolant System, PNL assumed there are only eleven systems listed as contaminated. Portland General Electric Company identified at least eighteen systems that are completely or partially contaminated.

PNL has not included any contaminated electrical systems, nor conduit or cable tray. TLG has included the applicable portions of these systems and components.

TLG reviewed the radioactive inventory of system components identified by PNL in Section C, and compared the inventory to the TLG site- specific inventory prepared for Trojan. Attachment I shows all of the systems PNL listed as contaminated, and provides a comparison to the TLG listed inventory for each system. Excluding the piping and pipe hanger inventory for the moment, it appears the TLG quantities are considerably larger than the PNL estimate. TLG has identified 4,328 large and small pipe hangers at the Trojan plant; not an insignificant amount. By inspection, for the components identified as contaminated by PNL, the PNL inventory is about 50% of the TLG inventory. However, as noted earlier PNL identified only eleven contaminated systems. Portland General Electric Company identified eighteen contaminated systems.

TLG also reviewed the PNL inventory of contaminated pipe and compared it to the TLG estimate. This comparison is shown in Attachment II. For the PNL list of contaminated piping shown on Pages C.30 and C.40, the TLG inventory lists 54,732 feet and PNL lists 477,835 feet. If the additional systems are included the totals are 79,762 for TLG, and 47,835 for PNL. This is about 60% of the TLG inventory estimate.

Attachment III shows the additional contaminated mechanical and electrical systems inventory identified by Portland General Electric Company.

It should be noted that total removal of all components, piping and electrical equipment will be necessary to support 100% verification surveys of pipe penetrations, equipment support pads, floor drains and internal surfaces of the buildings in the radiologically controlled areas.

Response: The piping inventory used by PNL was derived from the purchasing invoices received during construction of the plant. Since these invoices presumably itemized all of the piping purchased for the plant, they should represent the upper bound on the inventory of piping. PNL has no way to determine the source and validity of the inventories of piping suggested by the commentor.

As stated previously, due to lack of detailed information on pipe hangers, they were neglected in the PNL analysis.

The systems and inventories identified by the commentor have been added to the PNL analysis, and are now included in the CECP calculations. Some difficulties were encountered in attempting to utilize the commentor's inventories because of the lack of specifics, such as component volume and weight, which are needed to compute the appropriate packaging and shipping costs.

As stated previously, it is anticipated that essentially all piping and components will be removed from contaminated areas, so that surveys would be unimpeded.

003-25 Comment: C.2 Unit Cost Factors and Work Difficulty Factors
PNL assumes 8-hour shifts, two 15-minute breaks per shift and multiple shifts (two for most activities).
The Work Difficulty Factors (WDFs) for a 480 min shift break down as follows:

WDF	Percent
Work breaks	10.00
Anti-C suit up	40.00
ALARA activities	08.00
Respiratory protection	20.00
Scaffolding/access	10.00

The time lost for each 480 min shift is:

$30 + 120 + 25 = 175$ min

That leaves 480 - 175 = 305 minutes for productive work.

$$\{1 + (30/305) + (120/305)+(25/305)\} \times 305 = 480$$

$$\{1 + 0.098 + 0.393 + 0.082\} \times 306 = 480$$

The non-productive time adjustment factor is:

$$480/305 = 1.574$$

The respiratory protection factor is 100/83 = 1.2

The scaffolding/access factor is 100/93 = 1.1

The total work difficulty factor is:

$1.574 \times (1.2 \times 1.1) = 2.046$ times the estimated work duration

This appears to be PNL's worst case for work difficulty factor.

It is not clear where or how PNL takes into account the following:

a. Initial rad worker training and respirator fit testing
40 hrs/worker/year

b. OSHA training
24 hrs minimum, 40 hrs maximum

c. Tool box briefings - daily worker safety training 10 - 20 minutes daily, 1 hr nominally per week

d. Replacement worker training due to attrition, changeout for exposure, termination for cause

e. High dose worker training, mockups, dry-runs

f. Multiple shift briefings and debriefings. The 8% ALARA factor may be too low for this interface activity.

In general, utilities indicate that worker productivity is about 33% for work in radioactive work area.

TLG's worst case is a WDF of 2.96 for the following factors:

WDF	Percent
Work breaks	8.33
Anti-C suit up	30.00
ALARA activities	40.00
Respiratory protection	50.00
Scaffolding/access	20.00

Thus, the scaffolding factor, respiratory protection factor and ALARA factor are all multiplied by the estimated work duration.

$$(1 + 0.2 + 0.5 + 0.4) \times AWD = 2.10 \times AWD$$

The Anti-C suit up factor is multiplied by the above actual work duration, and the work break factor multiplied by the productive work duration.

$$(2.10 \times AWD) \times 1.3 = 2.73 \times AWD$$

$$(2.73 \times AWD) \times 1.0833 = 2.96 \times AWD$$

TLG compared these results against three work difficulty references as follows:

"Labor Productivity Adjustment Factors," B.J. Riordan, Mathtech, Inc., NUREG/CR- 4546, January, 1986.

"Validation of Generic Cost Estimates for Construction-Related Activities at Nuclear Power Plants," G. Simion, et. al., Science and Engineering Associates, Inc., NUREG/CR - 5138, May, 1988.

"Radiation-Related Impacts for Nuclear Plant Physical Modifications," F. Sciacca, et. al., Science and Engineering Associates, Inc., NUREG/CR- 5236, October 1989.These references refer to work difficulty factors for similar activities that are approximately 3.13 x AWD, slightly greater than the 2.96 factor used by TLG for large PWRs that have operated for their full license life.

PNL may wish to review these references for further information.

Response: The above comment reflects a long-standing disagreement between PNL analysts and the commentor's analysts regarding the appropriate values to use for work difficulty factors. It is the position of the PNL analysts that the commentor's values and those in the referenced reports are more representative of system modification work during an outage at an operating power reactor than of a dismantlement for disposal operation. Replacing PNL's factor of 2 by the commentor's factor of 3 would increase the direct labor cost for DECON from about $10 million to about $15 million.

003-26 Comment: C.2.2 Labor and Materials Costs per Crew Hour: The source document for materials references is not provided. PNL includes 110% overhead and 15% DOC profit, and a 10% shift differential for second shift on this (and all subsequent) unit cost factors. No basis is provided for these percentages.

Response: These are study assumptions and are considered to be reasonable for the type of work to be performed.

Comment: Furthermore, it appears PNL has assumed all work will be performed on multiple shifts. Yet Table B.1 lists only a single utility and DOC staff with no mention of second-shift management coverage. Clearly, if the first shift requires a management organization, the second shift also requires management (even if somewhat reduced in staff). From TLG's experience, the same problems that can occur on first shift will also occur on second shift and adequate coverage is required. If PNL has shortened the overall schedule taking credit for two shift operations without adjusting the management staff size, the overall costs will be low.

Response: Upon review, the number of DOE D&D Supervisors was increased from 3 to 6, in the final analysis.

Comment: With respect to materials costs (including equipment rental costs), all rental companies charge a 50% premium for equipment usage time in excess of eight hours per day (as recorded on engine operating meters). This charge covers the cost of wear and tear on the equipment and replacement. PNL has not included this cost in its materials costs or markup.

Response: The rental charges were derived from R.S. Means, and are incorporated into the Unit Cost Factors that utilize the equipment.

Comment: The estimate should address how multiple shift operations will provide for one--of-a-kind tool breakdown and repair. Adequate replacement parts and backup equipment must be provided such that second shift productivity is not affected. Vendor and supplier support is not available on second shifts. If the damaged equipment is a key to critical path activities, first shift operations will also be affected.

Response: See last response to Comment 003-10.

003-27 Comment: C.2.10 Removal and Packaging of the Pressurizer: PNL assumes the pressurizer will be shipped as its own container without grouting the interior. Current practice in the industry, and endorsed by NRC is to fill the pressurizer with a lightweight grout to prevent its radioactive contents from being released in the event of an accident. This effort would add to the cost of handling and disposal.

Response: Addition of grout to the pressurizer prior to shipment is now included in the analysis.

003-28 Comment: C.2.12 High-Pressure Water Wash/Vacuuming of Surfaces: PNL states high pressure jet pressure is 250 psi. This may be a typo, as 250 psi is less than used in a car wash. A minimum pressure of 2500 psi is more realistic. PNL claims a cleansing rate of 8 sq. ft per min. It is not clear what is meant by "cleansing rate." If it is intended to mean decon to free releasable condition, it is doubtful an 8 sq ft per min rate will accomplish that objective. It would be helpful if PNL were to state the reference material or plant experience relied upon for such performance rates. PNL adds 20% to labor for overhead surfaces and 5% for stairs. Again, experience citations would be helpful. PNL assumes only one gal per min for water generation. This appears very low, even for only 250 psig.

It should be noted that high pressure washing of overhead surfaces is not practical without water containment and collection systems. Additional setup and operating time should be included for this activity.

Response: The basic equipment postulated for the high-pressure water washing is the Kelly Decon System, which resembles a typical carpet cleaner for home use in that it sprays the water on the surface and vacuums up the water almost simultaneously, all within an enclosure surrounding the spray nozzles and the vacuum pickup. The performance parameters are those provided by the vendor. The system is intended to remove surface contamination that is not firmly fixed to the surface. Similar end-effector units are available for use on surfaces other than floors.

An adder of 20% was applied to the labor hours for non-floor surfaces.

003-29 Comment: C.2.13 Cutting Uncontaminated Concrete Walls and Floors: PNL assumes uncontaminated concrete is part of the "cascading costs." These are costs to remove clean concrete or structures to gain access to radioactive materials. However, PNL applies the same Radiation/ALARA factor (8.2%) as for contaminated systems and structures. There may be some inconsistency here which may warrant additional study. The suit-up factor and respiratory factor is probably appropriate as this work generates a dust-filled work environment.

Response: While the sections being cut may be essentially uncontaminated, they are generally located in an area considered to be a radiation zone, hence the same ALARA factor and personal protective equipment.

003-30 Comment: C.2.14 Removal of Contaminated Concrete Surfaces: ed on data collected at six nuclear power plants by Robertson at PNL, concrete contamination rarely penetrated more than one centimeter depth into concrete. Accordingly, a one inch depth is probably an overestimate.

Response: PNL agrees that 1 inch is probably conservative for most of the scabbled areas. The 1-inch depth was requested by the NRC.

Comment: PNL assumes the total surface to be scarified is 21,600 sq ft. Figure C.5d, (page C.12) lists only 6,570 sq ft of concrete to be removed. No other building concrete is shown. Some explanation of this difference would be helpful.

Response: Figure C.5d presents only the scabbled surface area for the Fuel Building. The total area scabbled in the Containment, Fuel, and Auxiliary Buildings was 21,598 ft^2, as shown in Table 3.22.

Comment: PNL assumes a five-year lifetime for amortization of this equipment. this appears optimistic, as most percussion equipment takes a terrific beating in use. Perhaps a two-year life would be more realistic.

Response: As stated in the Unit Cost Factor development for scabbling, the equipment is depreciated over a 5-year period, with an assumed utilization during that period of 25%, or about 1.25 years of operation.

Comment: PNL assumes walls would be four times the horizontal cost, based on the lower removal rates of the wall equipment. However, accessibility and operator fatigue are probably greater factors and might increase costs even more.

Response: This was a judgement call. Any definitive data on this matter would be appreciated.

003-31 Comment: C.2.15 Removal of Activated/Contaminated Concrete by Blasting: PNL assumes four B-25 containers (4ft x 4ft x 6ft) will be placed in the biological shield pit to catch falling rubble. Even with chutes to guide the rubble, the rubble will undoubtedly demolish or seriously damage to the containers to make them unusable for shipping. PNL should consider using 3/4 in. thick steel containers in the pit to catch the rubble, and removing them after each blast to transfer the contents to B-26 containers. The labor cost is greater, but there will be no damage to the containers.

The labor activity listing does not specifically list installation or removal of the wooden chutes to guide the rubble into the containers.

Response: This is a good comment. However, no change was made to the analysis for this report.

003-32 Comment: C.2.18 Removal of Steel Floor Grating: PNL estimates 11,265 sq ft of floor grating to be removed. However, it is not clear how this quantity is estimated. Some additional supporting data would be helpful.

Response: The areas of gratings were determined by scaling from the facility drawings.

003-33 Comment: C.3 Transportation Costs: PNL appears to have provided an comprehensive evaluation of transportation costs for the Reference plant. Has PNL prepared similar detail for other localities and modes of transport.

Response: The CECP contains information on distances from all reactor sites to the two available LLW disposal sites. Information on distances from cask owners locations to reactor sites and from disposal sites back to the owners locations are input numbers, since they are specific to the casks selected to be used.

003-34 Comment: PNL estimates the minimum spent fuel pool operating time prior to dismantlement is 7 years. In fact, most spent fuel dry cask suppliers are basing their designs on 5 years cooling. Rancho Seco is currently participating in a joint EPRI and DOE demonstration project to construct dry cask storage facilities to accept fuel after five years cooling.

Response: The required cooling time before dry storage is determined by the cladding temperature limits of the fuel rods, which are a function of the total burnup of the fuel the initial internal gas pressure and the initial enrichment of the fuel rods. As discussed in detail in Appendix D, the 7-year cooling requirement resulted from an analysis of cladding temperature limits for the high burnup fuel projected to be present at Trojan at end of its normal operating life. The 5-year cooling design point is for fuel with about 35,000 MWD/MTU burnup. The limits are very dependent upon the specifics of a given fuel assembly.

Comment: As noted in the footnote to Table D.4 (page D.18), PNL allocates 90% of fuel pool operating and maintenance cost to pool operations (non-decommissioning), and 10% to safe storage (decommissioning). This allocation is neither discussed in the text nor justified by NRC regulatory policy or guidance. If DOE had met its commitment to provide a spent fuel repository by 1998, spent fuel pool storage periods (and costs) would have been much shorter (no more than the 10 CFR 970 fuel contract with DOE to store fuel on site for a minimum of five years). These costs would have been borne by the utilities as operating costs. However, because of the recognized delay 100% of these costs should be considered as decommissioning costs.

Response: The 90%/10% allocation of the Period 3 operating costs into SNF storage operations and SAFSTOR operations was a judgement call by the analyst. It is based upon the fact that the same staff are performing both tasks, and that the amount of effort needed to accomplish SAFSTOR is very significantly smaller than the effort needed to support the spent fuel pool operations. The choice to exclude the SNF storage operations costs from the decommissioning costs is based on current NRC policy.

Comment: Please refer to the discussion in TLG's comments to Volume 1, Summary, Page xxvi, regarding the use of Present Value (PV) calculations for alternative evaluations for a utility licensee regulated by public utility commissions (PUCs). Such PV calculations are risky if they are based on expected expenditures rather than on PUC allowed revenue requirements.

Response: See the response to Comment 003-3.

003-35 Comment: E.1 Basic Disassembly Plan: PNL assumes the reactor pressure vessel (RPV) can be cut with an oxyacetylene torch from the outside of the RPV in the annular space between the RPV and the bioshield. This is nearly impossible, as there is only 8-1/2 inches radial clearance after the insulation is removed. While it is true cutting through the carbon steel shell wall will also cut through the stainless steel cladding, the practicality of cutting in such a limited access space should be re-examined by PNL. There is also limited access because of nozzles and vessel support structures.

Response: It is assumed that the cutting operations are carried out using remote cutting systems. With the possible exception of the area immediately beneath the nozzles, the clearance should be adequate. The cutting process begins at the top by removing the flange, which provides reasonable access for subsequent cutting operations. This method utilized a demonstrated approach that assured cutting both the carbon steel vessel wall and the stainless steel alloy vessel lining in one cut.

003-36 Comment: E.2.1 CRD Guides: PNL recommends unbolting or breaking the 244 bolts which attach the CRD guide collars to the top of the upper core support assembly. Neither method of removal is practical when performed underwater at a distance with long-handled tools. These collars should be cut with a torch or saw device. Table E.2 (page E.20) does not include a time or cost analysis for removing these 244 bolts.

Response: A discussion of the tools and the times required for removal of the bolts and nuts mentioned in the 9 of the next 10 comments has been added to Appendix E. Subject to a demonstration that the use of underwater impact wrenches and/or 'nutcrackers' are not practical ways to remove the nuts and bolts from the vessel internal structures, the analysis stands. In any event, cutting by plasma torch would be difficult, due to the geometries involved.

003-37 Comment: E.2.2 Top Plate: Similarly, PNL assumes 48 nuts are removed from the top ends of the support columns and mixer columns to free the top plate. These should be cut off, not unbolted. Table E.2 does not include a time or cost to remove these 48 nuts.

Response: See response to Comment 003-36.

003-38 Comment: E.2.3 Posts and Columns: PNL assumes 316 bolts attach the 79 Support posts and mixing columns, and will be removed. Table E.2 does not include a time or cost to remove these 316 nuts.

Response: See response to Comment 003-36.

003-39 Comment: E.2.4 Upper Grid Plate: PNL cuts the upper grid plate into 8- 1/2 inch wide strips to fit in the GTCC canisters. TLG performed a detailed activation analysis using Trojan plant operating histograms, flux data, the ORIGEN code, etc., to determine the vessel and internals activation levels. TLG's calculations indicate this section of the internals is Class C waste, not GTCC waste. PNL assumes the packing factor will be 41°(59% voids). Recent experience at Yankee Rowe cutting vessel internals with the plasma arc torch indicates Yankee is having trouble achieving 25% packing factors (75% voids). The Slag accumulation on the back face of the cut tends to interfere with the tight loading arrangement in the liners. PNL should reassess these assumptions.

Response: The activation analyses utilized in the report are based on an effective 30 full-power years of operation. If the TLG analyses reflect the actual irradiation history of the plant today, then their results will indicate much less GTCC material than the PNL results. Since the study was intended to reflect operation to the end of normal plant life, the PNL results are more representative of that bounding case. There are probably cost-effective ways to mitigate the problem of slag accumulation on the cuts that would permit the high density packing postulated by PNL. Because the potential disposal cost for the GTCC material is quite high, additional cleanup operations to improve packing density would be warranted. No costs have been developed to cover such operations in the study.

Comment: Currently, the GTCC wastes are a decommissioning "orphan waste". The new regional compacts are not designing their facilities to bury GTCC wastes, and the US DOE has not published estimated costs to send it to the federal repository when it becomes operational. Prudent conservatism (high estimated cost) would be appropriate for this waste classification.

Response: The GTCC disposal costs are based on information developed by DOE in the OCRWM program. While these costs are still highly speculative, they are probably the right order of magnitude.

003-40 Comment: E.3.2 Thermal Shields: PNL removes the 156 bolts that hold the shields to the barrel, and sections them into 8-1/2 inch strips for the GTCC canisters. TLG's calculations indicate these sections are Class C waste, not GTCC. Table E.2 does not include a time or cost to remove these 156 bolts. PNL assumes a packing factor of 81% (see above).

Response: See responses to Comments 003-36 and 003-39.

003-41 Comment: E.3.3 Core Shroud Plates: PNL removes the 900 bolts holding the plates to the shroud former plates. PNL cuts them into 8-1/2 inch strips for the GTCC canisters. TLG's calculations indicate these are GTCC waste. Table E.2 does not include a time or cost remove these 900 bolts.

Response: See response to Comment 003-36.

003-42 Comment: E.3.4 Shroud Former Plates: PNL removes the 700 bolts holding the former plates to the core barrel. PNL (and) TLG calculates these to be GTCC wastes. PNL assumes an 84% packing factor. Table E.2 does not include a time or cost to remove these 700 bolts.

Response: See response to Comment 003-36

003-43 Comment: E.3.5 Lower Grid Plate: PNL removes the 384 bolts attaching the lower grid plate to the core support posts, and 60 bolts are removed from the lower grid plate to the lower core barrel. PNL (and TLG) calculate these to be GTCC. PNL assumes a 70% packing factor. Table E.2 does not include a time or cost to remove these 444 bolts.

Response: See response to Comment 003-36.

003-44 Comment: E.3.6 Lower Core Barrel: PNL calculates the lower core barrel as GTCC waste. TLG calculates it as Class A, B, and C wastes (at various locations above and below the core centerline). PNL assumes a packing factor of 76%.

Response: See response to Comment 003-39.

003-45 Comment: E.3.7 Lower Core Support Structure: PNL assumes the 96 support posts and 26 instrument tubes will be cut off with a plasma arc torch. However, a plasma arc torch can not cut through multiple thicknesses of metal such as a tube, as the torch loses its arc to the rear side of the tube. PNL calculates these posts and guides are GTCC. TLG's calculations show them as Class C. PNL removes the 236 bolts on each side (total of 472 bolts) of the forging to remove the posts and guides. PNL assumes the forging which is 20 inches thick, can be cut up with a plasma arc torch. Sections of the forging are at least 10 inches thick. The cutting depth limit of a plasma arc torch on stainless steel under water is about six inches. Table E.2 does not include a time or cost to remove these 472 bolts which must be removed underwater with long-handled tools.

Response: The forging is postulated to be cut at the webbings between the holes through the forging, where the thickness is about 2 inches. Also, see responses 003-36 and 003-39.

Comment: For these internals, PNL lists 35,287 inches of cut (not including the insulation), which at 5 inches per minute plasma cutting speed (E.5.2, page E.18) amounts to 35,287 x 5 = 176,435 minutes, or 2,941 crew hours. At an average crew cost of $324.89 per hour, this cost should be $955,501. If the average cutting speed is as high as 10 inches per minute, the cost would be $477,750.

Response: The cutting rates ranged from 5 to 14 inches per minute, as appropriate for the material being cut. Each cut was considered individually, with no average values used.

Comment: In addition, PNL has removed 3,232 bolts in the disassembly process. At 3 minutes a bolt (highly optimistic), this will take approximately 162 crew hours. With the 162 hours to remove bolts, this adds 162 hours x $324.89 = $52,632, for a total cost of $530,382.

Table E.2 shows the cutting cost without insulation to be $385,772. PNL should review the cutting and unbolting assumptions and costs for the RPV internals.

Response: The table has been modified to include the installation and testing time for the cutting systems. Thus, the total cutting including installation and testing is $617,012. Also see response 003-36.

Comment: Note that in Table E.2, the cutting time for the Lower Barrel should be 1,753 minutes instead of 1,596 minutes.

Response: The error in the table has been corrected.

003-46 Comment: E.5.1 Cutting Team Compositions: PNL assumes the nine man team shown in Table E. 1 is used to cut the vessel and internals on a two shift per day operation. In addition, PNL assumes a second six man crew handles the packaged materials on-the third shift. This second crew is provided by the utility at a daily cost of $1,546.40 (about $193 per crew hour), but is charged off to the non-dedicated crew costs. PNL further assumes the DOC provides this same crew composition during cutting and packaging of the RPV at a daily cost of $2,500.48 (about $312 per crew hour), and is also charged off to non-dedicated crew costs.

It is not clear why the utility crew and DOC crew are considered non-dedicated when they clearly are performing dedicated activities related to the RPV and internals removal. It is not possible to identify the specific costs for this work in the non-dedicated cost category, so that it is not clear that this cost has been properly addressed. Also, why does the utility provide these crews when this work is stated as the type of work performed by the DOC? Why does PNL assume a different crew cost per hour for these crews than for the cutting crews? This type of reassignment of crew costs distorts the ability to track RPV and internals cutting and removal labor costs.

Response: The waste handling crews are provided by the utility in Period 2, when the DOC is not on-site. The DOC provides the waste handling crews in Period 4, when the DOC is running the whole operation. Thus, the crews have different labor rates during the two different periods. These crews are considered non-dedicated because they are present throughout the periods and the time they spend on packages from each specific disassembly operation is not uniquely estimated. The cost per crew-hour is a function of the size and makeup of each crew. The cutting crews are comprised of 9 persons while the waste handling crews are comprised of 7 persons.

003-47 Comment: PNL does not discuss grouting of the steam generators, which has become an NRC requirement prior to shipment for burial. This activity adds about three to four days to each steam generator and several thousands of dollars of material each.

Response: The time and cost of grouting the steam generators has been added to the costs of steam generator removal and disposal.

Comment: PNL estimates the total manhours for Phases II (Preparatory) and III (Removal) to be 86,557 manhours (without grouting). TLG estimated in the AIF Guidelines (NESP-036) a total of 92,170 manhours (without grouting). This represents reasonable agreement on the costs of this activity for steam generators of the Surry design. However, does PNL have a procedure to adjust for fewer number of steam generators? Is there a factor for removal of larger diameter generators of another NSSS vendor?

Response: The number of steam generators removed and disposed is very site-specific. Thus, the calculations for their removal, transport, and disposal are performed off-line by the analyst and input to the CECP.

RESPONSES TO COMMENTOR 006

006-1 Comment: Tables 3.2 and 3.3 show staffing levels which are about one-fourth those assumed in a site specific study performed by a consultant in 1993 for Callaway Plant. The staffing levels shown in the draft NUREG are apparently the minimum acceptable for funding purposes. If this is the case, it should be so stated since there appears to be some disagreement in the industry regarding required decommissioning staffing.

Response: The staffing levels shown in tables 3.2 and 3.3 represent the judgement of PNL analysts as to the minimum staffing needed to accomplish the task. Obviously, others can and do have other opinions. There is no one ‘right’ answer for all situations.

006-2 Comment: There are some inconsistencies in the staffing levels shown in the staff organizational structure charts. Figure 3.4 shows 23 persons in the Health Physics group; this should be 22, according to the breakdown. Figure 3.5 shows 13 in the Security group; this should be 12. Figure 3.6 shows 11 in the Utility Plant Operations group; this should be 12. That figure also shows 13 in the DOC D&D Engineering group; this should be 11.

Response: The inconsistencies have been resolved in the final charts.

006-3 Comment: Page 3.59 states that requiring funding to be calculated in constant dollars prior to reactor shutdown results in about a 22% overestimate of the funding needs for DECON, providing a significant safety margin to cover unforeseen events. In light of the 25 % contingency included in the cost estimate, it seems reasonable to allow credit for fund growth during the 9 year decommissioning phase.

Response: The Present Value analysis incorporates the growth of the fund over the time following shutdown until decommissioning is completed. Whether or not the utilities and the Public Utility Commissions can or want to agree on using PV analyses to establish the minimum fund requirements remains to be seen.

006-4 Comment: The words, "Radiation Dose" in the heading of Table 4.1 are out of alignment. They should be above "Estimated (person-rem)" - see Table 3.1.

Response: The heading has been properly revised.

006-5 Comment: Section B.14 discusses contingency, and concludes by recommending a contingency factor of 25% be applied to the bottom line. Since this is such a significant cost contributor, it may be appropriate to allow the licensee to apply specific contingencies to each line item.

Response: Other analysts have done exactly that, but the cumulative amount assigned as contingency always comes out fairly close to 25% of the total cost. Thus, PNL has retained the single contingency applied to the bottom line.

006-6 Comment: Section C restates verbatim much of NUREG/CR 6054. Consideration should be given to deleting this section from -5884; all discussion of the Cost Estimating Computer Program more appropriately belongs in 6054. If section C were deleted, the two volumes of NUREG/CR-5884 could be consolidated. (Furthermore, Figure 2.2 of 6054 is inconsistent with Figure C.2 of -5884 regarding sequence of data entry for menu items A, B, and C.)

Response: Disagree. Appendix C contains the development of the various unit cost factors, transportation algorithms, piping and equipment inventories, etc., which are only partially presented by examples in the User's Manual. In addition, the case outputs for the various alternatives evaluated for the PWR are presented in that appendix. The two documents serve separate purposes.

006-7 Comment: Section E describes the components of the reactor and internals. Figures E.1 and E.2 show many of these, but not all components are labeled and the names of those which are labeled do not always have the same names used in the text.

Response: All of the figures have been relabeled to agree with the text discussions.

006-8 Comment: 10 CFR 50.75(e)(1)(ii) requires that funds sufficient to pay radiological decommissioning costs be available at the time operations termination is expected. This means a utility may not take credit for fund growth during the several-year decommissioning project, even though the fund would actually continue to grow. 10 CFR 50.75 should be changed to allow for fund growth during decommissioning.

This action would allow for additional fund growth, thereby reducing annual funding to a level needed to assure funds are available only when they are anticipated to be expended during the decommissioning project. The funding cost savings would be on the order of $1,000,000 per year per reactor, using typical forecast and fund allocation assumptions.

While Union Electric may not realize this annual savings, there would be a reduction in the risk of underfunding for radiological decommissioning at the time of operations termination.

Response: The requirement that funds be available at time of permanent shutdown are based on the fact that cash flow may be in jeopardy once a plant is permanently shutdown. However, the NRC will take this suggestion under consideration.

RESPONSES TO COMMENTOR 007

007-1 Comment: The revised analyses indicate a determination of whether costs associated with the storage of spent fuel are operating expenses or decommissioning costs has not been made. It should be clear in the analyses that from a utility standpoint, all costs following permanent shutdown of a facility should be considered decommissioning costs. This ensures that current ratepayers (who receive the benefit of nuclear power) are properly providing funds to meet the decommissioning obligations. If these costs are not collected prior to shutdown the utility may be precluded from collecting operation and maintenance (O&M) costs after shutdown. These expenditures include operations maintenance of-the spent fuel pool for the five-year period (analyses assumes seven years), dealing with DOE's inability to accept spent nuclear fuel (continued spent fuel pool operation or dry cask construction and operation), transition costs (defueling, draining, decon, surveillances, etc.) as well as any other O&M. Whether dealing with the public utility commission or the NRC, the site cannot be fully decommissioned until all spent fuel has been removed. All of the expenses associated with the storage of spent fuel in a spent fuel pool, no matter what the length of storage is, should be decommissioning costs. Also the costs incurred in the construction, operation, and decommissioning of a dry cask storage facility (identified as the option to deal with the DOE problem in the study) at the site should be included as decommissioning costs.

Response: Current NRC policy does not include spent fuel storage costs as a decommissioning cost.

007-2 Comment: A contingency of 25% that is applied to the decommissioning costs is considered to be too low. Many significant uncertainties exist in decommissioning. These include: 1) the standards for residual contamination are still being developed and will not be issued for several years; 2) the industry has minimal experience; 3) problems/delays in siting low level radioactive waste disposal sites; and 4) problems/delays in siting the high level radioactive waste disposal site. Appendix B of the revised analyses states the contingency could be as high as 100% for an untried process where no engineering is complete and the job is to take place in the distant future. In addition, it states that a contingency of 20% - 35% is not uncommon for projects in the proposal stages. In order to assure that sufficient funds are accumulated during the operating life of nuclear power plants to support decommissioning, a more appropriate contingency should be in the range of 40% - 50%.

Response: Considering the level of detail utilized in the analyses in the report, and that essentially all of the technology postulated for use is currently available and has been demonstrated, the 25% contingency is thought to be adequate for the present state of knowledge.

007-3 Comment: The staffing estimates provided in the revised analyses should be scrutinized closely. First, the salary levels could vary significantly between utilities (e.g., privately-owned and public). The cost of living as it varies from region to region (Northeast, South, Midwest, West Coast, Northwest, etc.) is adjusted for in the computer program. Even with this adjustment, the salaries are not considered to be conservatively large enough.

Response: The salaries utilized in the analysis were specific to the reference site, Trojan. Obviously, a utility should adjust their estimates to reflect their local labor rates. The

Cost Estimating Computer Program (CECP) is designed to allow a user to change those parameters that may vary from site to site, including labor rates, overhead rates, transport distances, etc.

007-4 Comment: Second, the staffing levels identified in the revised analyses are considered insufficient. In Period 1, there should be more involvement from the lower levels, particularly, there should be significant involvement from licensing personnel. In general, there should be less involvement of management personnel through all four periods. Closer scrutiny may allow removal of certain management positions. In Period 2 the levels are too low to perform all the required activities (i.e., defueling, draining, decon, surveillances, etc.). In Period 3 again the levels identified are too low. At SONGS 1, we will require 104 equivalent persons for this stage versus the 53 identified in the revised analyses. In Period 4, the HP Tech Staff is provided by the Decommissioning Operations Contractor (DOC). The basis for not using utility personnel should be provided.

Response: The staffing levels represent the PNL analyst's judgement as to the minimum staffing that could reasonably accomplish the required tasks. Individual sites may have different requirements for a variety of reasons. Those types of adjustments can easily be made in the CECP to produce a site-specific estimate, or to examine the effect on cost of different staffing levels.

The judgement was made that the utility would no longer have the level of HP staffing available for the site by the time the actual dismantlement took place. Thus, a contract organization was utilized to provide the necessary HP support.

007-5 Comment: Also in Period 4 when the DOC staff has been mobilized, it is indicated that additional utility staff is returned to the site to support the active decontamination and dismantlement. This is not a good assumption. It should be expected that a large part of the utility staff would either leave the utility or be placed elsewhere in the company. If these people were placed elsewhere in the company, it is unreasonable to assume that they could all be brought back without adversely impacting their new organizations' operations. Returning these people to the site during Period 4 should not be assumed.

Response: The postulated utility staffing during Period 4 is that which is thought necessary to provide the proper degree of oversight of the decommissioning operating contractor operations. These persons could be regular utility staff returned to the site from other locations, or could be consultants/specialists employed by the utility to represent its interests.

007-6 Comment: The labor cost to perform certain tasks is low. Our estimate for removal of the reactor pressure vessel is \$2.9 million as compared to the \$0.1 million provided in the revised analyses. Our removal of the RCS piping is estimated to be \$1.1 million as compared to the \$0.13 million. These significant differences bring into question the labor costs for other activities.

Response: The detailed bases and calculations for the PNL estimates are contained within the reports. Without access to the detailed development of the commentor's estimates, PNL cannot comment on the differences between the two estimates.

007-7 Comment: In Period 2 of DECON it is considered unnecessary to remove the reactor vessel internals. Removal of the internals can be done as part of the removal of the reactor vessel. This is based on the fact that there is no compelling reason for handling the internals twice. In addition, cutting the vessel into so many pieces does not seem appropriate. A basis for cutting and shipping the vessel in 2 or 3 pieces should be provided. Other assumptions which should be considered or revised are as follows. Recycling of non-compactable LLW should be assumed. Assuming that one cask in and out of containment per day is too optimistic, a more reasonable assumption would be 1 or 2 casks per week. The revised analyses are not clear whether piping, electrical, and HVAC are removed by system or area. The appropriate assumption would be to remove this equipment by area. The revised analyses are not clear on the handling of equipment which is to be used as part of the decontamination and dismantlement. A discussion should be provided which addresses if onsite equipment will be maintained, laid up, or left to rust in place (e. g., radwaste processing). The discussion should also include temporary equipment which may be brought in for the dismantlement.

Response: The advantage of removing the vessel internals in Period 2 is two-fold: the material is packaged and stored with the fuel in the pool, and leaves the pool when the fuel is removed, allowing dismantling of the rest of the plant to begin in Period 4; the reactor refueling pool would have to be refilled following the short SAFSTOR period in order to facilitate the removal, cutting, and packaging of the internals in Period 4. The internals are not handled twice while intact.

Cutting the vessel into the pieces postulated in the analysis facilitated the transport of the strongly activated pieces in casks by truck. It is not obvious that larger segments could be adequately shielded to permit transport through the public domain.

Recycling of LLW via waste brokers/recyclers was not considered by direction of the NRC.

The assumption is that the handling crew would bring in an empty cask and remove a loaded cask. While accomplishing these operations in a single day may be optimistic, the analyses do not require cask turnarounds that quickly.

The piping removal (other than the main RCS pipe) is calculated on the total inventory of piping, by size and length. Electrical systems removal has been added to the study analyses in the final report. HVAC removal is analyzed as a system. In actual practice, it is likely that an area would be stripped of all piping and components until empty. This approach cannot be readily analyzed using the unit cost factor method of cost analysis.

In general, the waste processing systems are assumed inoperative following the end of Period 2. Thus, for waste processing during Periods 3 and 4, transportable systems are postulated to be brought in by contractors to provide the necessary services.

007-8 Comment: In addition to these comments, we believe the NRC should consider a new approach in handling decommissioning costs. Instead of the formula, use site specific estimates submitted by utilities on a periodic basis to provide a range of acceptable values. Utilities not wishing to develop a site specific estimate would adopt a minimum or average amount calculated by the NRC using statistical analyses on the estimates submitted to it by other utilities. Use of a minimum or average amount would be determined by the NRC. The statistical analyses would also be used to ensure that site specific estimates are within the acceptable range.

Response: The NRC will take this suggestion under consideration.

RESPONSES TO COMMENTOR 008

008-1 Comment: The NRC Should Reiterate That the Certification Amount in 10 C.F.R. § 50.75 Is Not a Cost Estimate But Rather a Minimum Level of Funding Deemed Appropriate to Provide Reasonable Assurance of Utility-Licensee Capabilities to Pay for Decommissioning to Ensure Protection of the Public Health and Safety

To avoid confusion as to the regulatory significance of the updated PNL study, the NRC should reiterate the purpose of the certification amounts in the decommissioning rule (10 C.F.R. § 50.75(c)(1)) and the distinction between a cost estimate and a certification amount. As the Commission explained in the Statement of Considerations accompanying the 1988 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 study may provide a more accurate (i.e., updated) prediction of decommissioning costs, differences between the old and new estimates do not necessarily implicate the validity of the existing certification amounts. 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. Clearly, the Commission did not intend to require the development, or NRC review, of a detailed cost estimate until near the end of reactor life.

In view of the purpose of the certification amounts, as explained above, the revised PNL cost estimate does not necessarily require revision of the certification amounts in 10 C.F.R. § 50.75. In fact, since the purpose of certification is to provide reasonable assurance of availability of funds, an NRC decision to retain a minimum certification amount that may be somewhat higher than an amount supported by the PNL study would not undercut the purpose of the rule.

Response: The PNL study is to revisit the assumptions that were used to support rulemaking in 1988 for financial assurance. The NRC has not yet decided if there is a need to change the certification amounts as are currently stated in the regulations.

008-2 Comment: The NRC Should Clarify Its Intended Use of NUREG/CR-5884. The NRC should explain how the revised PNL study will be used and should consider whether the intended uses are appropriate. Draft NUREG/CR-5884 states that the study "will be used to provide much of the basis information needed by the NRC Staff to perform their reviews of the adequacy and reasonableness of <u>the licensee submittals</u>, and will be used to provide the basis for potential revisions to the funding certification amounts to be specified in 10 CFR 50.75(c)."

The NRC should explain what "licensee submittals" will be reviewed using this information. 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 is submitted approximately five years prior to the end of plant operation (10 C.F.R. § 50.75(f)). 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 Trojan-specific analysis in draft NUREG/CR-5884 to review those site-specific estimates.

In considering whether there are appropriate applications for the study, the NRC should be mindful of the difference between certification amounts and cost estimates. The notice of availability for draft NUREG/CR-5884 explains that the report "should be viewed as a first step in developing a more parametric approach to estimating decommissioning costs" and solicits comments on the usefulness of the report in connection with the development of case-specific parametric analyses. 58 Fed. Reg. 66,386. At the same time, the notice states that the "results of these studies, including input from the public, will be used by the NRC staff as part of its effort to determine if revisions of the decommissioning regulations are warranted." 58 Fed. Reg. 66,386. As discussed above, these two objectives are distinct and to some extent incompatible. While one objective of the study might be to add precision to cost-estimating techniques, such precision is not necessary in establishing minimum certification levels as used in the NRC regulatory framework for decommissioning.

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.

008-3 Comment: The NRC Should Attempt to Reconcile the Apparent Discrepancy Between the PNL Cost Estimate and Recent Site-Specific Cost Estimates For Trojan and Other Plants. In view of the substantial discrepancy between the PNL estimate and recent site-specific estimates of the cost of the radiological portion of decommissioning for Trojan and other plants, the NRC should review the methods and assumptions employed by PNL. (In this regard, the notice of availability of draft NUREG/CR-5884 states that "publication of the reports does not necessarily constitute NRC approval or agreement with the information cited therein.") A recent site-specific study reportedly estimated the cost of radiological decommissioning at Trojan at $226 million. This is over $100 million more than the revised PNL estimate for the DECON option ($124.6 million). See draft NUREG/CR-5884 at xix. The NRC should consider conducting a survey of recent site-specific estimates for PWRs, to establish a baseline for comparison with the PNL analysis, in order to identify the areas of divergence.

Response: The NRC has performed review of the Trojan decommissioning cost estimate compared with the PNL study estimates and believes there is reasonable agreement for the estimates.

008-4 Comment: The NRC Should Address Several Potential Inconsistencies Between the Draft Study and Prior NRC Regulatory Positions or Assumptions Regarding Decommissioning.
a. To Assure Clarity in the Purpose and Scope of the PNL Studies and Their Continued Validity for NRC Decommissioning Funding Planning Purposes, the NRC Should Identify More Clearly the Factors That Resulted in a Reduced Cost Estimate.

The NRC should identify more clearly those factors that resulted in a cost estimate that is lower than the estimate used to support the 1988 decommissioning rule. "Major factors" considered in the cost estimate review are discussed on page 1.2 of draft NUREG/CR-5884, which states that "[t]he above factors have combined to . . . increase the costs of the viable decommissioning alternatives examined in this report" (emphasis added). Yet, the revised cost estimates reflected in Table ES.1 of the draft report appear to be lower, when adjusted for inflation, than the corresponding estimates used to support the 1988 rule. See NUREG/CR-0310, Addendum 4, July 1988, at 2.3. It would be helpful to include in the study an indication of whether each of the various factors considered (e.g., waste disposal, services, waste packaging, salaries, transport) tended to increase or decrease the earlier cost estimate (i.e., a "side-by-side comparison" of the various components of the NUREG/CR-0310 and NUREG/CR-5884 cost estimates).

Response: Using the formula in the Decommissioning Rule, the original analysis would predict a total DECON cost of about $154 million in 1993 dollars, and the reevaluation study report yielded a value of about $128 million in 1993 dollars. Two factors were principally responsible for this change: the depth of concrete scabbled was reduced from 2 inches to 1 inch, and the area scabbled was reduced from all floor areas in the Containment, Fuel and Auxiliary Buildings to only those areas within those buildings expected to have contaminants absorbed into the concrete surface layers; and the packaging of the highly activated was markedly modified to produce high-density packages of the GTCC material. As a result, the volume of materials requiring LLW disposal was greatly reduced, from about 18,000 cubic meters, to about 7500 cubic meters.

Comment: b. The Basis for the Redefined Phases of DECON, SAFSTOR, and ENTOMB Should Be Articulated. The definitions of DECON, SAFSTOR, and ENTOMB on pages 1.3 and 1.4 of draft NUREG/CR-5884 appear to create artificial separations of various stages of decommissioning, in a manner which could significantly affect the validity of the updated cost estimate. The NRC should explain the reasoning behind, or regulatory position which necessitates, the separation of these phases of decommissioning.

For example, the draft study assumes that the spent fuel pool must be emptied before decontamination and dismantlement can commence. The assumption appears inconsistent, for example, with NRC policy on decommissioning activities that can be undertaken prior to Decommissioning Plan approval and with decommissioning precedent set by prematurely shut down plants such as Shoreham and Yankee Rowe. As discussed further below, an assumption that various phases of decommissioning cannot proceed in parallel may unduly inflate the overall cost estimate.

Response: The scenario discussed in the report is one of several a licensee may pursue at time of permanent shutdown. The regulations do not incorporate any definitions of DECON, SAFSTOR, or ENTOMB. The definitions assigned to the various options for purposes of this study were changed slightly to incorporate the current US policy of not allowing reprocessing of spent fuel and DOE's policy for accepting spent fuel.

Comment: c. The Spent-Fuel-Pool-Cooling Assumption May Be Overly Conservative, Which Could Undercut Any Generic Applicability of the Study. The draft study assumes fuel pool operation for five to seven years following plant shutdown. In support of this assumption, the NRC cites 10 CFR 961, App. E, which specifies that, in a standard DOE contract for spent fuel disposal, the minimum cooling period for "standard fuel" is five years.

Response: The reference to 10 CFR 961 has been removed and a discussion of the bases for cooling time requirement (burnup, enrichment, cladding temperatures) has been inserted.

Comment: Some Group member utilities have indicated that this assumption is invalid for their plants. One member, for example, has determined that its spent fuel pool could be emptied as early as two years following permanent shutdown, using such techniques as partial loading of dry storage casks. Other utilities that have similar capability will find this aspect of the PNL cost estimate inapplicable to their plants. (As the study recognizes elsewhere, for example, at a multi-unit site spent fuel could possibly be transferred to an adjacent unit's pool (p. 2.8).) The draft study determines that operation of a spent fuel pool during SAFSTOR would cost about $4 million per year (p. 1.3) and that the 5-to-7-year storage assumption "results in major differences from the earlier estimates of both cost and doses" (p. 2.2). Because of the significant contribution of this element to the overall cost estimate, such assumptions, if inapplicable to other plants, could undercut the utility of the study to support a generic determination of the adequacy of the minimum certification levels.

Response: Each fuel assembly has its own unique cooling time requirement based on the cladding temperatures expected when placed into dry storage. Those temperatures depend upon both the burnup and cooling time of the fuel and on the heat removal characteristics of the storage cask. Emptying the pool by using partial loadings of storage casks would be a rather expensive approach, considering the capital investment in casks, and would probably exceed the cost of continuing the pool storage and SAFSTOR operations for a number of years.

Comment: In addition, the draft report misinterprets the DOE contract provision as a requirement that fuel be stored in a pool for at least five years before being put in dry storage (p.xvi). This is an inappropriate application of the DOE standard contract provision. The NRC has studied in other contexts the necessary duration of fuel pool storage (e.g., in connection with the promulgation of Part 72). Rather than relying on the DOE provision, the NRC should consider such studies here, while allowing licensees sufficient flexibility to develop their own analyses and timetables for spent fuel disposition.

Response: As mentioned above, the 10CFR 961 basis for cooling times has been replaced by a discussion of the parameters that really control when a fuel assembly can be placed into dry storage. The utility always has the choice of continuing the pool storage until DOE has picked up the total inventory, or to provide some other storage capacity outside of the pool (wet or dry). If dry, then the cladding temperature limits will be controlling the wet cooling duration.

008-5 Comment: Several Aspects of the Updated Study Appear To Be Inconsistent With the Decommissioning Rule: Whether or not the NRC ultimately elects to use NUREG/CR-5884 as the basis for revision of the certification amount in 10 C.F.R. § 50.75, it should recognize that several aspects of the study appear to be inconsistent with the NRC's decommissioning rule or associated policies. The NRC should acknowledge that to the extent such aspects would be considered in the context of NRC decommissioning, certain regulatory or policy changes would need to be implemented. We do not comment here on the desirability of undertaking such regulatory revisions.

- "pre-shutdown planning/engineering and regulatory reviews" as the first stage of decommissioning: While NUREG/CR-0310 considered "pre-decommissioning engineering" costs as decommissioning costs, draft NUREG/CR-5884 indicates that additional pre-shutdown planning and regulatory reviews are now considered part of decommissioning and that related expenses, not considered in NUREG/CR-0310, have been included in the revised cost estimate (pp. xvii, 3.4). The NRC should state whether this first phase of decommissioning as defined in the draft report is consistent with the NRC's definition of decommissioning. If not, this aspect of the revised cost estimate should be revisited. If so, the Commission should reconsider the need for special guidance on "de minimis" decommissioning fund withdrawals prior to Plan approval. (See Draft Policy Statement on Use of Decommissioning Trust Funds Before Decommissioning Plan Approval, 59 Fed. Reg. 5216 (1994).) Funds obviously will be expended in developing a proposed Decommissioning Plan and other NRC submittals associated with plant shutdown and decommissioning, prior to Plan approval. If these pre-shutdown and post-shutdown planning and regulatory activities are part of decommissioning, licensees should be able to undertake such activities, and withdraw decommissioning funds to support such activities, without prior NRC review or approval.

Response: The NRC has issued a proposed rule entitled "Decommissioning of Nuclear Power Reactors" in 60FR37374, July 20, 1995 that discusses the use of funds for decommissioning activities prior to permanent shutdown.

Comment: • 300-year SAFSTOR: The draft report suggests that 300-year ENTOMB is being considered as an additional decommissioning option. Under this option, no radiation survey would be required at the end of the SAFSTOR period in order to obtain license termination.

While this option may merit further consideration, it is not consistent with existing decommissioning regulations. For example, 10 C.F.R. § 50.82 provides that a decommissioning alternative will be acceptable to the NRC "if it provides for completion of decommissioning within 60 years" and that an alternative which provides for completion of decommissioning beyond 60 years will be considered "only when necessary to protect the public health and safety." 10 C.F.R. § 50.82(b)(1)(i). In addition, the NRC's decommissioning regulations require formulation, execution, and approval of a final radiation survey prior to license termination. See, e.g., 10 C.F.R. § 50.82(b)(3),(f). The NRC should make clear that PNL's analysis of this alternative, and the corresponding cost estimate, is hypothetical in the sense that it is not an available option under the current regulatory framework (i.e., rulemaking would be required to facilitate its use by licensees).

Response: The NRC does not favor this option under current regulatory requirements but will consider it under extenuating circumstances if health and safety is a consideration.

Comment: • spent fuel storage-related costs: The study treats as decommissioning costs 10% of costs incurred during the 5-to-7 year post-shutdown spent-fuel-cooling period (draft NUREG/CR-5884 at 2.3, 3.12). This analysis does not appear to be entirely consistent with the NRC's decommissioning rule. The NRC's definition of decommissioning activities specifically excludes the removal and disposal of spent fuel, which are considered operational activities. 53 Fed. Reg. at 24,019. The study apparently assumes that 10% of the costs incurred during this fuel-cooling period would be incurred despite the presence of fuel in the pool and therefore are legitimately considered decommissioning expenses. The basis for this allocation between "operations" and "decommissioning" is unclear and, in any event, would seem to have little regulatory significance. These issues should be addressed as part of the NRC's ongoing assessment of whether spent fuel storage and disposal costs should be included in decommissioning costs. See 58 Fed. Reg. 34,947, 34,948 (June 30, 1993).

Response: The commentor is correct that the allocation of 10% of the total operating costs during Period 3 to decommissioning is intended to estimate that portion of those costs that are attributable to SAFSTOR activities. Because the SNF pool storage operations are on-going, and are performed by the same staff, the costs associated with SAFSTOR are somewhat less than would be the case for SAFSTOR without fuel pool operations. The distinction is made because present NRC policy does not include SNF storage costs as a decommissioning cost.

008-6 Comment: The Treatment of Property Taxes and Insurance in the Revised Adjustment Formula Should Be Clarified: If the NRC chooses to revise the adjustment formula in 10 C.F.R. § 50.75(c)(2), in the manner described on pages 3.60 and 3.61 of the draft report, it should clarify its treatment of property tax and nuclear insurance costs. If the point is that insurance and property tax costs following cessation of operations will not be ordinarily subject to inflation but will be lower than during operations, then this should be spelled out.

Response: Property taxes and nuclear insurance do not necessarily follow any ordinary price indices that could be identified for use in the formula. Thus, the solution selected was to extract those costs from the base formula cost, perform the cost escalation on the balance of the decommissioning costs to the year under consideration, and then add in the taxes and insurance costs applicable in the year under consideration. This approach avoids the question of appropriate escalation factors for those cost elements.

As pointed out in the discussions in Sections B.9 and B.10, PNL expects the property taxes to be reduced once the plant is no longer producing power and revenue for the utility, and expects the nuclear insurance costs to drop following shutdown. Whether or not these expectations are realized depends upon the situation at a specific site in a specific taxing district, and upon the negotiations between the utility and their insurance carrier.

RESPONSES TO COMMENTOR 008a

008a-1 Comment: Since the initiation of NRC's contract with Pacific Northwest Laboratories (PNL), the Trojan Nuclear Plant prematurely shutdown on January 27, 1993; detailed actual cost estimates for decommissioning have been developed by Portland General Electric Company (PGE). Industry comparison of draft NUREG/CR-5884 methodology and PGE's cost estimates, based on empirical data of actual decommissioning activities, has identified numerous methodology inaccuracies in the draft NUREG that should be corrected in order to reach realistic cost estimates. Also, the absence of a complete methodology causes the current draft NUREG/CR-5884 to be technically incorrect.

Response: The "detailed actual cost estimates" developed by PGE and their contractor have not been made available to PNL to factor them into the report. Thus, PNL has no basis responding to the above comment.

008a-2 Comment: Decommissioning strategies and their attendant costs require many inputs and assumptions. Each of these parameters has uncertainty associated with it and the levels of uncertainty vary significantly among the various parameters. Additionally, each nuclear facility represents a unique situation with respect to size, location, single- versus multi-unit site, years of operation, etc. Thus, the report should only be considered as a guide and its conclusions and decommissioning cost estimate recognized as only applicable to the special case that it represents. Any use beyond that must be done with caution, recognizing the significant variability among plants. The draft report requires correction to achieve a valid estimate for the reference plant it uses and to help its methodology to become "generically" correct.

Response: PNL agrees with all except the last sentence. Statements to the effect that the report is incorrect, without providing any supporting information, are not useful toward improving the product.

008a-3 Comment: The final NUREG/CR-5884 should provide a cautionary statement regarding its use. This cautionary statement should be included in the executive summary and at the beginning of the report. The statement should make the following three points:

- The report is to be used as a guide and not as a "benchmark" for estimating the decommissioning costs associated with other facilities;
- The conclusions and decommissioning costs reported in draft NUREG/CR-5884 are specific to the reference PWR for the scenarios analyzed. They do not represent the conclusions and decommissioning costs which have been or could be obtained for an actual facility, including the Trojan Nuclear Plant which serves as the reference PWR in the report; and
- The cost estimates may vary significantly based on disposal costs. This is illustrated in Figure ES. 1 "Variation of DECON Escalation Formula Terms as Functions of Low-Level Waste Disposal Change Rates."

Response: A paragraph has been added to the Executive Summary: "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 PWR power station. However, the cost analyses and the computer program developed herein are in sufficient detail that a plant owner can substitute his own plant-specific details for any significant cost elements, thereby accounting for site-specific differences."

That the cost estimates vary strongly with disposal rates would seem to be self-evident, given the discussion of the sensitivity of total cost to disposal site location and Figure ES.1.

008a-4 Comment: The methodology in the report should only be based on constant dollars and refrain from any economic predictions. This will preclude faulty economic predictions from skewing report results and, perhaps incorrectly, making one decommissioning option look better than another. Financial predictions are not within the NRC's expertise or primary responsibilities. Users of the report can then judge for themselves the impact of real world economics in relation to the published decommissioning options.

Response: The purpose of the PV analyses is to illustrate the possible effect on funding requirements for the delayed D&D alternatives, showing that postponing expenditures for a number years could reduce the amount of money needed in the decommissioning fund at reactor shutdown, or could provide an additional safety margin to cover unanticipated costs or cost increases, i.e., an additional contingency. Whether or not the use of PV analyses will be accepted by the NRC for purposes of establishing an adequate funding base is not considered here.

008a-5 Comment: The NRC should not make any reference to demolition cost estimates that are speculative and the responsibility of State Rate Commissions. The report should delete assumptions that demolition costs can be estimated as high as $100 million; the NRC has no jurisdiction over these funds.

Response: The estimated costs for demolition of the decontaminated structures are included for information only, and are not included in the base cost estimated for decommissioning.

008a-6 Comment: The underlying assumptions regarding decommissioning manpower management are not clearly stated in the report. The use of crew-hours as a resource measure is confusing and misleading. Additionally, the basic work philosophy is not readily apparent. Shift length, shifts per workday, and workdays per week need to be clearly stated in the beginning of the report. For example, the report has decommissioning activities which rely on a three shift operation, such as internals removal. Obviously, the work-schedule approach directly affects period dependent costs and may affect activity dependent costs as pointed out below.

Response: A statement to clarify the basic assumptions regarding days worked per week and shifts worked per day has been added to Chapter 2. "Unless otherwise specified, all tasks are carried out using a 2 shifts/day, 5 days per week work schedule." Some operations that require 3-shift operations are clearly identified in the text, such as the chemical decontamination of the RCS, waste water deboration and treatment, etc. The waste handling crew is postulated to work on the third shift normally, to avoid interferences with the disassembly crews. When the costs of the indirect activities exceed the direct labor costs, there are clearly some incentives to perform the tasks in as short a calendar time as possible.

008a-7 Comment: In draft NUREG/CR-5884, reactor vessel internals removal is a three shift operation, with two cutting crews on each of two shifts and packaging and disposal occurring on the third. This may be too optimistic and current decommissioning experience questions the practicality of running simultaneous cutting operations. The assumption that four cutting-crews' worth of disposal can be accomplished on the backshift appears to be overly optimistic. Also, cask availability, which is a determining factor, is not addressed. Although there is sufficient room available for two cutting operations at the reference PWR, this may not be the case at other facilities.

Response: The analyses were developed for the specific situation at TROJAN and might have to be modified to fit within the geometry at a specific plant. The approach is to unbolt/cut major segments free from the rest of the internals and move the segments to the refueling pool for final segmentation and packaging. The cutting crews also loaded the material into the final canisters/casks, which the waste handling crews moved away from the work areas. Much of the internals are classified as GTCC, which would be packaged into canisters resembling spent fuel assemblies and stored in the SNF storage pool, and would not require any cask handling at the plant prior to eventual removal from the pool.

008a-8 Comment: There seem to be some conflicts in the deactivation (Period 2) schedule. Three activities overlap: deboration of the reactor containment system (RCS) water, RCS chemical decontamination/flushing, and reactor pressure vessel internals removal, cutting, and packaging. The ability to perform these activities in parallel is questionable. The report needs to better explain the sequence of these activities.

Response: No significant conflicts are expected. The schedule bars include the initial setup of the processes, then relatively short operating periods, followed by cleanup and removal of the processes. The schedule bars in Figure 3.3 have been modified to better illustrate these divisions of activities.

008a-9 Comment: Assumptions used in the development of unit cost factors may be unrealistic. For example, the unit cost factors for pipe removal were developed on the basis of removing 15-foot lengths of pipe per cut, which appears to be extremely unrealistic. Using this value, the number of piping cuts required will be significantly underestimated. Moreover, use of the 15-foot lengths in the report gives a false impression that it is readily achievable. It would be better to base piping removal costs on 5-foot lengths; achieving an average cut longer than that would result in cost savings. Additionally, consider the handling requirement differences between a 5- and 15-foot section of pipe. A 24-inch Schedule 160 pipe weighs 542 lbs./ft. It is much easier to handle and maneuver a 5-foot piece weighing 2700 lbs. as opposed to a 15-foot piece weighing 8100 lbs. Use of 15-foot sections of pipe is judged to be unattainable due to plant layout and actual access and egress within the reference plant. Calculating pipe removal costs assuming 15-foot lengths is not representative of actual experience.

Response: Similar handling capability is required for any pipe segments that exceed 70 to 80 lb. Thus, lifting capability is not a serious discriminator. The use of maritime containers for packaging encourages segmentation into the largest lengths (< 20 ft.) feasible. The sensitivity analysis for length of pipe cut showed an increase in cost of about $5 million and an increase in worker dose of about nearly 1000 person-rem. Thus, there are incentives to minimize the number of cuts made. As far as actual experience is concerned, that experience was driven more by the size of the disposal containers in which the pipe segments were packaged than by piping configurations in the plant.

008a-10 Comment: The draft NUREG/CR-5884 reported costs (without contingency) of reactor internals and reactor pressure vessel removal appear to be very low when compared to actual (PGE) estimated costs for removing these items. Many factors determine the overall removal cost for these items, with transportation and burial costs being the predominant factors.

Response: The PNL estimates are based on best available information. Without a side-by-side comparison of the PNL analyses with the PGE analyses, no response can be made to the statement that PNL costs appear very low.

008a-11 Comment: Asbestos removal can be a significant decommissioning cost. The report assumes an insignificant amount of asbestos is present in the reference plant at the time of decommissioning. This assumption cannot be generally applied to all PWRs.

Response: After discussion with PGE, about $165,000 was added to the cascading costs for asbestos removal and disposal, based on their probable inventory of about 50,000 lb. of asbestos, mostly non-friable and mostly located outside of the three contaminated structures.

008a-12 Comment: The draft NUREG/CR-5884 use of only Co-60 underestimates the amount of contamination to be removed from the site to be in compliance with NRC requirements. As a result, the associated decontamination, removal, and burial costs will also be underestimated. By not including a more valid isotopic inventory, including Beta emitters, the work schedule is underestimated leading to lower staff requirements and undistributed costs.

Response: The Co-60 activity is used as a surrogate for all types of radioactive contamination at the reactor facility, and comprises the principal source of dose to workers. Based on the detailed analyses of radionuclide inventories presented in the original PWR study (NUREG/CR-0130) it was concluded that, because Co-60 is the principal source of dose, if the decontamination process removes sufficient Co-60 to achieve release levels, it is very unlikely that the residuals from any of the other radionuclides will present a problem.

008a-13 Comment: The report did not include costs for site characterization studies. These extensive efforts include isotopic analyses and surveys to clearly define isotopic contents and the scope of required decommissioning activities. Site characterization costs should be included in the final document.

Response: For an operating plant just shutdown, there should be adequate contamination maps and dose-rate maps available from previous health physics surveys of the facilities to do initial planning. A limited number of additional surveys might be needed in areas not normally accessible in an operating plant. At the start of Period 4, the DOC HP staff provides the necessary surveys to obtain current information to guide planning and operations. These staff are already accounted for as part of the undistributed cost.

008a-14 Comment: There are multiple waste volume estimation errors. The draft NUREG/CR-5884 low-level waste volume is underestimated by neglecting to include 77,000 cubic feet of electrical components (cable, trays, conduit, panels, and breakers). The report does not consider state of the art decontamination volume reduction techniques. The analysis does not consider waste volume minimization technology during decommissioning. Incineration, metal recycling, reverse osmosis, iceblasting for decontamination are among the methods that can be used to reduce the low-level waste disposal volume. The report assumes the entire turbine building is uncontaminated and neglects some systems that have contamination, e.g., instruments in containment. The study uses packing factors higher than recent industry experience. It assumes that pipe supports are not significant in terms of waste volume. This is a non-conservative assumption as most of the contaminated systems are safety related. Safety related systems have far more and larger supports, to meet Seismic Category I requirements, than balance of plant systems. Large supports also present special rigging concerns.

Response: Inventories of electrical systems omitted from the PNL analyses have been provided by another contractor, and have been added to the final analyses. The volume of those systems was estimated (by the other contractor) at about 7,400 cubic feet, not 77,000 cubic feet.

Consideration of waste volume reduction via use of waste brokers, compaction, and recycling, was omitted from the analyses by direction of NRC.

The pipe supports were omitted from the PNL analysis, due to lack of information.

008a-15 Comment: The study estimate for scaffolding and rigging factors does not account for working in overhead areas, pipe chases and shielded rooms where a significant portion of the contaminated components are located.

Response: Time for handling scaffolding and rigging is included in the unit cost factors. There are some who disagree with the PNL estimates for those activities.

008a-16 Comment: The study included the payroll burden in the staff costs, but did not include corporate indirect costs. Corporate support staff costs should be allocated to the decommissioning project. The payroll salaries for both utility staff and the decommissioning operations contractor were considered low for the Pacific Northwest.

Response: The utility salaries and overhead factors were obtained directly from PGE. Whether or not they included all appropriate adders could not be determined. The DOC staff base salaries are postulated to be about the same as the utility salaries, but with a much larger overhead factor. Statement like "the payroll salaries for both utility staff and the decommissioning operations contractor were considered low for the Pacific Northwest" without providing any data are not useful for improving the product.

008a-17 Comment: The cost identified for the final license termination survey is underestimated by a factor of 5 to 10 based on actual industry experience from prematurely shut down plants.

Response: The final survey at Pathfinder cost about $1.2 million. The analyses used to estimate the cost at TROJAN were developed using the protocols given in NUREG/CR-5849, which were prepared by an organization who makes their living performing these types of surveys. The comment as stated, without data to support it, is not useful.

008a-18 Comment: Page xvi, second bullet: Title 10 CFR 961, Appendix E, requires a five-year Spent Nuclear Fuel (SNF) cooling for delivery to DOE for shipment as "Standard Fuel," not for storage in spent fuel pools prior to dry cask storage. Interim SNF placement in dry cask storage cells is limited by the heat removal capability of the cask design, which could be less than five years. The draft should be revised to recognize alternative methods of storing spent fuel.

Response: The statement has been revised to focus on the true reasons for the long wet storage requirements postulated in this report, i.e., the cladding temperature limits, which are a function of the fuel burnup, initial enrichment, and initial internal gas pressure. If the cladding temperature limits can be satisfied while in storage, fuel can be stored dry regardless of the length of the cooling time.

008a-19 Comment: Page xvii, xviii, and 2,5: Draft NUREG/CR-5884 use of only Co60 underestimates the amount of contamination to be removed from the site to comply with NRC requirements. The associated decontamination, removal and burial costs will also be underestimated. The underestimation of radioactivity leads to underestimated work schedules which cause incorrect estimates of staff and undistributed costs. Use of Co60 effects the assumptions used in SAFSTOR1 and ENTOMB1, where all activity (other than the reactor vessel and the biological shield wall) has decayed to unrestricted release levels by the end of the storage period. Among the contaminants at Trojan, Ni59 and Ni63 have half-lives which are much longer than Co60.

Response: PNL disagrees. Using Co-60 as the indicator of the presence of contamination on equipment and surfaces is a standard technique. Co-60 is by far the principal contributor to worker dose, because of its strong gamma-ray emissions. The longer-lived Ni-59 and Ni-63 are principally beta emitters, and present little dose hazard unless inhaled or ingested. Review of the composition of the reactor station contamination given in NUREG/CR-0130 shows that the Co-60 activity would dominate worker dose considerations for at least 60 years following shutdown. The long-lived Ni-58, Ni-63, and Nb-94 activities appear primarily in the highly activated vessel internals, which are removed for disposal in all cases.

008a-20 Comment: Page xvii-xviii: SAFSTOR 1 assumes that all radioactive material except the pressure vessel and bioshield decay to unrestricted release levels. SAFSTOR 2 assumes no volume reduction. More probable and realistic assumptions should be used such as state of the art decontamination and volume reduction techniques.

Response: These analyses are intended to bound the possibilities, thus showing the range of possible costs associated with SAFSTOR. PNL agrees that, in an actual decommissioning, the true situation will lie somewhere between these extremes.

008a-21 Comment: Page xix: Table ES. 1 should present the expected decommissioning costs for entombment using the reduced or more realistic security and insurance costs; i.e., the table should reflect the $88 million dollar figure on page 5.13.

Response: The entombment analysis made using the reduced security and insurance costs is intended to illustrate the range of possibilities. The reduced security and insurance costs, while probably reasonable estimates, are subject to considerable uncertainty, and were therefore omitted from the summary table.

008a-22 Comment: Table ES. 1 should list the costs of various alternatives assuming disposal at Barnwell instead of Hanford. There is currently a factor of 4.5 difference between Hanford and Barnwell. By not providing the range, the reader may draw the wrong conclusions regarding the range of costs associated with DECON, SAFSTOR, and ENTOMB.

Response: The baseline assumption throughout the study is disposal at Hanford, as is specified in the footnote to the table. The effect on cost of disposal at Barnwell is presented in Table ES.2. ENTOMB costs are relatively insensitive to the disposal site because of the small amount of actual disposal that would occur.

008a-23 Comment: The final NUREG/CR should recognize that Barnwell may not be available to out-of-compact generators after June 1994 and the charges at Barnwell do not represent the true cost of waste disposal, but rather the charges include substantial surcharges.

Response: The Barnwell rates, including the out-of-compact surcharges, are similar to disposal rates suggested to be likely at future LLW disposal facilities presently under development. Thus, the decommissioning cost resulting from disposal at Barnwell are a reasonable surrogate for disposal at these planned facilities.

008a-24 Comment: Page xxi, Table ES.2: For entombment, costs should be adjusted for the transportation and disposal associated with the long lived Nb95 and Ni59 activity.

Response: The costs for removal, packaging, transport, and disposal of the highly activated vessel internal, which contain the long-lived Nb-94 and Ni-59 are contained within the ENTOMB estimates. Those materials are presumed to all go to the repository, not to a LLW disposal facility, since much of it is GTCC.

008a-25 Comment: Page xxiv, and Volume II C.45: Draft NUREG/CR-5884 estimates the use of scaffolding and rigging factors that do not account for working in overhead areas, pipe chases and shielded rooms where a significant portion of the contaminated components are located.

Response: The size of the work difficulty factors assigned to the use of scaffolding and rigging is a matter of engineering judgement. It is important to remember that D&D removal operations can be simpler than a similar operation performed during a reactor outage when the system must be restored to service.

008a-26 Comment: Draft NUREG/CR-5884 assumes that all piping is removed in 15-foot sections. A 15-foot section of schedule 80 pipe weighs 1591 lbs. while a 5-foot section of schedule 80 pipe weighs 530 lbs. Rigging a 15-foot section of RHR piping out of a shielded compartment and up a 40-foot hoistway to get to grade level would involve significant rigging challenges.

Response: Once the weight of the segment exceeds 60-100 lb, special rigging will be required. Handling a piece weighing 5000 lb is not particularly more difficult than handling a piece weighing 500 lb. Clearances to hoistways may present a problem in some cases. It is important to remember that the structures are being stripped of equipment and piping. Thus, many of the interferences present in an operating plant may be removed before they become a problem during D&D.

008a-27 Comment: Page 1.2-1.3: The NUREG/CR should acknowledge that there are costs associated with structure demolition and site restoration which are in addition to the necessary cost to achieve termination of the license, but should not speculate on those additional costs; such speculation should be deleted.

Response: In response to many requests, the report now contains an appendix devoted to estimating costs for demolition and site restoration. The speculation regarding these costs have been replaced by actual cost estimates.

008a-28 Comment: Page 1.3, fifth line: The line implies that non-nuclear demolition and the on-site storage of retired steam generators could add $100 million or more to the decommissioning cost. The statement should either be removed, or should be expanded to differentiate between the added cost of non-nuclear demolition and that of individual items such as steam generators. The reader should not be left with the impression that a large percentage of the $100 million dollars is attributable to such things as "retired steam generators" removal from the site.

Response: As noted in the response to Comment 008a-27, the speculation regarding demolition and site restoration costs has been replaced with actual estimates. Similarly, the likely costs of dealing with additional retired steam generators has been considered, based on the S.G. transport and disposal analyses, and the likely costs appear to be less than $5 million.

008a-29 Comment: Page 2.2 last two paragraphs: The scheduling constraint on operation of the spent fuel pools following plant shutdown is directly related to the heat removal capability of the cask design. The text should recognize that some designs employ passive cooling techniques to increase the heat removal capability and reduce the time required for cooling in the spent fuel pools (i.e., less than five years).

Response: As stated in the response to Comment 008a-18, the wet cooling time is defined by the temperature limits on the fuel cladding, which are in turn defined by the fuel cooling time, the initial fuel enrichment, initial internal gas pressure, and the fuel burnup. Based on the postulated fuel characteristics for the final core in Trojan, 7 years of pool cooling for the hottest assemblies would be appropriate.

Some passive systems are more efficient in heat removal than others. However, the analysis presented in Appendix D utilized the heat removal capability of metal casks, which are about as good as can be obtained. If an active dry cooling system were to be used, i.e., forced air cooling, spent fuel could be removed from the pool at whatever time the dry cooling system could satisfy the cladding temperature limits.

008a-30 Comment: Page 2.3, first paragraph: The assumption that 90 percent of spent nuclear fuel (SNF) storage cost is assigned to plant operations and 10 percent assigned to decommissioning SAFSTOR should be reconsidered. The assumption is based on the premise that DOE will accept SNF by 1998. This seems optimistic. Therefore, the cost ratio for SNF storage cost should be reevaluated.

Response: The 90%/10% allocation of total Period 3 operating costs to SNF storage and balance of plant safe storage, respectively, is based on a brief analysis of how many of the staff are doing fuel pool work, and how many are doing surveillance and maintenance on the balance of the plant which is in safe storage, during that period. The allocation has no relationship to the assumption that DOE will begin SNF acceptance in 1998, and would be generally true for as long as the combined operations were continued.

008a-31 Comment: Page 2.5, sixth bullet: The radiation dose rate should be calculated using an effective dose factor for an assumed mix of radionuclides instead of being determined based solely on the short half-lived Co60.

Response: Co-60 is the dominant dose producer among the contaminants for about 60 years. See Figure E.2-1 in Appendix E of NUREG/CR-0672 (original BWR study).

008a-32 Comment Page 2.6 third and fourth bullets: The NUREG/CR states that a basic assumption is that an off-site low-level waste disposal site exists and will accept the waste. This may be a misleading statement as a utility might elect and obtain approval to do significant decommissioning work with the intention of storing the waste on the site pending off-site shipment. As an example, the licensee might find it cost-effective to section, remove and package the reactor internals for storage while the necessary plant systems are physically operable and the staff is available to support the operations, independent of disposal site availability. The NUREG/CR should recognize such alternative approaches.

Response: The example suggested above is essentially treated in the study, since the vessel internals are removed during Period 2, segmented and packaged for onsite storage in the SNF storage pool until either an approved repository is available or the packaged material can be moved into an onsite ISFSI. Similarly, the costs of steam generator and pressurizer removal are developed. There are, however, no costs developed for onsite storage of these latter items. The possible paths to be taken during a decommissioning effort are many, and tend to be quite site-specific. To have explored all of the possible permutations and combinations in this reevaluation would have been an enormous expansion of scope.

008a-33 Comment: Page 2.6, fifth bullet: It is not technically correct to assume that "contaminated" (not irradiated) concrete must be removed to a depth of 1 inch. Typically available decontamination methodologies exist that will clean painted concrete surfaces with essentially no concrete removal, and methods of very shallow surface removal (far less than 1 inch) have been demonstrated. The NUREG/CR should be corrected.

Response: PNL agrees that the 1-inch removal depth for contaminated concrete is probably overly conservative, based on available data. However, it does represent a reasonable upper bound, in most cases. The effect of this assumption on the total decommissioning cost is explored in the sensitivity analysis, for removal depths ranging from 0 to 1 inch. The relatively small areas postulated in the study to require scabbling reflects the belief that much of the plant floor surfaces will be able to be decontaminated without physical removal of the concrete.

008a-34 Comment: Page 2.7, first bullet: The removal of asbestos is an attendant and essential part of decommissioning. Many plants have active asbestos removal programs as implied on page 2.7. The NUREG/CR should recognize that the costing of asbestos removal is most appropriately performed on a plant- or case-specific basis.

Response: A paragraph has been added to Section 3.4 which speaks to the asbestos inventory present at TROJAN, and the likely cost of the removal and disposal effort, based on recent information from Portland General Electric Company. These costs have been incorporated into the total decommissioning cost. PNL agrees that the cost of this activity will be quite site-specific.

008a-35 Comment: Page 3.1 fourth sentence: Indicates "fuel from last core is postulated to have to remain in the pool for about seven years after shutdown until it is sufficiently cooled to permit dry storage..." Previously it was indicated that five years sentence was the minimum time for decay before transferal to DOE, and transfer to dry cask storage can be achieved earlier. (See comment regarding P.xvi, and P.2.2.)

Response: All discussions regarding SNF cooling times are now focused on the real constraint, i.e., the fuel cladding temperature limits. Statements regarding the 5-year cooling requirement of DOE for acceptance as standard fuel have been deleted or modified.

008a-36 Comment: Page 3.3, Table 3.1: The analysis should consider waste volume minimization technology during decommissioning. Incineration, metal recycling, reverse osmosis, ice blasting for decon, etc., are means to reduce the burial volume of radioactive waste. Rather than consider these options as potential savings at the time of decommissioning or case-by-case economic decisions for the future, it is realistic to include them as a variable or potential error in radioactive waste disposal costs. Based on the estimates in Table 3.1, decon and disposal costs constitute greater than 30% of the total cost without contingency.

Response: Consideration of the possible cost reductions resulting from waste volume reduction activities,such as waste decontamination and recycling, compaction, etc., was not performed at the direction of the NRC, to assure that the estimates more closely represented bounding situations. The actual amount of volume reduction that can be achieved will tend to be a site-specific parameter.

008a-37 Comment: Section 3.1: The correlation between the staffing level tables in person-years per period and figures providing staffing levels during comparable periods are confusing and not human-factored. The comparison figures and tables should be reevaluated in order to provide the reader with a clear understanding of Decommissioning Operations Contractor (DOC utility staffing levels.

Response: The staffing levels for the DOC are presented explicitly for each period in the staffing structure figures (3.2, 3.6) and in Table 3.3. The staffing levels for the direct labor activities of the subcontractors is derived from the crew sizes developed for the individual activities and the activity durations derived from the unit cost factors for those activities. It is not obvious what else is needed.

008a-38 Comment: The staffing estimates provided in draft NUREG/CR should be reevaluated. The staffing levels identified in the revised analyses are considered insufficient. In Period 1, there should be more involvement of the lower level positions, particularly, there should be significant involvement from licensing personnel. In Period 2, the levels are too low to perform all the required activities (i.e., defueling, training, DECON, surveillance, etc.).

Response: The staffing estimates provided are judgement calls by the PNL analysts. The comment that these estimates are too low, without any supporting bases, is not productive.

008a-39 Comment: In Period 3, the levels identified are too low. For example, one decommissioning utility required 104 equivalent persons for this stage versus the 53 identified by the Decommissioning Operations Contractor (DOC.) The basis for not using utility personnel should be provided. Also in Period 4, when the DOC staff has been mobilized, it is indicated that additional utility staff is returned to the site to support the active decontamination and dismantlement. This is not a good assumption. It should be expected that a large part of the utility staff would either leave the utility or be placed elsewhere in the company. If these people were placed elsewhere in the company, it is unreasonable to assume that they could all be brought back without adversely impacting their new organizations' operations. Returning these people to the site during Period 4 should not be assumed. A basis should be developed to support staffing level requirements. Staffing as presented did not include corporate overhead or the quality assurance activities.

Response: The staffing levels presented represent PNL analysts' best judgement regarding the number and types of staff needed onsite during a given period. The actual staffing that any individual utility may choose to maintain onsite during a given period is beyond PNL's control. Also, there are DOC staff present during Period 3 only during the final 6 months, as a ramp-up to Period 4.

The utility staff postulated for Period 4 again represent the PNL analysts' best judgement regarding the number and types of staff needed. Because of the owners' responsibility and liability, it seems unlikely that the utility will simply turn the site over to the DOC for decommissioning without maintaining some level of oversight. Whether these persons are regular utility staff or are temporary staff hired for the duration of the project will be determined by the individual utility.

The Quality Assurance function is explicitly staffed in both the utility and DOC organizations. The overheads applied to the utility staff are provided by PGE. PNL has no information on the detailed makeup of that overhead rate.

008a-40 Comment: Page 3.20, 3.21, 3.22, C.33, C.39, C.35, and C.45: The draft NUREG/CR-5884 cost estimate omitted contaminated electrical components (cable, trays, conduit, panels and breakers). The study assumes that pipe supports are not significant in terms of waste volume. The study also omits some contaminated systems and piping.

Response: An inventory of contaminated electrical systems has been provided by the utility client and has been incorporated into the cost analysis. An effort is in progress to determine the effect on decommissioning cost of omitting the pipe hangers. Some of the system components previously treated as clean have been treated as contaminated in the final analysis.

Comment: The contaminated electrical components included in the Trojan estimate prepared by Portland General Electric represents 77,000 cubic feet of LLW. The insulation on cables in contaminated overhead areas and contaminated electrical motor windings can not be decontaminated. Most of the contaminated systems are safety related. Safety related systems have far more and larger supports, to meet Seismic Category I requirements, than Balance of Plant systems. Large supports also present special rigging and packaging concerns. The linear feet of stainless steel pipe used in the draft NUREG/CR-5884 estimate is approximately 48,000 feet. The linear feet of stainless steel pipe calculated, based on Trojan drawings, is estimated at more than 55,000 ft. Carbon steel pipe used in systems like Instrument and Service Air inside containment is not included. (PGE estimate is 56,000 cubic feet.)

Response: The piping inventory used in the analyses is based on the total amount of pipe purchased when the plant was built, not on scaling from drawings. If significant amounts of pipe have been added to the plant since initial construction, the PNL would not reflect that material. The carbon steel pipe that provides cooling water and return lines for the containment air coolers is included in the contaminated pipe inventory. The estimate of 56,000 cubic feet of the small-size piping that comprised the Instrument and Service Air system inside containment seems extraordinarily high. If it is assumed that most of that pipe is 3/4 inches in diameter and occupies about 12 in^3 per linear ft, then 144 linear ft of pipe will be needed to occupy 1 ft^3, and the 56,000 ft^3 of pipe would be made up of over 8 million linear ft of pipe.

008a-41 Comment: Page 3.59: The final NUREG/CR should base its funding calculations on constant dollars and avoid any economic predictions on discount rate.

Response: The present value analyses are intended to illustrate the potential reduction in the amount that would be required in the decommissioning fund at shutdown because of the distribution of expenditures over an extended time period. The 3% net discount rate postulated represents a reasonable estimate of the historic long-term value. This approach has not yet been accepted by any regulatory agencies as the basis for the funding reserves required to assure decommissioning.

Comment: Requiring 100 percent of the estimate on the last day of operation in constant dollars provides excessive conservatism. This is especially so when a 25 percent contingency is used.

Response: The intent of the funding assurance requirements is to assure that the utility has set aside sufficient funds to decommission the plant. The best time to accumulate these funds is while the plant is operating. Whether this funding requirement is defined in constant dollars or present value dollars makes a significant difference in the up-front funding requirement, especially for the deferred dismantlement alternatives.

Comment: In use, the methodology should accept other time value of money considerations at licensees discretion.

Response: Acceptance of the PV analysis approach by NRC and the Public Utility Commissions as the basis of funding requirements remains to be determined.

Overall, this set of comments seems rather ambivalent regarding the use of PV analyses to define decommissioning funding requirements. Initially, the use of PV analysis is rejected, but finally it is suggested that licensees should be allowed to use PV analyses at their discretion.

008a-42 Comment: C.30: The cost identified for the final survey is underestimated based on actual Table C.4 industry experience. The cost of PGE's Trojan License Termination Survey is consistent with other plants currently prematurely shut down. The cost of the Trojan Licensing Termination Survey is estimated as follows:

Radiation Protection Supervisor	1	$68,000
Radiation Protection Technicians	29	$1,305,000
Craft Labor	20	$1,160,000
Total salary (including payroll burden at 27%)		$2,533,000
Corporate Indirect Costs		$2,500,000
Total annual cost of Licensing Termination Survey		$5,033,000

Duration of Licensing Termination Survey	15 months (1.25 yr)
Total cost of Licensing Termination Survey	$5,033,000 x 1.25 = $6,291,000

Response: The corporate indirect costs are not included in the license termination survey costs because the indirect costs are developed by period and apply to all of the activities that take place during that period.

Another commentor (003-20) has indicated that the license termination survey at Shoreham required about 35 persons for 4 months. Using these values and rationing with the PGE estimates of 50 persons for 15 months, the PGE estimates would become: $2,533,000 x 35/50 x 4/15 = $472,827, which is about 50% of the PNL estimate for direct labor. Thus, it would appear that the PNL estimate is not particularly low. Another industry experience (Pathfinder) had termination survey costs of about $1.25 million.

008a-43 Comment: Page E.20, E.23, E.24, and E.25: Draft NUREG/CR-5884 assumes packing efficiencies of 60-90% for packaging the reactor vessel internals. The NUREG/CR-5884 should recognize decommissioning data now available. During the current removal of reactor vessel internals at a prematurely shut down plant, the packing efficiency achieved is between 30% and 35%. In the case of the reactor vessel, the draft NUREG estimate for removal and burial is $1.2 million versus $10.7 million in the PGE estimate. Adjusting the draft NUREG/CR-5884 estimate for the Trojan packing factors of 25% and greater than Class C burial rates gives a cost of $13.3 million.

Response: The packaging efficiencies are a function of the cutting patterns. The cutting patterns postulated by PNL are explicitly presented in the report. PNL cannot respond to statements regarding other estimates when the bases and details of those estimates are not made available for examination.

RESPONSES TO COMMENTOR 010

010-1 Comment: The report does not provide a cautionary statement regarding its use. Such a cautionary statement should be included in the executive summary and at the beginning of the report. The statement should make the following two points:

- The report is to be used as a guide and not as a "benchmark" for estimating the decommissioning costs associated with other facility.
- The conclusion and decommissioning costs reported in NUREG/CR-5884 are specific to the reference PWR for the scenarios analyzed. They do not represent the conclusions and decommissioning costs which have been or could be obtained for a real facility, including the Trojan Plant, which serves as the model for the reference PWR.

Decommissioning strategies and their attendant costs require many assumptions and input parameters each of which have greatly varying levels of uncertainty. Additionally, each nuclear facility represents a unique situation with respect to size, location, single vs multi-unit site, years of operation, corporate structure, etc. Thus, the report should be considered only as a guide and its conclusions and decommissioning costs limited only to the special case that it represents.

Response: Statements have been added to the executive summary and the report proper that remind the reader that the results are specific to the scenarios and assumptions used in the analyses, and other plants, scenarios, and assumptions could lead to different results.

010-2 Comment: The basic underlying assumptions for dismantling are not clearly stated in the report. The use of crew-hours as a resource measure is confusing and misleading. Shift length, shifts per workday, workdays per week need to be clearly stated in the beginning of the report. For example, the report has decommissioning activities which rely on three shift operation, such as internals removal. Obviously, the work philosophy/strategy directly affects period dependent costs and may affect activity dependent costs as pointed out below.

Response: A statement has been inserted to clearly indicate that unless otherwise stated, all of the decommissioning operations are carried out on an 8 hour per shift, 2 shifts per day, 5 days per week basis. The internals cutting operations are on 2 shifts, with movement of packaged wastes from the work areas to the storage or shipping point handled on the 3rd shift. Continuous operations such as deboration of RCS water, chemical decontamination of the RCS, treatment of contaminated water, are carried out on 3 shifts. PNL agrees that the duration of the D&D activities affects the period-dependent costs, and therefore suggests that working 2 shifts per day will significantly reduce those period-dependent costs.

010-3 Comment: Reactor vessel internals removal is presented as a three shift operation, with two cutting crews on two shifts and packaging and disposal occurring on the third. This may be too optimistic. The assumption that four cutting-crew's worth of disposal can be accomplished on the backshift appears to be overly optimistic. In this regard, cask availability, which is a determining factor, is not even addressed. Additionally, although there is sufficient room available for two cutting operations at the reference

PWR, this may not be the case at other facilities. Our decommissioning experience makes us question the practicality of running simultaneous cutting operations.

Response: This approach may be too optimistic for facilities that have very limited space. In the reference PWR, space appears adequate to permit this approach. Reducing the cutting operations to a single shift would not affect the direct labor cost for the cutting, but could influence the duration of the period, and hence the period-dependent costs.

010-4 Comment: Period 2, Reactor Deactivation For Safe Storage, includes overlapping activity sequences and aggressive activity durations. Reactor defueling, followed by the simultaneous processing of reactor coolant system (RCS) water, performing an RCS chemical decontamination, performing systems layup, and preparing for and segmenting reactor core internals in the refueling cavity, all within a 32 week timeframe, is considered extremely optimistic. This duration compares with more than 32 weeks currently projected for the segmentation and disposal of the Yankee core internals, which are smaller than Trojan's. We seriously question the ability to perform many of these activities in parallel. The report needs to better explain the sequence of these activities.

Response: The schedule and durations of the tasks represent the best judgement of the PNL analysts, and are based on detailed analyses of the individual tasks. Review of the schedule of activities given in Figure 3.3 shows that the periods of overlap are given to mobilization/demobilization, setup and testing, and cleanup and removal of the special systems and equipment used in the tasks. Without any knowledge of the circumstances at Yankee-Rowe, PNL cannot respond to the comment regarding the duration of cutting operations at Yankee-Rowe.

010-5 Comment: Assumptions used in the development of unit cost factors may be unrealistic. For example, the unit costs factors for pipe removal were developed on the basis of removing 15-foot lengths of pipe per cut. This appears to be extremely unrealistic. Using this value, the number of piping cuts required will be significantly underestimated. Moreover, use of the 15-foot value in the report gives a false impression that it is readily achievable. It would be better to base piping removal costs on the 5-foot value and achieving an average cut longer than that would result in a cost savings. Additionally, consider the handling requirement differences between a 5 and 15-foot section of pipe. A 24" Schedule 160 pipe weighs 542 lbs/ft. It is much easier to handle and maneuver a 5-foot piece weighing 2700 lbs as opposed to a 15-foot piece weighing 8100 lbs. To assume pipe removal costs based on a 15-foot length cut may not be appropriate.

Response: The 15-ft segments of piping are based on the assumption that packaging is in maritime containers. Admittedly, there will be instances where a 15-ft cut is not feasible. The handling operation for a segment of pipe is essentially the same regardless of weight once the segment weight exceeds 70-100 lb. The piping removal costs are bounded by the 5-ft and 15-ft segments considered in the sensitivity analyses, with the difference in direct labor cost being about $5 million.

010-6 Comment: The reported cost for reactor internals removal is $395,187, and $109,756 for reactor pressure vessel removal (1993 $, excluding contingency), as presented in Volume 2, Table C.1. This compares with Yankee decommissioning cost estimates of $1,434,000 and $3,207,000 (1992 $, excluding contingency), for the same activities conducted in the same relative timeframe after final plant shutdown. (Based on an order of magnitude comparison, one would expect the reactor vessel removal cost to be at least comparable to or higher than the cost of steam generator removal. Table C.1 presents direct removal costs for steam generators as $4,790,297, or approximately $1.2 Million per generator. Compared to this estimate, the $109,756 estimate for reactor vessel removal appears unrealistic).

Response: The analyses leading to the cost estimate for RPV removal are presented in detail in Appendix E, for the reader's inspection. These results are the best judgement of the PNL analysts. PNL cannot respond to statements regarding the YAEC estimates for their RPV removal, since the bases and detailed analyses for those estimates are not available for review.

010-7 Comment: Removal of contaminated or noncontaminated asbestos to access contaminated systems can be a significant decommissioning cost. The report assumes an insignificant amount of asbestos is present in the reference plant at the time of decommissioning. This assumption cannot be generally applied even with the asbestos removal programs in place today. Other hazardous materials exist which need to have their removal cost properly characterized (e.g., chromates, PCBs, lead, etc.)

Response: The costs for removal and disposal of asbestos have been included in the final analysis, based on information provided by PGE regarding the quantity, location, and nature of the asbestos. No estimates were made regarding the removal and storage of mixed wastes.

010-8 Comment: The handling of SNF appears to be reasonable. However, it needs to be strongly emphasized that no progress has been made by DOE in siting an MRS and that the linkage of MRS operation to the repository still exists. This makes acceptance of SNF by DOE in 1998 improbable and even casts doubt on the acceptance of reference PWR SNF in CY-2002.

Response: The assumptions that the reference PWR operated until the end of its licensed life, and the postulated inventories resulting from those operations were made so that the study analyses would better represent a full-term reactor life, and not be limited to the specific situation at TROJAN. The assumptions regarding the DOE schedule for acceptance of SNF were used to have a consistent basis for the SNF characteristics and inventory. Aside from the cooling time of 7 years calculated for the hottest assemblies from the final core discharge, which defined the duration of Period 3, these assumptions have no impact on the cost estimates.

010-9 Comment: The report should only be based on constant dollars and refrain from any economic predictions. This will preclude economic predictions from skewing report results and making one decommissioning scenario look financially better than another. Users of the report can then better evaluate the economic impact of the published decommissioning scenarios. Since economic and financial considerations will vary from utility to utility, any cost estimating approach other than "constant dollar methodology" will only serve to complicate the analysis.

Response: The present value analyses were intended to illustrate the effect of delayed expenditures on the total funding needed at the outset of decommissioning. Because both the constant dollar estimates and the present value estimates are presented in the results, the reader has the opportunity to take his choice, or to do his own analysis, using whichever approach is most satisfactory to him.

010-10 Comment: The report's assessment of the impact of the time value of money is misleading (Sections 3.5.2 and D.4..3);

First, use of the net discount rate (interest - inflation) is inappropriate for assessing decommissioning fund requirements (especially in Section 3.5.2). The net earnings rate (fund earnings rate - average decommissioning cost escalation rate) must be used in present value determinations. This is extremely important because decommissioning costs do not necessarily escalate with inflation but escalate according to the cost escalation experienced by each decommissioning cost component: energy, labor, material, LLW burial, etc..

Response: The 3% net discount rate was selected as representative of the long-term value. PNL agrees that the net discount rate achievable by any given utility may vary significantly from 3%, either up or down, and the careful attention needs to be paid to the true net discount rate for the individual utility in any site-specific analyses.

Comment: Second, assuming a 3% net earnings rate differential (see above definition) is unrealistic given the escalation in decommissioning costs, especially LLW burial costs. A net earnings rate of 1% or less may be more appropriate, however, it is very possible to have a Negative earnings rate differential which means fund contributions would have to Increase to cover decommissioning cost escalation.

Additionally, utilities under FERC jurisdiction can only invest decommissioning funds in a limited number of secure investment vehicles whose earnings are only slightly above inflation (and most likely less than the decommissioning cost escalation rate). For these utilities, it may be necessary to plan on a negative earnings rate differential versus the decommissioning cost escalation rate.

Response: PNL agrees that the 3% net discount rate may be unrealistic for any specific utility. The PV analyses were intended for illustration of the potential impact of delayed expenditures on the total funding needs. Obviously, the escalation of LLW disposal rates is entirely outside normal experience, and must be followed closely. An ongoing analysis would be appropriate to determine the net discount rates over time to assure that adequate funding is set aside.

Comment: Because of the above factors, the difference in total cost of decommissioning determined by the present value method, $101.6 Million, and the constant dollar method, $124.6 Million, really does not exist. Stating that funding based on the constant dollar method results in a 22% overestimate of funding needs for DECON and provides a significant safety margin may be overly optimistic.

Response: The difference between the constant dollar and the present value estimates may or may not exist, depending upon the real net discount rate effective over the time period under consideration. However, if the net discount rate is positive, using the constant dollar estimate will result in an additional contingency on the estimate. The margin predicted by the 3% value may well be optimistic.

Comment: Use of the net discount rate in Section D.4.3 for determining the life cycle costs associated with SNF storage options may be appropriate if the cost components for SNF storage options track with inflation. However, using a value of 3% for the net discount rate may be too optimistic for reasons stated above.

Response: Labor and materials generally track inflation. The appropriate value of the net discount rate for any given utility will be specific to that utility and its circumstances. The text was revised to suggest caution when considering present value analyses.

Comment: The conclusion given in the Executive Summary and in Section 6 that SAFSTOR is less expensive than the DECON alternative based on present value is misleading because of the unrealistic differential earnings rate used in the analysis (i.e., 3% net discount rate). Given the above arguments supporting little, if any, differential earnings, the DECON option becomes much more attractive. This is because DECON minimizes the length of decommissioning and affords utilities a measure of protection against rampant escalation of decommissioning costs.

Response: The reader must remember that the PV analyses were intended as an illustration of the possible impact on the amount of funding needed at shutdown to assure decommissioning, not as an absolute basis for selecting the funding amount. As long as the net discount rate is positive, using the constant dollar estimate will provide an additional contingency on the decommissioning cost.

010-11 Comment: The subject report also raises the issue of whether costs associated with the storage of spent fuel after final shutdown are operating or decommissioning expenses. The report incorporates only 10% of these costs in the decommissioning estimates. 10 CFR 50.54(bb) states that each licensee is responsible "to manage and provide funding for the management of all irradiated fuel at the reactor upon expiration of the reactor operating license 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." Accordingly, it is YAEC's position that all costs associated with the on-site storage of spent fuel, until possession of the fuel is transferred to the Secretary of Energy for its ultimate disposal in a repository, are legitimate decommissioning expenses which should appropriately be included in decommissioning cost estimates. This approach establishes a basis for each licensee to establish a decommissioning strategy and cost estimate which incorporates all site-specific, post-shutdown activities into one integrated plan.

Response: PNL does not necessarily disagree with the above position. However, the current NRC policy does not consider SNF storage costs as decommissioning costs.

010-12 Comment: Tables 3.2 and 3.3 give the estimated utility and Decommissioning Operations. Contractor (DOC) staffing requirements for DECON in terms of person-years per period which is used to arrive at staffing costs. However, the term does not readily convey actual staffing requirements. For example, Table 3.2 requires 112 persons-years of utility staffing for Period 2 which translates into 182 persons (112 person-years divided by a period length of 0.62 years). These tables should readily reflect the <u>total staff</u> required during any given period and not just the integrated person-years which, when given by itself, can be misleading.

Response: The postulated makeup and levels of staffing for the various periods are presented in detail in the figures (3.2, 3.4, 3.5, 3.6). Those same staffing levels can be derived from Table 3.2 by dividing the total person-years per period by the length of the period.

010-13 Comment: There are no DOC staffing requirements listed in Table 3.3 for DECON Period 2 during which three major decommissioning activities are taking place: chemical decontamination, internals segmentation, and systems deactivation. This is a highly unrealistic assumption, especially when considering the fact that only 3 equivalent utility people have been assisting 19 DOC staff in DECON Period 1 preparing for these activities. Even though specialty contractors are involved, it is Yankee's experience that a significant amount of DOC staff is required to assist DECON Period 2 activities. An implicit (and very unrealistic assumption embedded here is that uninvolved utility staff can just turn into decommissioning "gear" during Period 2 without any involvement in Period 1 preparation activities.

Response: The DOC effort in Period 1 is focused on developing the detailed work plans and schedules for the total task, i.e., work packages that could be put out for bid by subcontractors, and require only limited utility oversight.

The activities that occur in Period 2 are closely related to normal operational activities, and can best be handled by the utility staff, assisted by some specialty contractors.

The work packages prepared in Period 1 for use in Period 2 activities are developed based on information from plant operating procedures, where possible, and with consultation with utility staff when necessary. Because the plant operations staff are most familiar with the plant operating systems, they are best qualified to perform certain tasks and to oversee the specialty contractor efforts in Period 2, especially since many of these operations may have to be performed under the plant operating specifications, as modified for post-shutdown conditions.

010-14 Comment: The duration of DECON Period 3 is 6.3 years. The report assumes that the DOC staff in place at the end of Period 1 simply restarts activities 6-months prior to the end of Period 3 to begin preparation for dismantlement activities in DECON Period 4. This start-up time seems to be insufficient. Consider the following: (1) magnitude of Period 4 activities, (2) the DOC has not been active for 5.8 years, (3) the Period 4 DOC may not be the same contractor as the Period 1 DOC, and (4) even if the DOC is the same contractor, the staff may be entirely different. Additionally, decommissioning status and available activity options could change dramatically over the Period 3 time period, necessitating a thorough review of planned activities. This plus the previously mentioned factors would support restarting DOC activities much earlier in Period 3 than assumed in the report.

Response: PNL disagrees. If the DOC effort in Period 1 was properly done, with adequate plans, schedules, work packages, and work procedures prepared and documented, a relatively short (6 months) should be adequate to review those documents and amend any that need revision due to conditions being different than envisioned during the Period 1 effort. Obviously, if major changes had occurred to the plant status conditions postulated during the Period 1 analyses, more time would be required. However, it would be difficult to quantify the additional time required without knowing what the changes were. The assumption made was that no significant changes had occurred.

010-15 Comment: The staffing levels for all DECON periods appear to be low when compared to recent decommissioning experience. DOC plus utility staff levels for Periods 1-5 are 22, 180, 5, 22, and 85 respectively. Although the decommissioning schedule is different from the Yankee schedule, the report's assumed staffing levels are low when compared against Yankee staffing estimates for periods with comparable activities.

For instance, the DOC plus utility staff level assumed in the report during Period 4 (when a majority of plant dismantlement occurs) is about one-half that assumed for Yankee Rowe, a plant that is approximately 1/5th the megawatt rating of the reference plant. Scaling on the basis of size may result in overestimating actual staffing requirements. However, one would expect, at a minimum, a comparable staffing level.

Response: The staffing levels indicated for the utility and DOC are for indirect labor only. The direct labor staffing is provided by subcontractors, and are costed using the unit cost factor approach. PNL has no knowledge regarding whether or not the YAEC estimates incorporate the subcontractor direct labor staffing into their staffing estimates, and thus cannot respond to the allegation that the PNL estimates of staffing are too low.

010-16 Comment: DECON Period 1 costs are not fully explained in Section 3.1. The total cost for DECON Period 1 given in Table 3.1 is estimated at $9 Million. DOC and utility staff costs account for $5.4 Million while the balance ($3.6 Million) is not explained. Table C.1 reports this balance as being distributed between regulatory costs ($0.4 Million) and special tools and equipment ($3.2 Million). The line items comprising the balance of DECON Period 1 costs are not identified nor is any explanation of these costs given in the report.

Response: Text has been added to identify special equipment purchases of $3.2 million and regulatory activity costs of $0.4 million in support of the decommissioning plan, preparations for shutdown, and post-shutdown specification changes.

010-17 Comment: The overhead rate (42%) applied to utility salaries appears to be low. Overhead rates for utility staffs are dependent on many variables and should be determined on a case by case basis. Smaller, single asset companies may need to absorb a higher percentage of corporate indirect overhead costs than would a larger utility with many units. It would be beneficial for the report to include a listing of the components which comprise the overhead rate in order to clarify what is and what is not included in the 42%.

Response: The salary and overhead rates for the utility staff were provided by PGE. PNL has no direct knowledge of the various elements that make up the overhead rates.

010-18 Comment: There is no consideration given nor discussion provided on the impact these storage alternatives have on the overall decommissioning schedule and cost. Comparing only their life cycle costs fails to capture the impact on decommissioning schedule and cost. [For example: What is the overall strategy with keeping the pool running? Does the report assume decommissioning around the pool, release the balance of the site, and decommission the pool once all the SNF is gone? Or does the report assume that the SAFSTOR period simply gets extended? The overall strategy has a significant impact on the cost of decommissioning with either the pool or ISFSI option.]

Response: The assumption was made that the utility would want to remove and dispose of the plant as quickly as SNF cooling considerations would permit, which dictated the 7-year cooling period. This approach required the development of an onsite ISFSI for storage of the remaining SNF inventory, because the NRC's position at that time that disassembly and removal of the plant systems other than the SNF pool systems was not an acceptable approach. Due to a mistake in the expected inventory in the pool after 7 years, the ISFSI inventory of casks was much larger than was really required, thus increasing the initial capital cost of the ISFSI. Upon correction of the inventory error, the cumulative present value cost of SNF pool operations remains less than the cumulative present value cost of ISFSI operations until about 16 years after reactor shutdown, by which time the pool would have been emptied by DOE acceptance. Thus, building an ISFSI would maximize SNF storage costs and would provide little incentive to construct an ISFSI. On the other hand, there would be continuing SAFSTOR costs of about $1 million annually (constant dollars) for keeping the plant in safe storage while the pool was operating, so there might be a small net reduction of total cost (D&D +SNF storage) by building an ISFSI and removing the SNF from the pool after 7 years.

Comment: The report states (page D.2) that the minimum period for pool operation without an ISFSI is 14 years. Based on Table D.2 data, this 14-year minimum period is contingent on 193 SNF assemblies being removed in CY2029, the final year of pool operation. This will require "earlier" removal of the last of the reference plant's SNF by DOE. We fully support DOE giving priority to removal of SNF at shutdown facilities. It can be done without compromising SNF removal at other facilities.

Response: A statement was added to the effect that it is assumed PGE is successful in executing enough exchange agreements to permit shipping the final 193 assemblies in the 14th year.

Comment: Assumptions used in the economic analysis presented in Section D.4.3 comparing the life cycle costs of the two SNF storage alternatives appear structured to favor keeping the spent fuel pool operational.

Response: All other considerations being equal, economics would suggest that keeping the pool open until the total inventory has been accepted by DOE is the least expensive choice. Other considerations, such as waste disposal escalation, might encourage earlier dismantlement.

Comment: It may not be correct to assume that the cost of deactivating and decommissioning the spent fuel pool after all the SNF is removed (CY2029) will be the same cost incurred during normal decommissioning. A significant penalty may be incurred due to the restart of decommissioning activities (i.e., a second set of mobilization and demobilization costs).

Response: A significant penalty is unlikely. Layup of the pool systems is one of the first major activities in Period 4. The pool must be drained and decontaminated regardless of which decommissioning alternative is selected. For SAFSTOR, the operating staff onsite at the end of Period 3 should be adequate to supervise the efforts of the appropriate contractors. In the case of DECON, the whole DOC team in onsite.

Comment: No consideration is given nor discussion provided on the impact of having to decommission "around" the spent fuel pool if it is left operational until CY2029. There will be constraints on decommissioning activities which will add to the cost of this alternative.

Response: NRC directed PNL <u>not</u> to consider decommissioning "around" the pool, due to possible legal difficulties. Thus, no analysis of a scenario wherein the plant systems not associated with the pool were deactivated and disassembled prior to deactivation of the pool was performed.

Comment: There is no basis given for the estimated $0.5 Million cost of separating spent fuel pool systems for the balance of the plant. This estimate appears to be very unreaListic. Having examined this option for Yankee (i e., creating a spent fuel pool island separate from the rest of the plant), it appears that this estimate could be low by an order of magnitude! [One item for consideration is the licensing cost associated with separating the spent fuel pool and related systems and securing a Part 70 license However, this is not necessary until the Part 50 license is relinquished.]

Response: That estimate was predicated upon the balance of the plant remaining intact until the pool had been emptied. Thus, no major system revisions were assumed, just deactivation of those systems not utilized by the pool.

Comment: It is not always clear in Section 1).4.3 as to whether the dollar amounts reported are constant value, present value, or future value, especially in the discussion presented on pages D.18 and D.19. As recommended in a previous comment, all costs should be reported in current year (1993) dollars.

Response: This problem was overcome by adding "(1993 $)" to the various statement, where appropriate.

Comment: As mentioned m a previous comment, use of the net discount rate in the economic analysis is misleading. It is really the differential earnings rate (earnings-escalation) that should be used. The 3% value assumed in the present value calculations is overly optimistic. Additionally, each option may have its own differential earnings rate based on how the cost of the option escalates.

Response: As defined in the study, the net discount rate was exactly as suggested above, i.e., (earning rate - escalation rate). PNL agrees that applying a fixed net discount rate over a long period of time is speculative. However, the analysis does provide some insight into the possible effects on the level of funding needed in the decommissioning fund when the time-distribution of expenditures is considered.

Comment: The cost of SNF storage casks appears to be much higher than expected: $0.714 Million per cask ($35 Million/49 casks). A unit cost in the range of $300K-$400K per cask would appear more reasonable. This would reduce the cost of this option by about $15-$20 Million. [Note: it is not clear if cask unit cost is based on future or present value. If it is a future value number, then the unit cost per cask in present value dollars in about $0.581 Million. This would still represent a cost reduction in the range of $9-$14 Million for the option.]

Response: The cost of storage casks was taken from the DOE's Final Version Dry Cask Storage Study. There was an error in the original PNL analysis regarding the number of assemblies that would require dry storage which, when corrected, reduced the cask costs to about $17 million in 1993 dollars, for 24 casks. If appropriate storage casks can be obtained for $300K- $400K each, then the cask cost would indeed be reduced by about 50%, and the reduced early cost would tend to favor the use of an ISFSI over the pool, with the breakeven point occurring around 10 years after reactor shutdown.

Comment: Additionally, the $65/MTU or $35 million cost for the dry casks provided on page D.19 is inconsistent with the figures quoted in the 1989 Dry Cask Storage Study which was used as a reference. The costs cited in this Study were $45-$65/Kg for a 100 MTU facility and $40-$55/Kg for a 1000 MTU facility. The reference facility is about 500 MTU. The value used in the report appears to be much too conservative and the use of a lower value could be substantiated.

Response: The inventory originally used in the analysis was incorrect and should have been 263 MTU instead of 541 MTU. The correct value is closer to 100 MTU than to 1000 MTU, thus the higher end of the cost range was used.

Comment: The estimated cost of $5 Million for the ISFSI's concrete storage pad and related equipment appears to be quite high. Conversely, the labor cost for removing SNF from the pool appears to be low by a factor of three. Furthermore, the cost to decommission the ISFSI is much higher than expected: $4 MilLion in year 15 or $2 6 Million in present value dollars. All that will be left of the ISFSI after all SNF is removed is the concrete pad, the surrounding fence, and transfer equipment (assuming DOE takes the concrete casks). Thus, the cost of decommissioning the ISFSI should be nominal (under $500K).

Response: The ISFSI costs included the pad, roadways, fences, and handling equipment, in addition to the casks. The analysis assumed a cask could be loaded and prepared for the ISFSI in 3 days, for a campaign duration of about 72 days on a single shift basis. D&D cost for the ISFSI was postulated to be 10% of the capital cost, including the casks. Depending upon the cask design, those costs might be high or low. Certainly if the ISFSI used multi-purpose canisters as presently conceived, the D&D of the casks would be minimal, and the principal cost would be the removal of the pad, fences, and roadways. There is no assurance that DOE will accept the whole cask, especially the concrete casks which cannot be shipped intact.

Comment: There is no line item representing real estate taxes in Table D.4, "Estimated SNF Storage Operational Costs at the Reference PWR." Although real estate taxes for the spent fuel pool and ISFSI will be similar, they should be included for completeness.

Response: That entry was inadvertently omitted from the table, and is now included.

Comment: The report states, in the first paragraph on page D.1, that transfer to a dry ISFSI is constrained by allowable fuel cladding temperatures which necessitates an extended cooling period in water prior to transfer into dry storage. The report fails to mention that the transfer of SNF to a dry ISFSI is also constrained by the heat removal capability of the dry cask storage system. Furthermore, in the discussion on page D.21, thermal data for the assumed storage system was not discussed or mentioned. Proper matching of SNF heat load to dry cask heat removal capability in, the real issue. Given the design constraints of cask heat removal capability, SNF burn-up/power density, number of SNF assemblies loaded, total heat load, and temperature limits, cask loading requirements should be readily determined. On this basis, it should be possible to transfer SNF to dry cask storage in a much shorter time frame than the 7-years cited in the report. Additionally, many of the currently licensed dry storage systems are licensed for S yea.r cooled fuel. However, they are also licensed for maximum burnups in the 35-40,000 MWD/MTU range.

Response: The allowable cladding temperature for dry storage of SNF is independent of the heat transfer capability of the cask. However, the duration of wet cooling required before placement into dry storage is strongly dependent upon the heat transfer capability of the cask. In this analysis, the heat transfer capabilities of 3 different metal casks were used. If detailed COBRA-SFS (or equivalent) analyses showed that some different casks had significantly higher heat removal capability, thereby lowering the cladding temperatures of the contained SNF assemblies, then the cooling time in the pool could be shorter. Similarly, partial loading into a cask should also permit a somewhat shorter cooling time, but the same detailed calculations would be needed to demonstrate that the cladding limits were satisfied.

Comment: The conclusion at the end of Section D.S, page D.26, D.26 is that the spent fuel pool could not be emptied until at least 7 years following shutdown. However, no consideration has been given either to mixing SNF or partially filled casks as a way to reduce the time SNF remains in the spent fuel pool, It should be possible to license either a mix and match arrangement (older SNF with newer SNF) or derated casks (i.e., loading fewer assemblies) so long as the heat removal capability of the dry storage cask is not exceeded.

Response: See previous response. The 7-year cooling period was chosen as a bounding case. With sufficient analysis to demonstrate satisfying the cladding temperature limits, shorter cooling times could probably be permitted.

Comment: Appendix D basically concludes that it is more cost effective to store SNF in the pool than to build a dry ISFSI. Yet the report assumes an ISFSI is built in CY2022. This is confusing. If the conclusion is valid, shouldn't the report follow its own conclusions and begin dismantling once all SNF would be removed from the pool (i.e., CY2029)?

Response: The scenario agreed upon for DECON required that decontamination and disassembly be accomplished as early as possible, thus requiring an ISFSI. As discussed in an earlier response, with the corrected inventory values the breakeven point for ISFSI storage occurs at about 16 years after reactor shutdown. If DOE could accept all of the SNF by or before that time, it would be more cost-effective to continue to store the SNF in the pool. However, since these costs are not considered by NRC to be decommissioning costs, whichever approach is taken for SNF storage would effect only the on-going costs for the plant safe storage operations which are carried on in parallel with the SNF storage operations.

Comment: Figure D.2, which compares the present value cost of the pool option vs. the ISFSI option, does not present a valid comparison. First, the use of the 3% discount rate distorts the comparison. Second, the assumptions favored the pool option more than the ISFSI option. Third, and most importantly, the comparison does not address the impact on the overall decommissioning cost and schedule.

Response: The revised Figure D.2 illustrates the cumulative present values of the costs for SNF storage, using either the pool-only approach or the pool + ISFSI approach. The net result of the analysis would tend to favor pool-only storage for the first 16 years. If the inventory remains greater than zero beyond 16 years, the ISFSI approach becomes more cost-effective. The estimated annual cost for safe storage operations during the pool storage period are about $936 K in constant 1993 dollars. Thus, the D&D costs would increase by that amount for every year that the pool remained in service.

Comment: The document should also consider the effect of the Multi-Purpose Canister System on decommissioning cost or at least recognize that it's implementation may affect such costs.

Response: The SNF storage analysis was intended to be informational only, since NRC does not include those costs as a D&D cost. Thus, there was no justification for examining a wide range of possible SNF storage scenarios for their impacts on D&D costs. If DOE provides the MPCs, then the utility's cost for the ISFSI would probably be significantly smaller.

Comment: D.29 Paragraph following the three "bullets": Pacific Nuclear is in the process of licensing a cask to contain a leaking canister. The same cask is being licensed for transport.

Response: Until the cask is licensed, the statement is true.

010-19 Comment: The systems identified in the study for complete or partial removal comprise fewer systems and at a far lower cost than those identified for Yankee Nuclear Power Station. Actual radiological characterization data from Yankee indicates that many other systems, not listed in the study, will need to be decontaminated. Some of these systems include Feedwater inside containment, Purification, Primary Plant Sampling, Primary Plant Vent and Drain, Fuel Handling, steam generator blowdown, and Containment Heating and Cooling, to name a few. As a result, the total cost for removal and disposal of contaminated systems at Yankee has been estimated to be more than $25 Million compared to the study estimate of approximately $5 Million.

Response: Additional systems proposed as contaminated by TLG Engineering, Inc. have been incorporated into the final analyses. Without access to the details of the YAEC data and analyses, PNL cannot respond to the comment regarding removal and disposal costs being $25 million rather than $6 million as in the PNL analyses. If all of the decontamination/removal/disposal operations in the PNL analyses are included, the estimated cost is about $31 million.

010-20 Comment: No effort was made in the study to quantify the number and characteristics of pipe hangers, under the assumption that most of the hangers are sufficiently small that they can be placed in the piping containers without further consideration. Yankee has estimated approximately 2500 small bore and 800 large bore pipe hangers as part of its preliminary contaminated equipment inventory. These quantities of pipe hangers represent a significant work effort and waste volume and, therefore, warrant a more rigorous cost engineering assessment than that contained in the study.

Response: Detailed information was not available to PNL on the pipe hangers at the time of the analysis. However, information has been recently obtained from PGE and an effort is planned to evaluate the magnitude of this omission.

RESPONSES TO COMMENTOR 012

012-1 Comment: Westinghouse takes issue with the assumptions regarding fuel costs. The draft report correctly recognizes that licensees will have to store spent fuel and may have to continue operating a dry storage facility beyond the time when the nuclear license is terminated. However, the assumption in Section 2.3 that 90 percent of total plant costs should be allocated to fuel storage .. operations and only 10 percent to plant decommissioning activities does not agree with our knowledge during any phase of decommissioning activities. Our experience indicates the staff required to maintain the ISFSI is insignificant compared to the staff levels required for decommissioning planning and oversight activities.

Our experience is primarily with early dismantlement activities, but many of the same plant activities would be required to prepare plant systems and equipment for an extended safe storage period, and this effort should not be underestimated. During active dismantlement and SAFSTOR preparatory activities, it would be more consistent with our experience to allocate 75 percent of the total costs to decommissioning activities and 25 percent to fuel storage. If only general plant maintenance and fuel storage activities are in progress, an even division of costs would seem appropriate.

Response: The 90% - 10% split assumption applies only during the initial safe storage period, Period 3, when the plant (except for the SNF pool systems) has been deactivated. The safe storage preparatory activities occur during Period 2, and the active dismantlement activities occur during Period 4. There is no ISFSI in place at this time. The safe storage operations are limited to surveillance and maintenance, with the bulk of the activities being carried out related to the SNF storage operations. The same staff performs both activities. The SNF operations include not only pool maintenance and surveillance, but also includes active fuel out-loading operations since DOE is postulated to be accepting fuel throughout that period, plus the eventual out-loading to the ISFSI. Thus, these activities are postulated to comprise 90% of the total staff activities during that safe storage period.

012-2 Comment: Westinghouse believes that scenario assumptions of radioactivity levels that are based only on cobalt-60, as in the SAFSTOR1, ENTOMB1, and ENTOMB2 alternatives, are hypothetical and misleading. Our experience is that there are many activated impurities in concrete and other structural materials that will still be around after cobalt-60 levels have substantially decayed. Examples such as Ni-59 and Ni-63 have extremely long half lives which will impact removal and disposal methods. Some vessel internals will still be greater than Class C waste. There are enough of these long-lived nuclides that dismantlement activities will still require remote tooling and access controls after the allowed SAFSTOR period, and the radioactive waste volumes will not be significantly reduced.

Response: The analyses of activated concrete developed in the original PWR D&D study (NUREG/CR-0130) showed the dominant species after 10 years were Fe-53, Ni-63, and Co-60, with only the Co-60 producing any significant worker dose. The activity levels were too small to be GTCC material, so the material could be disposed as LLW.

The vessel internals are postulated to be removed during Period 2 and segmented and packaged to facilitate disposal as GTCC material. Those dismantlement, segmentation, and packaging activities were postulated to be carried out under water within the confines of the RPV and in the refueling pool, using remotely operated equipment. Their volumes were minimized by careful cutting and packaging. See the discussions in Appendix E.

012-3 Comment: The contractor staff levels based on crew hours per task, as shown on the summary schedules and staffing charts in Figures 3.7, 3.8, and 3.9, is confusing and misleading. For example, project staffing illustrated in Figure 3.9 reflects as assumption that crew sizes will vary widely over the project, to a degree which is not realistic. This figure shows staffing levels that fluctuate up and down every month by up to 900 crew hours. In reality, staffing levels will be more stable and prudent planning would levelize work activities. The driver for this includes training time for badging, qualification, etc. and learning curve. However, even with the best planning, there will be times when work crews are not fully utilized and the associated costs will be higher than those assumed for the rapidly variable crew sizes shown in Figure 3.9.

Response: The staffing levels in Figure 3.9 were derived by calculating the staff requirements task by task and manually arranging the task sequences to 1) be logical and 2) to levelize the numbers of staff on site over time. The staffing shown are for the direct labor of the subcontractors and do not include any of the utility or DOC staff. Thus, as the tasks change, the numbers of subcontractor staff onsite would change. It would be useful for future D&D analyses if information generated during actual D&D projects were collected on matters such as these to provide bases for adjusting for the anticipated staff non-productive time that is not accounted for within the Unit Cost Factors.

012-4 Comment: The staffing shown in Table 3.2 includes fractional utility staff levels that vary from Periods 2 (Deactivation) to 3 (Safe Storage) to 4 (Dismantlement) in a manner that is confusing and misleading. Also, in several operations and engineering positions, personnel are assumed to disappear for a period and then reappear. Depending on the length of the SAFSTOR period, this may not be realistic. Utilities may elect to retain qualified individuals through active dismantlement, thus increasing costs for Period 3.

Response: The utility and DOC staffing presented in the staffing diagrams for the various periods are PNL's best judgement as to what is needed and when, with the intent to <u>not</u> retain unneeded staff during inactive periods such as Period 3. How the utility may choose to handle the staffing question is, of course, their prerogative.

012-5 Comment: The component removal and dismantlement periods appear to be short by a factor of 2 or 3. Dismantlement is assumed to be completed within 1.7 years, where at Fort St. Vrain, these activities are expected to take 3.25 years. PWR's and BWR's would be expected to be even longer with more contaminated areas.

Response: It must be remembered that some significant efforts were completed during Period 2, e.g., removal and packaging of the RPV internals, and RCS water cleanup and disposal, which would otherwise extend the active dismantlement period. Also, the D&D activities were postulated to be carried out on a 2 shifts per day, 5 days per week schedule, thereby shortening the overall calendar duration of those efforts.

012-6 Comment: The presentation of costs in the executive summary table, Table ES.1, is misleading, in that costs are based on an unrealistically low disposal cost. The basis for the summary table is $50 per cubic foot. This number clearly does not account for taxes, surcharges, and other fees. In addition with this being such a volatile area it would not be prudent to assume this number to low.

Response: The bases for disposal costs are the published charge schedules provided by U.S. Ecology at the Hanford site and by Chem-Nuclear at the Barnwell site. These schedules include all applicable taxes, surcharges, and other fees. PNL agrees that disposal site charge rates are volatile. However, the Barnwell rates do appear to be a reasonable surrogate for LLW disposal sites that may come on-line in the future.

012-7 Comment: The final site survey cost estimate of $1.2 million, in Section 3.4.12, is significantly low. Even for Fort St. Vrain, which is significantly cleaner than most PWR's and BWR's, this survey is projected in the range of $5 million to $10 million, and Shoreham's latest estimate is reportedly in the range of $10 million to $12 million. There are still a lot of unknowns about the extent of this process, including the treatment of hard to detect nuclides which is not mentioned in the draft report. However, it appears impossible to perform this task for $1.2 million.

Response: The analysis was based on the protocols and procedures in NUREG/CR-5849, which was prepared by persons who perform site termination surveys for a living. Also, the cost for the termination survey at Pathfinder was in the same range. PNL agrees that there are still a number of areas needing clarification regarding the depth of detail and analysis to which the surveys must be carried out, and that until more experience and data are available, the survey costs are somewhat speculative.

012-8 Comment: The draft report does not account for mixed wastes, noting that these would likely have been generated during operations and their disposal would therefore be an operational cost. This potentially costly task is one that in some instances could end up being a decommissioning expense for permanently installed items that become activated and only removed during dismantlement.

Response: No data were available regarding the likely inventories or treatment and disposal costs for mixed waste. It is likely that more mixed waste will have been generated during reactor operations than will arise during D&D. Thus, the utility has already had to create a permitted facility for storage of these materials during plant operations, which would be available for the storage of the D&D mixed wastes. Any information developed during the Fort St. Vrain reactor decommissioning regarding volumes and types of mixed waste would be very useful to future analyses.

012-9 Comment: The draft report does not include costs of initial site characterization studies, activation analyses, and any other studies to determine the extent of decommissioning activities. The initial site characterization of Fort St. Vrain involved over 20,000 survey locations and required a substantial documentation effort. PWR's and BWR's would be expected to have 2-3 times the number of survey points. In addition environmental characterization is extremely important and costly.

Response: The initial characterization should utilize, to the maximum extent possible, the data routinely collected during operations regarding contamination levels and activation levels. The real criteria for defining a characterization program is "Does this bit of information influence how the D&D effort is conducted?" If the answer is NO, then the information is not needed. Detailed information on radioactivity content of the wastes is needed to manifest the shipments, and can be obtained at that time. A large pre-decommissioning effort should not be necessary.

RESPONSES TO COMMENTOR 013

013-1 Comment: PSC takes issue with the assumptions regarding fuel costs. The draft report correctly recognizes that licensees will have to store spent fuel and may have to continue operating a dry storage facility beyond the time when the nuclear license is terminated. However, the assumption in Section 2.1 that 90 percent of total plant costs should be allocated to fuel storage operations and only 10 percent to plant decommissioning activities does not agree with our experience during any phase of decommissioning activities.

PSC constructed and loaded an on-site Independent Spent Fuel Storage Installation. After a six-month loading period, this stand-alone, passive facility has required minimal security, surveillance, and upkeep. The staff required to maintain the ISFSI is insignificant compared to the staff levels required for decommissioning planning and oversight activities.

Our experience is with early dismantlement activities, but many of the same plant activities would be required to prepare plant systems and equipment for an extended safe storage period, and this effort should not be underestimated. During active dismantlement and SAFSTOR preparatory activities, it would be more consistent with our experience to allocate 75 percent of the staffing levels to decommissioning activities and 25 percent to fuel storage. If only general plant maintenance and fuel storage activities are in progress, an even division of costs would seem appropriate.

Response: See the response to Comment 012-1.

013-2 Comment: PSC considers that scenario assumptions of radioactivity levels that are based only on cobalt-60, as in the SAFSTOR1, ENTOMB1, and ENTOMB2 alternatives, are hypothetical and misleading. Our experience at Fort St. Vrain is that there are other activated impurities in concrete and other structural materials that will still be around after cobalt-60 levels have substantially decayed. There are enough of these long-lived nuclides that dismantlement activities will still require remote tooling and access controls, and the radioactive waste volumes will not be significantly reduced, even after many half-lives of cobalt-60 have taken place.

Response: See the response to Comment 012-2

013-3 Comment: The presentation of staff levels in summary charts like Figures 3.2, 3.5 and 3.6 is difficult to evaluate, considering the assumed 90/10 allocation of staff between fuel and decommissioning activities discussed above. Even if it is assumed that the positions shown in these staffing charts are devoted full-time to decommissioning activities, the assumed staffing seems light, especially for the utility. During active dismantlement (Period 4), as shown in Figure 3.6, most of the activities are being conducted by the decommissioning contractor. However, it is PSC's experience that the utility must play an active oversight role. This role is greater than we had originally envisioned and is greater than that assumed in the PNL draft report. PSC has retained approximately 50 percent more staff than PNL assumed, particularly in the HP and Engineering positions.

Response: The 90% / 10% allocation of utility staff occurs only during Period 3 (Figure 3.5). The size of the utility staff postulated represents the PNL analysts' best judgement as to how many and what kind of personnel would be required to maintain oversight of the DOC operations. The HP coverage is provided by the DOC, with very limited utility oversight. The postulated DOC staff contains a reasonably-sized engineering staff. The actual staff size needed will depend largely upon the site-specific situation.

013-4 Comment: The presentation of contractor staff levels based on crew hours per task, as shown on the summary schedules and staffing charts in Figures 3.7, 3.8, and 3.9, is confusing and misleading. For example, project staffing illustrated in Figure 3.9 reflects an assumption that crew sizes will vary widely over the project, to a degree which is not realistic. This figure shows staffing levels that fluctuate up and down every month by up to 900 crew hours. In reality, staffing levels would be more stable and prudent planning would levelize work activities. However, even with the best planning, there will be times when work crews are not fully utilized and the associated costs will be higher than those assumed for the rapidly variable crew sizes shown in Figure 3.9.

Response: See the response to Comment 012-3.

013-5 Comment: The staffing shown in Table 3.2 includes fractional utility staff levels that vary from Periods 2 (Deactivation) to 3 (Safe Storage) to 4 (Dismantlement) in a manner that is confusing and misleading. It is difficult to relate the fractional person-years to staffing levels to evaluate their reasonableness. This is especially true for periods that extend over multiple years. It would be useful to identify the staff levels and time periods assumed. Also, in several operations and engineering positions, personnel are assumed to disappear for a period and then reappear. Depending on the length of the SAFSTOR period, this may not be realistic. Utilities may elect to retain qualified individuals through active dismantlement, thus increasing costs for Period 3.

Response: See the response to Comment 012-4.

013-6 Comment: The component removal and dismantlement periods appear to be short by a factor of 2 or 3. Dismantlement is assumed to be completed within 1.7 years, where at Fort St. Vrain, these activities are expected to take 3.25 years.

Response: See the response to Comment 012-5.

013-7 Comment: The presentation of costs in the executive summary table, Table ES.1, is misleading, in that costs are based on an unrealistically low disposal cost. The basis for the summary table is $50 per cubic foot. This figure does not reflect taxes, curie and exposure surcharges, or the impact of escalation over the SAFSTOR period; low level radioactive waste disposal costs have historically increased by over 11 percent per year, considerably outpacing the rate of inflation. PSC based the Fort St. Vrain waste disposal cost estimate on $140 per cubic foot.

Response: See the response to Comment 012-6.

013-8 Comment: The final site survey cost estimate of $1.2 million, in Section 3.4.12, is significantly low. PSC's latest estimate for this survey is in the range of $5 million to $6 million, and Shoreham's latest estimate is reportedly in the range of $10 million to $12 million. There are still a lot of unknowns about the extent of this process, including the treatment of hard to detect nuclides which isn't mentioned in the draft report. However, it appears impossible to perform this task for $1.2 million.

Response: See the response to Comment 012-7.

013-9 Comment: The draft report does not account for mixed wastes because it assumes that these would likely have been generated during operations and their disposal would therefore be an operational cost. This potentially costly task is one that in some instances could end up being a decommissioning expense. For example, PSC is investigating the possibility that some originally minor impurities in lead shielding at Fort St. Vrain could have become activated, thus creating a potential mixed waste. Since this material is part of a plant component, its storage/disposal could clearly be considered a decommissioning cost. There could be other such conditions where mixed waste disposal would not be considered an operational cost.

Response: See the response to Comment 012-8.

013-10 Comment: The draft report does not include costs of initial site characterization studies, activation analyses, and any other studies to determine the extent of decommissioning activities. The initial site characterization of Fort St. Vrain involved over 20,000 measurements on more than 5000 survey locations and required a substantial documentation effort.

Response: See the response to Comment 012-9.

013-11 Comment: PSC considers that the report should assume that piping would be cut into 5-foot lengths instead of 15-foot lengths. The Fort St. Vrain design included many crowded areas, and it has not been possible to remove much piping in lengths longer than 5-feet.

Response: As stated in response to similar comments, the 15-ft length was selected as a nominal length that would fit well within a maritime container. There are undoubtedly many piping runs that could be cut into 15-ft lengths without difficulty. It is recognized, however, that there will also be many instances where shorter lengths would be more readily made and handled. The sensitivity of the total D&D cost and dose to pipe cutting length was examined, which showed about a 4% increase in total labor costs, and a two-fold increase in total worker dose if all piping were cut into 5-ft lengths. Thus, there are incentives to make the cuts as long as feasible.

RESPONSES TO COMMENTOR 014

014-1 Comment: The draft report correctly assumes the existence of an on-site ISFSI to allow decommissioning activities to proceed. However, the report does not include costs associated with such an ISFSI in the total decommissioning cost estimate.

The Department of Energy spent fuel disposal program status indicates that the first off-site spent fuel shipment may not commence until around 2015, although 2010 is the official start date of a possible repository at Yucca Mountain. Moreover, lack of progress on the Monitored Retrievable Storage (MRS) facility suggests that spent fuel may not be shipped off-site any time soon either, for temporary storage. Further, given the oldest fuel first spent fuel acceptance criteria, spent fuel shipments from Salem and Hope Creek units are expected to occur much later than the year 2015. Therefore, we expect to incur costs associated with on-site storage at an ISFSI during the plant operation and decommissioning periods.

We recommend that all expected costs associated with an ISFSI such as design, construction and operation, incurred during the decommissioning phase of the plant be included in the decommissioning estimate. The design and construction related costs could occur during the decommissioning phase because the ISFSIs are expected to be expanded incrementally, as needed. The operation costs will occur until the last spent fuel assembly is shipped off-site.

Response: Current NRC policy does not include spent fuel storage costs as a decommissioning cost.

014-2 Comment: There is a large uncertainty related to the low level waste disposal charges. As waste generators reduce waste volumes using state of the art volume reduction techniques, the unit burial costs are expected to increase to maintain the economic feasibility of the burial facility. Therefore, the equilibrium burial cost has not been identified at this time. The economic forces at the time of decommissioning will determine these costs.

Response: PNL agrees with the statement. For the purposes of the PWR reevaluation study, it was necessary to use available LLW disposal sites and their rates, recognizing that those rates change over time. NUREG-1307 provides a way to adjust an existing cost estimate for changes in waste disposal costs.

014-3 Comment: It appears that the draft report does not provide sufficient detail of the overall project schedule. We believe it is important to identify critical path activities during decommissioning. In our opinion decommissioning costs are a strong function of the decommissioning schedule. Extension or compression of decommissioning schedule would increase or decrease manpower costs which represent a large component of the total decommissioning cost.

Response: PNL agrees that extension or reduction of the schedule duration can have a significant effect on the project cost. Such schedule variations will have little effect on the direct labor costs, because the same amount of work is required to remove and decontaminate. The big effect is on the indirect labor costs and other costs that are related to project duration. While PNL did not use a formal critical path program to analyze the project, a similar effort was carried out manually, to arrange the tasks in a logical sequence, avoid task interferences, and levelize the project direct labor staff.

014-4 Comment: We recommend that the draft report incorporate, to the extent possible, the recent experience gained in estimating decommissioning costs for the Yankee and Trojan Nuclear plants. In our opinion, these plant specific estimates would provide good benchmarking data points. For example, the draft report assumes less staff to perform decommissioning tasks compared with the experience from Shippingport, Shoreham, Ft. St. Vrain and Yankee. We believe such comparisons could make draft report estimates more realistic.

Response: The information from those activities was not available when the report was prepared, and, to a large extent, still is not available. PNL agrees that a careful comparison of actual performance on the D&D tasks with a priori estimates of the same tasks would provide very useful information for improving future D&D estimates.

014-5 Comment: We recommend that the spent nuclear fuel storage insurance costs be included in the decommissioning costs. The utilities are expected to hold title to spent fuel during the decommissioning period which would result in incurring nuclear insurance costs.

Response: See response to Comment 014-1

RESPONSES TO COMMENTOR 015

015-1 Comment: We recommend that the NRC establish regulations which require that licensees perform (and update) site specific decommissioning cost estimates (instead of using generic NRC methodology). The NRC should verify the adequacy of the cost estimate methodology and verify subsequent contributions to funding programs. In other words, the NRC should not prescribe the cost estimating methodology, but instead should prescribe that a verifiable site specific method be used and then monitor adequacy and compliance.

If the NRC does require use of the generic cost estimating methodology, there should be a provision (exemption) for licensees to use, if available, a site specific funding value in lieu of values derived using NRC methodology.

Response: The NRC will take this suggestion under consideration.

015-2 Comment: The new NRC draft site cleanup standards are dose based standards, which essentially require ALARA cost/benefit analyses which decide the appropriate cleanup level somewhere between the 15 mrem/y limit and the 3 mrem/y goal. One of the important pieces of information upon which to make this determination will be the dose estimates for occupational workers; therefore, the dose estimating methodology associated with decommissioning cost estimates should be improved so that this data is available. Improvements that should be made are use of site specific radionuclide spectrums instead of basing everything on Co-60.

Response: See the response to Comment 008a-12.

015-3 Comment: Table ES.1 should present the expected decommissioning costs using reduced or more realistic security and insurance costs; i.e., the table should include the $88 million dollars "cost effective" assumptions for entombment (see page 5.13).

Response: See the response to Comment 008a-21.

015-4 Comment: NRC regulation 10 CFR 50.75 should be further explained via a Regulatory Guide interpretation regarding the acceptability of entombment as a decommissioning alternative. Note: The GEIS for decommissioning of nuclear facilities (NUREG-0586) does include evaluation of the entombment option. However, we note that with the proper preparation for entombment with off-site licensed disposal of high level waste and decontamination waste, there would not be large amounts of radioactivity available for escape, as hypothesized in Section 4.4 of NUREG-0586. Therefore, there would not be a significant environmental impact from a breached structure.

The Congressional Office of Technology Assessment prepared a report on "Aging Nuclear Power Plants: Managing Plant Life and Decommissioning". In the verbal brief to the Commission on November 10, 1993, Dr. Roy states (page 27) that in the 1988 rule, the NRC "considered dropping entomb as an option for decommissioning, but instead decided to develop more specific guidelines on how entomb could be applied and how useful it would be". On page 28, Dr. Roy states: "Entomb option may be a realistic approach for safety and economic reasons, and receive -- it depends on the site and you'd have to find this out, do some more examinations -- might receive a favorable state and public acceptance in some cases."

Response: As explained in 10 CFR 50.75, the NRC will consider the ENTOMB option only in special cases when it is necessary to protect the public health and safety and that alternatives are acceptable only if they provide for the completion of decommissioning within 60 years. For this reason the NRC does not consider additional guidance necessary.

015-5 Comment: Even though NUREG-5884 is developed for the referenced PWR, Table ES.1 should present the values for disposal at the new Regional compacts, as both Hanford and Barnwell will cease operation by the time most facilities are decommissioned.

In addition, the disposal values for both Hanford and Barnwell should be provided, since this document will be used generically for PWRs and the cost differences are very significant.

Alternatively, the costs should be shown for Barnwell "only", which is more representative of costs expected at future LLW compacts; and also, since Hanford is inaccessible to most utilities. If the higher costs of disposal at Barnwell are not "shown", the reader develops a false impression of the relative costs of the decommissioning alternatives.

Response: The D&D cost for the reference PWR with disposal at Barnwell is developed in the report, with the incremental increases of transport and disposal costs given in Table ES.2, and discussed in Section 3.5.1. The disposal rate charge schedules for both the U.S. Ecology site at Hanford and the Chem-Nuclear site at Barnwell are given in Appendix B. Because no rate schedules yet exist for any of the "yet to be developed" regional compact sites, there was no way to consider them in detail.

015-6 Comment: We believe that NUREG-5884 should provide decommissioning cost alternatives which provide both constant and present value cost estimates, because cost comparisons between decommissioning alternatives must be made. A "present S value" calculation provides a much better basis for "current time" comparison of funds necessary to meet future costs than do "constant dollars", in spite of the uncertainties. Note: Constant dollars expended in the future are projected with similar uncertainties as back calculation of present value dollars.

Response: Present values for the estimated D&D costs of all alternatives examined are presented in Table ES.1, and are discussed in their respective chapters of the report.

015-7 Comment: Title 10 CFR 961 Appendix E requires five year SNF cooling for delivery to DOE for shipment as "Standard Fuel". There is no time requirement which specifies cooling in reactor pools. Interim SNF placement in dry cask storage cells is limited by the heat removal capability of the cask design.

Response: The statements that implied a five-year cooling period was required before removal from the pool have been replaced with discussions of the actual basis for pool cooling time requirement, i.e., cladding temperature limits, which are functions of the fuel burnup, initial enrichment, and initial internal pressurization of the fuel rods. The heat removal capacity of the dry storage device also has an influence on the necessary pool cooling time to assure satisfying the cladding temperature limits.

015-8 Comment: pg. xxi: The costs of transport and disposal associated with disposal of long-activity for the decommissioning alternative of entombment should also be listed.

Response: The costs for transport of GTCC material to the repository are developed in Appendix C. The costs for disposal of that material in the repository are based on earlier analyses carried out within DOE's OCRWM program, and remain rather speculative. The specific disposal rate used in the analysis was $6,500 per ft^3, as given in Section B.7.2.

015-9 Comment: pg.xxii, 2nd full paragraph: The statement that "one can be assured that disposal costs are unlikely to decrease over time" may be pessimistic. In looking for cost effective solutions to enhance the nuclear option, we propose that the NRC and EPA be encouraged to develop regulations which allow use of Very Low Level Waste Disposal sites. These regulations would essentially replace the 20.302 (now 20.2002) exemption process. If this were achieved, then the cost of waste disposal may be dramatically reduced since many of the materials may be only slightly contaminated, especially after aggressive chemical decon.

Response: Historically, LLW disposal costs have only increased over time, and rather dramatically in recent years. PNL agrees that disposal costs could be reduced by decontaminating much of the material to levels that would not require disposal as LLW. However, as LLW waste volumes go down, the disposal sites may have to increase their rates to cover their fixed costs, thus negating some of the cost reductions obtained by the waste generator by reducing the volume of LLW disposed.

015-10 Comment: pg. xxv, 2nd full paragraph: The cost estimating computer code (CECP) should be developed to allow sensitivity analyses, including variable security and insurance costs for SAFSTOR and ENTOMB options, instead of relying on data from the old NUREG/CR-1755 analyses. In addition, future site cleanup standards and decommissioning regulations should allow/require this type of evaluation.

Response: Those values can readily be changed within the CECP to permit the type of sensitivity studies suggested.

015-11 Comment: pg. 1.4: The on-site costs of dry spent fuel storage are being considered operations costs. Actually these should be included in decommissioning costs, since the cost of operation is no longer supported by generation at the plant and the funds allocated to DOE are for disposal.

Response: Current NRC policy does not consider SNF storage costs as decommissioning costs.

015-12 Comment: pg. 2.2, last 2 paragraphs: The scheduling constraint on operation of the spent fuel pools following plant shutdown is directly related to the heat removal capability of the cask design. Some designs employ passive cooling techniques to increase the heat removal capability and reduce the time required for cooling in the spent fuel pools.

Response: PNL agrees. The critical parameter is cladding temperature, and whatever dry storage approach will assure satisfying the cladding temperature limits for the fuel rods should be acceptable.

015-13 Comment: pg. 2.5 6th bullet: The radiation dose rate should be calculated using an effective dose factor for an assumed mix of radionuclides, instead of determined based on the short, half-lived Co-60.

Response: See the response to Comment 008a-12.

015-14 Comment: pg. 5.1, 1st Paragraph, last sentence: The NUREG interpretation is incorrect that the "only" reason for allowing consideration of delaying decommissioning beyond the 60 year limit is the "unavailability of waste disposal capacity". This is "only" an example and not a conclusive list of the possible considerations "necessary to protect the public health and safety". The NRC should be open to alternatives suggested in decommissioning plans which provide alternate methods of decommissioning, as long as they "protect the public health and safety". (Refer to comment No. 1).

Response: See the response to Comment 015-4.

015-15 Comment: pg. 5.2, 3rd paragraph: The statement "that entombment is not a particularly viable decommissioning alternative" should be deleted, as the conclusions on page 5.13 show that entombment is probably the most cost effective decommissioning alternative.

Response: The NRC does not favor this option under current regulatory requirements but will consider it under extenuating circumstances if health and safety is a consideration.

015-16 Comment: pg. 5.7, 3rd full paragraph: The spent fuel racks can be cut up underwater and then placed in the containment building at a lower cost, instead of being disposed in a licensed facility. Note: Many utilities have already re-racked to high density spent fuel racks and, therefore, have experience in underwater cutting.

Response: The rather high density of the fuel racks makes it questionable whether their volume can be reduced sufficiently to justify the effort. An analysis of such a trade-off was not performed for the reevaluation study, because of probable space limitations within the entombment boundary.

015-17 Comment: pg. 5.8, first full paragraph: For the entomb option, it may not be necessary to decontaminate the polar crane since it will have mainly low-level, short-lived contamination.

Response: The polar crane is outside of the entombment barrier postulated for the study. Thus, for essentially unrestricted access to the upper portion of the containment building, the crane had to be decontaminated. If the entire containment structure were made unaccessable, then the crane would not require decontamination.

015-18 Comment: pg. 5.10 "Activities during and following ENTOMB": It appears that the values are in the columns for ENTOMB1 and ENTOMB2 where, in fact, these values are for ENTOMB1 and ENTOMB3.

Response: True! The columns in the table are now properly labeled.

015-19 Comment: pg. 5.11, first partial paragraph: The values are discussed in constant dollars and would be more meaningful if discussed in terms of present value dollars.

Response: The present value analysis is presented on the following pages.

015-20 Comment: pg. 5.13, first partial paragraph: The first complete sentence comes to the wrong conclusion. The statement should read "the funding should be required in present value" instead of in constant dollars (which provide an unnecessary and misleading cost estimate and funding requirements).

Response: The statement has been rephrased as follows: Thus, calculating the funding needs in constant dollars of the year 2.5 years prior to reactor shutdown can overestimate the actual funding needs for ENTOMB by up to about 53%, depending upon the real discount rate available, and can provide a significant safety margin to cover unforeseen events.

RESPONSES TO COMMENTOR 016

016-1 Comment: The cost estimation basis needs further clarification. For example, in the draft report reference is made to 10 CFR 961 Appendix E as requiring spent nuclear fuel (SNF) to be cooled in the reactor pools for at least five years before it can be placed into dry storage. This is technically incorrect as the regulation only states that the minimum cooling time for fuel is five years and does not specify where it should be cooled. Thus, for compliance, some latitude is provided which should lead to an evaluation of various scenario's with concomitant cost impacts. Although the choice of spent fuel pool cooling for the required duration may be the most cost effective, the NUREG fails to provide information supporting this.

Response: The statements regarding 10CFR961 and required pool cooling time have been removed and replaced by discussions of the actual basis, i.e., the cladding temperature limits. A detailed discussion of this topic is contained in Appendix D.

016-2 Comment: Also, the draft report provides only a brief qualitative assessment of the cost impact to the decommissioning alternatives for a multiple reactor site, based on an 1982/1983 study performed by the NRC (NUREG/CR-1755), and alludes to potential savings under this scenario. As we are a multiple reactor site, and recognizing that this draft NUREG will form the basis for reassessment of costs associated with the decommissioning of a facility as currently reflected in 10 CFR 50.75, we believe that more than just a cursory mention is warranted. Rather, whether separately or integral with this report, a more comprehensive assessment of this scenario should be conducted and included in this reassessment effort.

Response: The basis of the study was the reference PWR, which is a single-unit facility. This provides an upper bound for considering a multiple-unit site. PNL agrees that some significant cost reductions could be made when decommissioning a multiple-unit site.

016-3 Comment: Additionally, we support the position of NUMARC with regard to their identification of difficulties experienced by the industry in the implementation of the current rule and the stated necessary improvements to the draft NUREG/CR-5884 to achieve a more valid model for decommissioning cost estimates.

Response: See the responses to the NUMARC comments, 008a.

016-4 Comment: Also, as noted in NUMARC's response, we are equally concerned that this effort should not result in decommissioning funding requirements for spent nuclear fuel beyond those needed for license termination. As you are aware, we have been contributing separately to a trust fund for disposal of spent fuel as mandated by the Nuclear Waste Policy Act of 1988. It would be unconscionable for our customers to pay twice for this requirement.

Response: Current NRC policy does not consider spent fuel storage costs as decommissioning costs, i.e., no spent fuel storage costs are included in the total decommissioning cost estimates developed in this reevaluation study.

016-5 Comment: Finally, Con Edison agrees with NUMARC that a unit-specific, detailed cost analysis of decommissioning should be the basis for seeking a permissible exemption from generic funding requirements based solely on reference plant estimates.

Response: The NRC will take this suggestion under consideration.

RESPONSES TO COMMENTOR 017

017-1 Comment: This comment is much on my mind--and in frustration on the my unknown due date (or if I've already sent my 2 page piece) I forwarded this "on precautionary grounds" (a policy all nuclear development must take).

Notice (over) a sample of your repeated display of the misleading mindset that radioactive wastes/materials are a disposal positivity: NO THEY ARE NON DISPOSABLE and can only be stored/managed/isolated/recycled/monitored "forevermore". So DO NOT USE that "disposal" term. Nor "SPENT" meaning toxic fuel irradiated up to 100,000,000 times during use.

Public faith will only come without weasel-words and upon BANNING continuous production of nuclear (a noun!)

Response: The terms to which the commentor objects are the common usage in the nuclear industry.

RESPONSES TO COMMENTOR 018

018-1 Comment: Allocation of Costs to Operations: The assignment to operations (or any non-decommissioning fund source) of any set fraction of costs by the NRC or PNL can result in a serious underestimate and underfunding of costs for safe and complete decommissioning. This underestimate occurs because the "operations" costs are not included in the base estimate totals, although these tasks are indubitably part of decommissioning. The NRC and PNL should not assume any allocation to "operations" of any sort in this cost estimate. The PNL report is represented as a cost estimate, not a report on funding requirements. If the NRC wishes to assume funding fractions and divisions at a later time, they should explicitly do so, and not provide a fund size as a cost estimate.

Even if PNL identifies some costs as "operational" funding and others as decommissioning funding, this report should provide both -- as well as a total. This will allow Utilities and their rate commissions to judge what costs will be and who will fund these costs.

The stated purpose of the decommissioning fund is to provide "assurance" that the reactor can be safely decommissioned if the reactor operator fails financially. In the event of financial failure of the reactor operator, operational rate agreements with the Utility's rate commission would not apply, and the only source of funds for decommissioning would be the decommissioning fund. If the NRC wishes to allow utilities credit for operations not covered by the decommissioning fund, this contradicts the intent of the 1986 Decommissioning Rule.

Removal of this incorrect practice increases labor costs alone during periods 3 and 4 were underestimated by $32 million with contingency. Spent fuel storage costs (from Appendix D) are another $73 million with contingency ((40.3+14+4)*1.25). Nuclear insurance costs ignored add $10.7 million after contingency (Table B.7). NRC licensing costs ignored add at least $6. 1 million (section B. 13). The underestimate of decommissioning costs is therefore at least $122 million for DECON ($247 million total cost). Non-radioactive demolition costs are not considered in this evaluation of improper allocation of costs.

Response: The commentor has taken the position that all SNF storage costs should also be included in the decommissioning costs. As stated in numerous previous responses, the current NRC policy does not consider SNF storage costs as decommissioning costs for the purpose of defining the amount of funding that must be assured. Therefore, those costs, while developed and displayed within the report, are not included in the totals for license termination. The commentor has apparently miscalculated the total costs associated with SNF storage. Using the information in Tables 3.2 and D.4, the total SNF storage costs from the end of Period 2 to the end of Period 5 is about $82 million (1993 $), including contingency.

018-2 Comment: Early Shutdown Estimates: Every reactor that has shut down prior to planned time has found that decommissioning costs are significantly higher for plants shut down unexpectedly (before NRC approval of decommissioning plans). These costs have not been evaluated in this report. An unplanned shutdown can more than double the true cost of decommissioning from the planned shutdown costs. This primary justification of the 1986 Decommissioning Rule was financial assurance in the event of unplanned shutdowns. I would strongly recommend the NRC evaluate the effect of early shutdowns, as well as planned shutdowns.

Response: The scope of the PWR Reevaluation Study was for a plant that had shutdown at the end of its licensed operating lifetime. Thus, the problems associated with premature shutdown were not examined. Because the situation for each prematurely shutdown plant is rather unique, it is unlikely that any generic analysis would be very useful to anyone.

018-3 Comment: DECON No Longer a Viable Option: The NRC term DECON identified in the Decommissioning Rule specified immediate dismantling. This report makes it clear that, with the assumptions identified, DECON is no longer a viable option. The option termed "DECON" in this draft report is not DECON per the Decommissioning Rule, it is SAFSTOR with Deferred Dismantling and with a relatively short (5 year) interim care period. The difference from the Decommissioning Rule is the staffing levels and maintenance due to fuel in the spent fuel pool. The option of using operating plant staff to perform significant DECON tasks has been lost in the current usage of the term "DECON." The only choice remaining to a plant operator is the determination of how long the continuing care period will be.

Response: PNL agrees that DECON was re-defined in this study to be a short safe storage period followed by deferred dismantlement. In the scenarios selected for evaluation in the study, once Period 2 (plant lay-up) was completed, no active decommissioning activities were permitted until Period 4, because of NRC concerns that active disassembly of plant systems might present a risk to the integrity of the SNF storage in the pool. Recent actions at several prematurely shutdown reactors have included removal of some major components (steam generators, pressurizers, etc.), which have been permitted by NRC on a case-by-case basis.

018-4 Comment: Out-of-Date Waste Operations Assumptions: The draft report presumes that decommissioning wastes will go directly from the plant site to a disposal site. The largest contribution to waste costs in this report (see below) come from waste streams of contaminated wood, metal, and concrete structural materials, piping, and equipment. These types of wastes have been handled through intermediate waste recycling and volume reduction firms for over 10 years. Companies such as SEG and Quadrex routinely process these types of wastes from operating reactors at a significant cost savings. Ignoring current industrial standards is contrary to the stated assumptions in the draft report, and would significantly reduce the waste cost estimates and sensitivity analyses contained in the report. The NRC should either direct PNL to incorporate this well-established industry practice into the report or determine a correction factor for the use of intermediate waste processors in the eventual: update of the decommissioning funding basis.

Response: The use of waste brokers who could decontaminate and/or reduce the volume of LLW arising from the plant disassembly was expressly omitted from the analysis by direction of the NRC. As a result, the disposal costs are probably significantly larger that would be the case with waste decontamination and/or volume reduction, and should represent an upper bound for those costs.

018-5 Comment: Lack of Funding for Emergency Response Capability: After the Three Mile Island, Unit 2 accident, the NRC imposed significant emergency planning requirements on operating reactors. Although the focus of these regulations is a core melt in an operating reactor, any facility with radioactive material in inventories sufficient to exceed Part 100 or Part 25 limits offsite requires a functional emergency plan. Recent risk analyses have indicated that spent fuel handling is actually riskier than operation of the plant. A reactor with fuel in the spent fuel pool is still a significant source of risk to the public. This risk exists because the spent fuel pools are not within the containment structure or pressure vessel that protects against releases during reactor operations. Two of the four "barriers" to release do not exist for spent fuel. Spent fuel is also stored in wet pools. If these pools are accidentally drained, the heat from these fuel assemblies will burst the cladding and may melt some of the fuel. Reactor facilities have accidentally drained their spent fuel pools in the past, and have removed emergency filtration systems from "safety" status during decommissioning. I have attached a simple calculation showing potential off-site doses far in excess of 25 REM to members of the public.

When the original PWR reports were developed, there were no detailed NRC requirements for Emergency Planning. The current draft report reduces staff levels below those that would be required if true emergency response capability were maintained. The NRC should evaluate PNL to incorporate emergency planning costs in the base estimates.

Response: The NRC requires licensee's to maintain a modified Emergency Plan during permanent shutdown based on the plant's configuration. Depending on the decommissioning option selected, these costs will vary plant to plant and are adequately covered by the contingency factor for the estimate.

018-6 Comment: Time Value of Money (Present Value Costing): This report brings the time-value of money into consideration for the first time in the arena of the Decommissioning Rule. Although NUREG-0514 (1979) provided a basis for evaluating the time-value of money for SAFSTOR, ENTOMB, and DECON prior to the Decommissioning Rule, the Rule expressly avoided the use of the time-value of money in the rulemaking. Although the time-value of money is certainly of interest to Utilities and Rate Commissions, the NRC has no jurisdiction over the rate of return or present value of a decommissioning fund. This avoidance makes the use of time-value of money (or present-value costing) inappropriate for this engineering cost estimate.

If the NRC would wishes to utilize present-value costing, the NRC must project decommissioning inflation rates for the next 60 years. Even so, rates of return are completely out of the NRC's control (they are controlled by Rate Commissions and tax laws). Thus, the NRC cannot directly use a "present-value" cost without specifying the assumed or expected interest rate, inflation rate, and tax rate. This kind of regulatory change must come through normal rulemaking processes, and cannot be imposed through an "update" of the basic decommissioning cost estimate reports.

Response: The present value analyses are included to illustrate the effect of the time-distribution of expenditures on the amount of funding that would be needed at reactor shutdown. Also see the response to Comment 003-3.

018-7 Comment: Nominal Length of Pipe Sections: The length of pipe cutting has two components, of which one is ignored in this analysis. The length of the pipe segment is inversely proportional to the number of work hours required to remove the pipe (the number of cuts needed). Original pipe length assumptions were based on the packing efficiency into an 8 foot long box. Industry discussions focused on the effects of 5 foot to 7 foot average assumptions. The current use of sea/land containers for disposal effectively makes the 5 foot versus 7 foot argument irrelevant. However, the 15 foot assumption used in this study is overly optimistic. The 15 foot nominal lengths used in this study do not allow for the removal of heavy pipe after cutting. The labor hours used assume that the pipe sections are easily moveable by hand with a few individual workers. Pipe weights of 100 pounds or more cannot be moved in this fashion. In fact, the useful length of a pipe cut is inversely proportional to the weight (diameter) of the pipe being moved. As a minimum, a nominal length for small pipes and large pipes should be different.

Response: See responses to Comments 008a-26, 010-5, 013-11.

018-8 Comment: Abandonment of Use of "Reference Site": NUREG/CR-0130 (and the BWR Study, NUREG/CR-0672) used costs evaluated at a generic "reference site" located somewhere in the midwest. This reference site was one of the bases for the Decommissioning Rule. The switch in cost bases to Pacific Northwest costs and waste transport conditions should be explained. The location of Trojan on the Columbia river nearby to the (relatively low cost) Hanford disposal site makes a significant cost difference.

Response: The analyses in this report reflect the site-specific situation at TROJAN reactor. Using the CECP, adjustments can be made to any specific site desired. However, the user would have to determine the transport costs via rail for the steam generators.

018-9 Comment: Lack of Consideration of Annual Radiation Dose Limits: The NRC has imposed annual radiation dose limits for occupational exposure. This limit is roughly 5 REM per year per worker. Many of the tasks undertaken during decommissioning (especially DECON and ENTOMB) take place in high radiation areas. Use of a unit cost approach to determining the number of personnel needed to perform a task must be modified to take such limits into account. For example, pipe removal (page 3.28 in this study) identifies a situation where the identified work crews would receive radiation doses in excess of NRC limits.

The original NUREG/CR-0130 failed to consider this situation. Addendums to NUREG/CR-0130 corrected this the original study. There is no mention of evaluating this situation in this report, and it appears (from the discussions on page 3.28) that this very important consideration has been overlooked again.

It is true that 7 years of decay will significantly reduce radiation levels in the plant and therefore reduce the need for additional radiation workers. The lower manpower requirements due to decay of radioactivity has always been one of the major economic advantages of SAFSTOR over DECON. It may be that decommissioning staff rotation may be sufficient to remove the need for additional radiation workers. The determination of when sufficient decay has occurred to remove any need for additional radiation workers (3 years?, 5 years?, 9 years?) should be included in this study.

Response: The annual doses to workers in the analyses average to about 4 Rem/yr. Specific tasks may have dose rates that are higher or lower than that average. Thus, for the base case, the annual worker dose limits would not be exceeded.

018-10 Comment: Page xvi, 1st bullet: The commercial spent fuel reprocessing industry was terminated in 1977 by President Carter and the NRC. This took place prior to the initial Decommissioning studies, and is not a change in parameters for this new study.

The accumulation of large inventories of SNF at reactor facilities does not affect this study or its results in any way. SNF is presumed to be removed to dry storage in this study.

Response: The original study assumed SNF shipment to the reprocessor within 1 year after discharge. The elimination of early, wet shipment of SNF and the need to meet cladding temperature limits for dry transport and storage are significant parameter changes from the original study.

018-11 Comment: Page xvi, 2nd bullet: 10 CFR 961, Appendix E does not require that spent fuel be cooled five years prior to placement in dry storage. First, 10 CFR 961, Appendix E is a DOE rule (not a NRC regulation) that defines spent fuel for DOE receipt. Second, spent fuel cooled less than five years is not prohibited, it is classified as "Class NS-3, short-cooled." There is therefore no such regulatory requirement necessitating pool operations for a minimum of five years.

Response: The text has been revised to identify the need to meet cladding temperature limits as the controlling factor for pool cooling duration.

Comment: Currently-available dry storage casks are designed to hold fuel cooled at least 5 years. This is due to current industry needs (temporary storage of spent fuel at operating plants). Because spent fuel pool capacity at operating plants has been the focus of dry storage activities to the present day, there has been no need for cask manufacturers to design and license a cask for dry storage of fuel cooled less than 5 years. There is no technical barrier to the manufacture of casks for cooling spent fuel that has been pool cooled as little as 120 days (the assumption in the original Battelle study). Construction and licensing of such casks could be included in this report.

Response: Those casks would have to use wet cooling internally to achieve sufficient heat removal rates to satisfy cladding limits for the short-cooled fuel. The fuel could not be shipped currently because NRC no longer licenses wet casks.

018-12 Comment: Page xvi, 3rd bullet: No basis is provided in this document for the claim that future LLW disposal facilities will have higher charge rates than the current waste sites. This event would not require a re-evaluation of itself, as the waste volumes generated would not change. Only if waste volume generation is reduced (through technology or changes in regulation) is a reevaluation needed.

Response: The statement was that it was unlikely that LLW disposal rates would decrease over time. That statement is true, regardless of whether significant volume reductions actions are taken or not.

Comment: The use of intermediate waste companies (see general comment #4) does require a reevaluation, but it is not included in this report.

Response: See the response to Comment 018-4.

018-13 Comment: Page xvii, 1st paragraph: The Part 50 license for decommissioning could not be terminated upon removal of spent fuel to dry storage for the spent fuel would remain. The dry storage facility would retain a Part 50 license (or at least the operational equivalent), even if the reactor power plant structures no longer needed a part 50 license. The dry storage facility could be licensed under Part 72, general licenses.

Response: Once the SNF has been removed from the pool and placed in an ISFSI which is licensed under 10CFR72, the Part 50 reactor license could be terminated at the conclusion of the D&D of the reactor.

Comment: No basis is provided in this report for the claim of relative cost of keeping spent fuel in the fuel pool, as the cost of this option is not evaluated in this study. This claim should be supported or removed.

Response: The cost analyses for pool storage versus ISFSI storage are given in Appendix D.

018-14 Comment: Page xix, last paragraph: The costs included in Table ES.1 do not incorporate the costs for termination of the nuclear license. Many costs have been incorrectly ignored. See general comment #1. Only demolition of noncontaminated structures and restoration of the site may be classed as non-NRC license termination costs. Spent fuel storage pool operations, and ISFSI costs are required when defining the amount of money for the NRC decommissioning fund.

Response: Present NRC policy does not include SNF storage as a decommissioning cost for the purpose of defining the amount of financial assurance required.

018-15 Comment: Page xx, 1st paragraph: There is no basis for this report to claim that structures demolition and site restoration could increase costs by $100 million. This has not been evaluated in this report, and completely contradicts the results from the initial PWR study (NUREG/CR-0130) which estimated demolition and restoration costs at only $8 million in 1978.

Response: The sentence has been rephrased. A new appendix (L) has been added which develops the cost of demolition and site restoration as $38 million.

018-16 Comment: Page xx, 2nd paragraph: The use of the "CECP" cannot be instituted without rulemaking on the part of the NRC, as the Decommissioning Rule specifies the use of generic formulas. Although the CECP allows documentation of many of the inputs, it does not allow documentation of assumptions and formulae used. As such it is inferior to a printed study.

Response: There is no requirement that anyone use the CECP in their decommissioning analyses. The bases for the CECP calculations are given in Appendix C and in the User's Manual for the CECP (NUREG/CR-6054), together with the discussions of operations given throughout the PWR Reevaluation report (NUREG/CR-5884).

018-17 Comment: Page xxii, 3rd paragraph: This paragraph is speculative and unsupported. This report has documented a 60% reduction in waste (by not generating contaminated concrete waste due to NRC regulatory changes). This report has ignored technological changes (see general comment #4).

Response: The statement in the report refers to disposal cost rates, not actual disposal costs. Also see the response to Comment 018-4.

018-18 Comment: Page xxii, 4th paragraph: There needs to be more description of the "conservative" removal of concrete assumed in the original study. This "sensitivity analysis" was flawed in that it assumed the (relatively tiny) surface area considered by "engineering judgement" to need spalling did not change. This area was less than 1% of the area considered in the original study. Such significant changes in "engineering judgement" must be evaluated in detail.

Response: The sensitivity analysis was on the parameters of this study, not the original study done nearly 17 years ago. The areas considered in this study were based on discussions with plant operating personnel. The original study took the very conservative position that 100% of all floors would require scabbling.

018-19 Comment: Page xxv, 2nd paragraph: This analysis did not consider the effect of NRC annual radiation limits on workers. No correction was attempted for the additional radiation workers needed to avoid overexposing the radiation workers. See general comment #9.

Response: The average over all direct labor staff was about 4 Rem/yr, less than the NRC limit of 5 Rem/yr.

018-20 Comment: Page xxvi, 2nd paragraph: The use of present value costing requires detailed development and support for the interest rates, tax rates, and inflation rates used. The bald assumption of a non-conservative 3% net rate of return is not sufficient to support such a claim.

Response: See the response to Comment 018-6.

018-21 Comment: Page xxvi, last paragraph: This paragraph describes a result which completely contradicts the assumption for immediate use of dry storage casks made in the base report. According to this paragraph, it takes at least 33 years to pay off the additional cask expenditures (40 years after reactor shutdown). The basic cost numbers provided in the report are based on the assumption that dry storage will be done as soon as possible, and for economic reasons. This result is not described anywhere else in the body of volume 1 of this report.

Response: This analysis appears in Appendix D, and has been revised since the draft. It now takes about 16 years for the cumulative present value of expenditures for SNF storage in the ISFSI to become less than for the pool storage. The choice of using an ISFSI was predicated upon the owner wishing to terminate his Part 50 license as soon as possible, not on SNF storage economics.

018-22 Comment: Page 1.2,3rd paragraph: It is my understanding that 10 CFR 961, Appendix E requires that spent fuel must be cooled in the reactor pool for five years before it can be shipped to DOE. It does not preclude dry storage of spent fuel. This limitation is not a problem for operating plants. The limitation is a problem for plants undergoing decommissioning. If the five year administrative limit does apply to dry storage, then the NRC should evaluate the safety and cost impact of allowing shorter cooling times for dry storage.

Response: The statement has been revised to attribute the pool cooling times to the need to satisfy the cladding temperature limits when placed into dry storage. Also, see the response to Comment 008a-29.

018-23 Comment: Page 1.4, 1st paragraph: Dry storage costs are <u>not</u> considered operational costs if they are a part of a decommissioned reactor. They are operational costs only for operating reactors. The final decision is made by the Utility Rate Commission, and the NRC cannot affect that decision. See general comment #1.

Response: NRC can and has made the decision that, at present, SNF storage costs at a retired reactor are not included in the amount of funding required for decommissioning assurance.

018-24 Comment: Page 1.4,3rd and 4th paragraphs: Which assumption is correct based upon the assumed activation and contamination? There is no difference here except the duration of interim care and safe storage (the decay period). An estimate of the decay period needed to reach SAFSTOR1 would clarify this.

Response: The purpose of these analyses is to bound the problem, not select the exact solution.

018-25 Comment: Page 1.4, 5th, 6th, and 7th paragraphs: ENTOMB1 is not a valid option for PWRs. As comment above, specify the minimum decay time expected for ENTOMB2 to be valid. The Decommissioning Rule assumption of 60 years here is not appropriate, as the 60-year limit was based on the original PWR and BWR studies in 1980. ENTOMB3 should be dropped as not valid (unless 300 years will reduce the activation products to unrestricted release levels).

Response: As above, the purpose of the analyses is to bound the problem, not select the exact solution.

018-26 Comment: Page 1.5, last paragraph: This report brings the time-value of money into consideration for the first time in the arena of the Decommissioning Rule. See general comment #6.

Response: See response to Comment 018-6.

018-27 Comment: Page 2.1, last paragraph: The use of site-specific cost estimates was determined to be not needed by the NRC in the Decommissioning Rule. It has been determined by many Utilities and Rate Commissions that site-specific studies are more precise and reliable than the use of generic factors required by the NRC rule. This has been determined by the NRC not to be a "principal step" for NRC license purposes, and cannot be made so by such a statement in this report. This sentence should be deleted.

Response: This is general statement, not an NRC requirement. The commentor would probably agree that any owner seriously considering decommissioning would have a site-specific decommissioning estimate developed for his plant.

Comment: The second sentence should read "One method...," not "The basic method..."

Response: The sentence has been revised to "One frequently used method"...

Comment: Reliable cost estimates are not found solely by the use of plant-specific inventories Engineering designs (the physical layout) of plant can greatly affect the costs of decommissioning a nuclear plant. Engineering design affects the type of equipment that can be used, the proximity of radioactive or other hazardous material, operational history (contamination and activation), and many other engineering parameters. The assumptions made to support cost estimates may have far more impact on decommissioning costs than obtaining more precise (though not necessarily more accurate) inventories of components, piping, and structures.

Response: PNL does not disagree with the above statement.

Comment: The use of "current technology" should have more emphasis in this report. In fact, this report ignores improvements in technology in waste handling and dismantling of nonradioactive structures.

Response: See response to Comment 018-4

018-28 Comment: Page 2.2, 2nd paragraph: The original PWR study (NUREG/CR-0130) did not include safety analyses or dose projection for Emergency Planning. Potential accident exposures and doses should be evaluated. See general comment #5.

Response: See the response to Comment 018-5.

018-29 Comment: Page 2.3,2nd paragraph: The question of chargeability of spent fuel storage is not an area of NRC jurisdiction. The NRC cannot determine this, since it is up to Rate Commissions. The 90% assumption is invalid. See general comment #1.

Response: NRC can determine which costs they consider as included within the amount needed for decommissioning financial assurance. Presently, SNF storage is not included in the NRC's definition of decommissioning costs. Also see the response to Comment 018-1.

018-30 Comment: Page 2.3,3rd paragraph: It would be useful to compare current cost estimates are for keeping spent fuel in the spent fuel pool to costs for transfer to dry storage. This would result in a determination of the optimal decisions based upon DOE spent fuel shipment dates.

Response: See Appendix D.

Comment: Although dry storage would permit decontamination and dismantlement of the reactor plant, an NRC license would still be required for the (now) stand-alone dry storage facility. The termination of a Part 50 license is not, in itself, a beneficial result. Beneficial results would be reduced risk and cost reduction.

Response: The ISFSI would be licensed under Part 72, thus allowing the Part 50 license to be terminated once the plant was decontaminated. There are significant differences between the efforts needed to maintain a Part 50 license and a Part 72 license.

018-31 Comment: Page 2.4, 2nd paragraph: It would be useful to identify here where these analyses are located in this report.

Response: The locations of the analyses are now included in the text.

018-32 Comment: Page 2.4,5th paragraph: The pipe length should be based upon the size of the pipe. See general comment #7.

Response: See the response to Comment 008a-9.

018-33 Comment: Page 2.5, paragraph 8: It would be useful if the report identified the specific contamination and activation levels (of each nuclide) that were used to allow unrestricted release.

Response: See Regulatory Guide 1.86.

018-34 Comment: Page 2.6, paragraph 4: The change to a one-inch concrete spalling depth from the 2-inch spalling depth in the original study is a significant change, as it reduces the contaminated concrete waste volumes by a factor of two. Because of this strong effect, this change should be explained further. A spalling depth based on concrete coating and/or use (ceiling, wall, dry floor, wet floor, tank, and/or coating) should be provided.

Response: The 1-inch depth was specified by NRC. Actual experience suggests that even shallower removals would be sufficient in many cases. See Section 3.4.8 for supporting references.

018-35 Comment: Page 2.6, paragraph 6: The first sentence is unclear. In fact, in this study the decommissioning planning is drawn primarily from DOC personnel.

Response: That is correct. The bulk of the planning is done in Period 1, prior to shutdown, with limited utility staff support. Plant lay-up is done in Period 2 by utility staff and subcontractors. Disassembly and decontamination is done by DOC subcontractors in Period 4.

018-36 Comment: Page 2.6, paragraph 7: The NRC annual and quarterly radiation dose limits, and the expected Utility Administrative Dose Limits and average worker doses are critical in determining the results of this study. The assumed average annual exposure limits for radiation workers must be expressly identified. "ALARA" is not a sufficient description, due to the need for "spreading" dose around workers in high radiation areas.

Response: See the response to Comment 018-9.

018-37 Comment: Page 2.7, paragraph 1: The presence of asbestos affects primarily the protective equipment needed by workers. Workers in radioactively contaminated areas will already be using protective equipment equal to or in excess of that required by asbestos workers (ALARA requirements). Asbestos should have effect only if asbestos is prohibited in contaminated waste disposal.

Response: A brief analysis of asbestos removal was added to Section 3.4.

018-38 Comment: Page 2.7, paragraph 6: The use of the CECP (or any other computer program) by the NRC is not allowed by the Decommissioning Rule. Use of the CECP (or any other single product) cannot be required by the NRC. Unless the NRC uses actual site-specific costs for manpower, energy, waste, etc. the CECP will not provide site-specific answers. The NRC concern of "reasonable" is an order-of-magnitude estimate. Use of the CECP must be specified in a and justified in a separate rulemaking. (See page 2.8, second paragraph).

Response: Use of the CECP is <u>not</u> required by NRC for any purpose. The user of the CECP can choose to use the PNL TROJAN default values or can change those parameters to fit any site or facility of interest.

018-39 Comment: Page 2.8, paragraph 3: The assigning of costs to "operations" at a multiple plant site is out of the NRC jurisdiction, and is the responsibility of the Rate Commission. See general comment #1.

Response: Agreed! However, the point of the discussion was that the costs for plant-wide services, such as security, would generally be less per unit than on a single unit site.

018-40 Comment: Page 3.1, 1st paragraph: The description of DECON provided here is not DECON as described in the Decommissioning Rule. This description is SAFSTOR with deferred dismantling. DECON is apparently not an option due to the five-year delay imposed by the DOE/NRC/dry storage limits. The only option is how long a continuing care period is used before deferred dismantling is begun. See general comment #3.

Response: DECON has been redefined for the purposes of this study, and will probably be redefined when the Decommissioning Rule is revised. Immediate dismantlement, without the availability of another pool in which to store the SNF is not feasible.

Comment: Why use DOC for the 2.5 year planning period? Why not use onsite staff with only one or two contractors for advice? In the original studies bringing a DOC onsite during planning made sense, since the DOC would immediately begin work with no loss of continuity. In the current description, there is no significant benefit to using DOC as primary development during planning. The DOC staff must be trained in plant design and operations. The DOC staff then disappears for seven years, to be replaced by new DOC staff who must be trained all over again. Two DOC activation costs must be paid. Other than specialty contractor tasks (remote cutting), most DECON tasks are of a type encountered during operations. There is no reason plant staff (who would be laid off because they are no longer supporting future refueling and maintenance outages) cannot support this effort with advisory assistance from potential DOCs. There is no reason to expect that the same DOC will work both planning and dismantling efforts.

Response: The intent of the scenario used in this study was to proceed as rapidly as possible to termination of the Part 50 license. Many utilities would not have the extra staff available for the detailed planning effort as long as they were still operating the plant. If the owner were willing to delay the planning effort until after the plant had been shutdown, thus delaying the start of actual decommissioning for several more years, the approach suggested above could be viable.

018-41 Comment: Figure 3.1: The On-Site ISFSI is a part of the decommissioning tasks. The ISFSI is provided to allow quick dismantling of the reactor portions of the facility. However, the ISFSI remains beyond the removal of the reactor facility. This ISFSI must also be decontaminated and dismantled, and is an unavoidable part of decommissioning this facility. This structure is developed solely as part of the decommissioning effort and cannot be charged to operations (as there is no operating plant). See general comment #1. Note that figure is not to scale.

Response: Post-shutdown SNF storage costs are not included in the costs included in the NRC's funding assurance requirements.

018-42 Comment: Page 3.4, 1st paragraph: Per general comment #6, the time value of money is not under NRC jurisdiction, and should be deleted from the final report values.

Response: See the response to Comment 003-3.

018-43 Comment: Tables 3.2 and 3.3: The labor position order in these tables is different from tables in the CECP (Tables B. 1). There are minor totals differences in columns 3 (7.9 years instead of 8.0) and 5 (112.0 instead of 113.5) versus the values of columns 2 and 4.

Response: The discrepancies have been corrected.

Comment: Per General Comment #1, it is not appropriate to allocate only 10% of manpower to decommissioning and 90% ignored as operational in Period 3 and 12% of security in Period 4. This one instance gives a $25 million (no contingency) underestimate ($32 million after 25% contingency).

Response: The actual cost is $27 million w/contingency. As noted numerous times previously, the costs of SNF storage are not included in the costs NRC includes in their funding assurance requirement.

Comment: Period 1 identifies partial plant staff loading during Period 1 with two full-time Plant Engineers. Periods 2 and 3 identify only fully-committed staff. Period 4 identifies several partial plant staff, and odd fractions of loading. The fractional Period 4 staff loadings should be explained, as there is no operational activity from which to "borrow" staff. [0.235 Chem Techs, 1.76 Ops Sups, 2.65 Control Operators, 2.65 Equip Operators, 3.53 Plant Engineers, 0.9 Maint Sups, 3.12 Crafts, 0.9 Indust. Safety Specs., 0.9 Rad Ship Specs, 0.9 Training Engineers.]

Response: Different categories of staff are needed for varying lengths of time during Period 4. Some complete their work and leave early, others stay longer. Most of the staff are gone before the end of the period.

018-44 Comment: Page 3.4, last paragraph: This study should not assign costs to operations. Identify all costs. See general comment #1.

Response: This assignment of staffing was Analyst's choice.

018-45 Comment: Figure 3.2: The utility staffing levels identified here (full-time) for Pre-Decommissioning do not match the decommissioning levels (part-time) identified in Table 3.2.

Response: The figure has been corrected.

018-46 Comment: Page 3.8, last paragraph: The use of Rancho Seco staffing level reductions must be justified for planned shutdown cost estimates. Rancho Seco was not a planned shutdown (no approved plan was in place). The NRC may require different staffing levels and reduction timing for planned shutdowns.

Response: One uses such information as is available. If the commentor has other information that is better or more appropriate, PNL would be happy to consider that information.

018-47 Comment: Figure 3.3: The third note ("Decon can start upon receipt of Decom. Plan approval") perpetuates the erroneous notion that decommissioning only means DECON. Decommissioning begins the moment the reactor is shut down for the final time. The existence of a plan, the decommissioning option used, and the source of funding are all irrelevant to the beginning of decommissioning from a Rate Commission viewpoint.

Response: The word "DECON" has been replaced by "Decommissioning".

018-48 Comment: Page 3.12, paragraph 2: The assumption of 90% costs to "operations" is not valid. See general comment #1.

Response: See the third response to Comments 008-5 and the response to Comment 008a-30.

018-49 Comment: Figure 3.5: The security staff identified (13 total) for Period 3 is not consistent with having spent fuel on site, with Period 2 (37 security staff), or with original studies (39 security staff). The movement of spent fuel to dry cask storage does not reduce site security staff requirements. This may be a result of arbitrarily assigning spent fuel security costs to "operations." See general comment #1.

Response: The security staffing level is based on staffing for an ISFSI, GE Morris, as an example.

018-50 Comment: Table 3.5: Allocation of 90% of costs to "operations" is not valid. List all costs. See general comment #1. Use of "present value" costs in this table is not clear. List both actual 1993 cost and present value if present value must be used.

Response: No present value numbers are presented in the table. A footnote was added to the table to clarify that these costs are cumulative over 6.3 years. Also, see the response to Comment 018-48.

018-51 Comment: Figure 3.6: The security staff identified (13 total) for Period 4 is not consistent with having spent fuel on site, with Period 2 (37 security staff), or with original studies (39 security staff). The movement of spent fuel to dry cask storage does not reduce site security staff requirements. This may be a result of arbitrarily assigning spent fuel security costs to "operations." See general comment #1.

Response: See the response to Comment 018-49.

Comment: DOC staff structure should clarify overhead and support structure. No crew is included.

Response: The crews are direct labor by subcontractors, not DOC staff.

018-52 Comment: Figure 3.7: Apparent loading for Remove Floor Drains task should be 2, not 1.

Response: The correct value is 1 week, as indicated.

018-53 Comment: Figure 3.8: Elapsed time is 49 weeks, not 54 weeks (51 weeks if all tasks in line).

Response: 62 - 8 = 54 No change.

018-54 Comment: Figure 3.9: Elapsed time is 46 weeks, not 50 weeks. Indicated radwaste packaging loading is 46, not 48.

Response: Agreed. Changed on figure.

018-55 Comment: Page 3.21, paragraph 2: What is the "conservative" approximation used to calculate the space occupied by the valve body/ valve stem operator?

Response: The volume of the cylinder defined by the valve body and by the valve stem/operator were summed, using dimensions from vendor literature.

018-56 Comment: Page 3.22, paragraph 1: The assumption that all pipe purchased for construction is installed in the plant with no waste is indeed a conservative assumption. However, this conservatism is not identified in the assumptions section, and should be so noted. As-built drawings should be able to provide precise values for pipe lengths in each system. If the emphasis on precision identified in the unit cost method is indeed as strong as indicated in the assumptions section, this conservative estimate is not appropriate.

Response: Other commentors have suggested that this conservative estimate is too low, without providing any basis for the statement. PNL believes that unless significant quantities of piping have been added to the plant since startup, the inventory based on purchases should indeed by conservative.

Comment: How does the total pipe length identified in this report compare to the pipe lengths identified in the 1980 estimates (NUREG/CR-0130).

Response: The inventories are identical.

018-57 Comment: Page 3.23, last paragraph: The assumption of one-piece removal and barge transport is not valid for most power plants in the US (possibly only for Trojan is this available). The cost for heavy haul from plant to disposal site should be evaluated here for use by other facilities. Reference Appendix F for source of numbers here.

Response: The analyses in this report were for the site-specific situation at Trojan. Analyzing alternative modes of transport of large components was not within the scope of the study.

018-58 Comment: Page 3.25, bullet 2: The nominal 15 foot length should be a function of piping size and weight. See general comment #7.

Response: See the responses to Comments 008a-26, 010-5, 013-11.

018-59 Comment: Page 3.25, bullet 6: No use of waste recyclers and no use of reference site. See general comments #4 and #8.

Response: The reference site for this study was the Trojan site. Consideration of the use of waste brokers and recycling were expressly omitted by NRC direction.

018-60 Comment: Table 3.9: The use of HP techs as undistributed cost may not be appropriate. HP techs are task-specific just as laborers, craftsmen, and foremen.

Response: The allocation of HP staff to the DOC organization was an Analyst's choice.

018-61 Comment: Page 3.26, 1st paragraph: The use of a barge for primary pump removal is not representative. See general comment #8.

Response: Barge transport was the natural choice for the Trojan site.

018-62 Comment: Page 3.28, 2nd paragraph: The use of nominal 15-foot sections of pipe is not reasonable. A 14-inch pipe section 15 feet long could not be carried by 2 workers. See general comment #7.

Response: See the response to Comment 018-58.

018-63 Comment: Page 3.28, last paragraph: The sensitivity analysis on piping cuts shows that direct labor costs for pipe removal would triple if nominal pipe cuts were decreased from 15 feet to 5 feet. The direct labor and dry waste cost increase was estimated to be $4.9 million (about 4% of the total cost listed). This would indicate that exact values for piping length are not that important, contrary to the assumptions identified early in the report (reliability of the cost estimate is a function of the precision of the inventories).

Response: The sensitivity analyses bounded the problem.

Comment: A more significant cost effect may have been ignored, however. The increased radiation dose (from 931 p-rem to 1910 p-rem) can have a much more significant effect. If the average worker annual dose is 4 REM/year (based on an NRC annual dose limit of 5 REM/year), this requires a direct worker staff increase from 233 workers (931/4) to 478 workers (1910/4). Crew loading from Figure 3.7 indicates a worker loading of 14 for these tasks (42 for the higher number of cuts). It is clear that these workers cannot do this work within the NRC annual dose limit. 11 times as many workers will be needed for this task due to the radiation dose limits. It is not likely that worker rotation among tasks will be able to offset this dose limit penalty. This effect (worker radiation dose spreading) was evaluated in the original NUREG/CR-0130 study and addenda. I did not find any mention of this effect in this report.

Response: If the amount of work were increased by a factor of three, and the original schedule were to be met, then the number of pipe cutting crews would also have to triple, providing more persons to share the dose.

018-64 Comment: Page 3.29, 3rd paragraph: The sectioning method used here for the PRT should be duplicated for the PZR and the heat exchangers and steam generators. See general comment #8.

Response: The Pressurizer, Heat Exchangers, and Steam Generators were presumed to be internally grouted, sealed, and disposed intact. No sectioning would have been appropriate.

018-65 Comment: Table 3.11: The radiation dose is unclear. Note d indicates that the radiation dose is based upon 55 mrem/crew-hour. However, the exposure hour column and radiation dose column in Table 3.11 does not indicate this value. Does this indicate 55 person-rem per crew hour? If so, what is the assumed dose rate and crew staffing level? Dose rate indicated is 12 mrem/crew-hour for primary pumps, pzr, and PRT; 6 mrem/crew-hour for misc. RCS piping; and 8 mrem/crew-hour for primary piping. The total dose (24 person-rem) is significantly less than the 931 Person-REM identified just for miscellaneous RCS piping on page 3.28.

Response: The dose value is 9.36 person-rem, not 931 person-rem. Footnote (d) did not belong with the table and has been removed.

018-66 Comment: Page 3.37, 2nd paragraph: Figure 3.7 indicates that the staff loading for bio shield removal is 6.5 people. Doses of 26 person-rem (13.4 pCi/gm or below) would therefore require additional staff to reduce dose rates to below NRC radiation dose limits. There is no indication that this has been done in this report.

Response: The average dose rate for this task was 11 mrem/hr, over about 2,724 person-hours. Some tasks had higher dose rates, others had lower dose rates.

018-67 Comment: Page 3.48, last paragraph: It would help this section if a comparison was made to the original NUREG/CR-0130 estimates, due to the significant change in assumptions made in this update. In the original version 100% of concrete surfaces were scabbled to 2 inch depths (containment building was 37,400 ft^3 Table G.4-4, and other buildings were 338,000 ft^3 Table G.4-5). In this version, only 29% of fuel building, 4% of containment building, and 22% of the aux building are scabbled to 1 inch depths (a total of 1800 ft^3 volume). The values are not consistent, even given the different assumptions between the two versions of the studies. The new version provides a contaminated concrete volume that is only 0.4% of the original version of the report. The cost reduction (based on Table B.4 would be from $13.5 million disposal only to $65,000).

Response: The point was made in the text that the new assumptions on depth and area of scabbling had a large effect on the total cost. The drums were loaded to 600 lb/drum. The burial volume was 3,199 ft^3.

018-68 Comment: Page 3.50, whole page: This sensitivity analysis is apparently flawed. The 0 to 1 inch variation includes only those areas that are currently identified as having one inch removed (a small fraction). Although it is not identified, it appears the cost differential includes only labor costs, not waste disposal costs. The activity concentration needed for unrestricted release that was used for this evaluation should be clearly stated. More discussion needs to be drawn from Reference 7, since this is such a major change from the original study. No mention is made of packing efficiency (waste volume from structural volume .. . typically a factor of 2).

Response: All of the appropriate cost are included. The question being answered by the sensitivity study was: what is the sensitivity of the total D&D cost to the depth of concrete removed by scabbling? It was not a comparison with what the cost would have been if the assumptions of NUREG/CR-0130 were used.

018-69 Comment: Page 3.53,4th paragraph: It is not appropriate to allocate any environmental costs to "operations." See general comment #1.

Response: This was an Analyst's choice. The principal source for releases during the short safe storage period is the SNF in the pool. Thus, the environmental monitoring cost was assigned 90% to SNF storage operations and 10% to safe storage operations.

018-70 Comment: Page 3.56,3rd paragraph: This sensitivity analysis makes clear that one of the primary parameters affecting decommissioning costs is the basic burial rate. The LLW burial costs increase from $21 million (with contingency) to $97 million (with contingency). This increase of $76 million is 59% of the total cost estimate! This highlights the fact that Battelle cannot neglect the standard use of intermediate waste handling companies to reduce burial volumes and burial costs. See general comment #4.

Response: Consideration of waste brokers and recycling was expressly omitted from the analysis by direction of NRC.

018-71 Comment: Section 3.5.2: See general comment #6. This section is overly simplified. Time value of money is a term that reflects the investment value of money, not just the interest that may be earned in an account. The net interest rate is the fund interest rate multiplied by one minus the fund tax rate and minus the decommissioning inflation rate(s). *Discount rate is more properly used with the utility rate-of-return (which does not apply here). A net three percent rate of return is relatively high versus normal inflation, and is very optimistic when compared to the decommissioning inflation rates (primarily waste costs) encountered in the last 15 years. A negative net interest rate (as in the last 15 years) will lead to an underestimate of decommissioning costs.

This funding calculation method was proposed during the development of the Decommissioning Rule and was specifically denied by the NRC during the rulemaking. Although it would be reasonable for the NRC to allow this determination to be made, this will not be controlled by the NRC, but by the decommissioning fund performance and tax rates.

Response: See the response to Comment 003-3

018-72 Comment: Page 3.60, 1st paragraph: The total low-level waste identified in this report was 6,980 m^3 or 247,000 ft^3. The original version (NUREG/CR-0130) provided a total low-level waste volume of 17,900 m^3 or 633,000 ft^3 (Tables G.4-2, G.4-3, G.4-4, G.4-5, and G.4-6). This shows a total reduction factor of 0.39. A significant change of this magnitude needs more justification and explanation.

Response: The reduction was mostly concrete from scabbling. The disposal volume of scabbled concrete was reduced by 330,000 ft^3 from the NUREG/CR-0130 assumptions. The rest of the volume reduction arose from improved packaging densities for the LLW and GTCC wastes.

018-73 Comment: Page 3.60 2nd paragraph: The categories of Labor, Energy, and Disposal identified in the Decommissioning Rule have demonstrably failed in application over the last 8 years. This study conclusively proves that the NRC Decommissioning Rule cost categories -- as identified -- cannot be reasonably used. "T&I" costs are excluded because the "do not follow" inflation trends. But energy costs have decreased, labor increases have exceeded inflation, and waste costs have exceeded inflation tremendously. The "revision" of the formula is far from adequate.

Response: The formula is intended to yield an approximate result, not a precise value for a site-specific plant. Using actual rates in the formula will yield an appropriate result. PNL would be happy to consider other solutions that are equally easy to implement.

018-74 Comment: Page 4.1, 1st paragraph: There is no difference between SAFSTOR1 and SAFSTOR2 here except the duration of interim care and safe storage (the decay period). An estimate of the decay period needed to reach SAFSTOR1 would clarify this. There is no need to assume or postulate this event.

Response: These cases are simply bounding cases. Any actual situation should lie between these bounds.

018-75 Comment: Page 4.1,2nd paragraph: Same comment as DECON DOC. Why use DOC to plan SAFSTOR at this time. There is no real benefit as DOC must learn plant. At most a few management-level specialists to direct utility outage planning staff is needed. See comment for page 3. 1.

Response: See the response to Comment 018-40.

018-76 Comment: Page 4.2,2nd paragraph: The assumption of dry storage for early DECON may have been a good one (see comment for page 2.3). However, it does not follow that dry storage for SAFSTOR is consistent. The dry storage option (incorrectly uncosted) is <u>necessary</u> for DECON to proceed. It is <u>not</u> needed for SAFSTOR or ENTOMB.

Response: PNL agrees, and so stated in the referenced paragraph.

Comment: An option with dry storage and without dry storage should be prepared here. Costs for dry storage cannot be ignored or "allocated" to "operations."

Response: See the responses to Comments 008-5, 008a-30.

018-77 Comment: Page 4.2, 3rd paragraph: The assumption of Safe Storage to the 60 year Decommissioning Rule limit is not appropriate here. The 60-year limit was determined by the original Battelle studies (NUREG/CR-O130). As such, an evaluation should be made as to determination of optimal safe storage times, based upon economic and/or radiation dose benefits from radioactive decay. (These turned out to be 30 to 50 years in NUREG/CR-0130.) Actual contamination levels used by Battelle to determine "unrestricted release" should be identified here.

Response: The analyses were intended to bound the problem, not develop some intermediate case in detail. The primary radiation dose producer is cobalt-60. Specific inventories are not necessary for the purpose of determining the cost of the bounding cases.

018-78 Comment: Page 4.6-,3rd paragraph: The SNF inventory is <u>not</u> reduced to zero. Costs of dry storage must be determined. See general comment #1.

Response: Paragraph has been revised for clarity. What was intended to be conveyed was that the inventory in the pool was reduced to zero, even though the inventory on the site remained greater than zero.

018-79 Comment: Page 4.9,last paragraph: The security staff must be maintained for the dry storage facility. This is a decommissioning cost. See general comment #1.

Response: SNF storage costs are not currently considered decommissioning costs by the NRC for the purpose of defining the funding assurance requirements.

018-80 Comment: Table 4.4: The total cost with contingency is 2.0 million per year. This compares with a NUREG/CR-0130 estimate of $160,000 per year. The bulk of this increase is in security costs (increased from one full-time guard to 12 guards), and inspections, taxes, and licenses. In addition several full-time staff are added, who were not included in NUREG/CR-0130. These new positions should be explained.

Response: The size of the security staff needed to guard the safe stored plant is largely up to the owner's perception of his risks. The indicated staffing would provide 2 persons on site at all times. Some of the other staff could be on a call-in basis, if appropriate. This level of staffing is believed to represent a reasonable upper bound.

Comment: The security staff is not sufficient for possession of spent fuel (in dry storage).

Response: The security staff is equivalent to that at an operating ISFSI (G.E. Morris).

Comment: Property taxes have not been considered decommissioning costs before this study. These taxes exist whether the facility is decommissioned, dismantled, or not.

Response: The taxing rates change when an income-producing property is no-longer producing income. They are also very site-specific. They are also costs to the owner throughout the decommissioning period(s), and should be included in the cost.

Comment: Lack of inclusion of dry storage costs is not appropriate. See general comment #1.

Response: Not NRC policy to include SNF storage costs in those costs that make up the decommissioning funding assurance requirement.

018-81 Comment: Page 4.11, last paragraph: Contamination levels used should be specified here, not just Reg Guide 1.86.

Response: The appropriate source data are referenced.

018-82 Comment: Page 4.12, fast paragraph: Contamination levels used should be specified here, not just Reg Guide 1.86. The estimated decay period needed to reach unrestricted release levels (estimated at between 30 and 50 years in NUREG/CR-0130) should be specified here. Do not use "60 year" basis, as 60 year Decommissioning Rule value was based on original study.

Response: The SAFSTOR cases are bounding analyses. The release levels presently in-force are still Regulatory Guide 1.86. No need to restate them in the report.

018-83 Comment: Section 4.4: See general comment #6. Same comments as for 3.5.2.

Response: See the response to Comment 018-6 and Comment 003-3.

018-84 Comment: Page 5.1, last paragraph: An estimate of the decay period needed to reach unrestricted release would clarify the difference between ENTOMB 1, 2, and 3. There is no need to assume or postulate this event. The 60-year assumption is not appropriate here, as the 60-year period was based on NUREG/CR-0130.

Response: Again, the ENTOMB cases are bounding cases.

Comment: ENTOMB may be viewed the same as SAFSTOR, that is a period of continuing care may be followed by DECON. It is not necessary to ignore a final DECON step.

Response: The intent of the ENTOMB scenarios is to not have to remove anything from the site at the end of the entombment period, whatever the length. SAFSTOR, on the other hand, may require removal of all of the plant equipment, etc., at the end of the SAFSTOR period.

018-85 Comment: Page 6.1, 1st paragraph: The statement that changes in the industrial and regulatory situation have forced revisions to viable decommissioning alternatives is not correct. The one change that has forced the change in viable decommissioning alternatives is the non-availability of the DOE to accept spent fuel within 120 days after plant shutdown. This one change (not industrial or regulations) effects a delay on removal of spent fuel and therefore DECON activities.

Response: PNL considers the ban on reprocessing of SNF and on wet-transport of SNF as falling into the category of industrial and institutional changes.

Comment: The statement that major decommissioning activities must be delayed for at least 5 years is also not correct. Major decommissioning activities include all plant modifications for SAFSTOR and ENTOMB. This statement perpetuates the attitude that DECON is the only real method for decommissioning.

Response: The term MAJOR as used here is intended to mean physical disassembly and disposal of plant components and systems. All alternatives have disassembly delayed until the SNF has been removed from the storage pool.

Comment: In fact, DECON has been removed as a viable alternative. The only question is how long the continuing care period will be for SAFSTOR or ENTOMB. A secondary question is will spent fuel be stored in dry casks or in the spent fuel pool. See general comment #3.

Response: The answers to these questions are simply a matter of definitions. DECON has been redefined for the purposes of this report. Also, see the response to Comment 018-3.

Comment: The evaluation of retaining spent fuel in the spent fuel pool until final decontamination and dismantling (SAFSTOR) <u>should</u> be evaluated. The possibility of dry storage may turn out to be economically unsound, based on duration of continuing care and installation/decommissioning costs for the dry storage facility.

Response: See Appendix D, Section D.4.3.

018-86 Comment: Page 6.1,2nd paragraph: "Undistributed costs" are not a cost element, they are an arbitrary classification of costs. These costs labor, license fees, insurance, energy, etc. are very real costs and need to identified. Calling these costs "undistributed" fails to identify those areas that contribute to true decommissioning costs. One of the reasons these items are lowered in apparent importance is the improper "allocation" of significant labor and construction costs to "operations" that are not included in these totals.

Response: Undistributed costs, as used in this report, are those costs not readily assignable to individual tasks.

Comment: There should be a conclusion here with regard to the significant reduction in expected radioactive waste volumes (roughly 40% of prior estimates). This reduction (contaminated concrete waste is determined to be 0.4% of prior estimates) is of major significance to the decommissioning cost.

Response: See the responses to Comments 018-67 and 018-68.

Comment: Many of the overhead labor costs are not incurred unless decontamination and dismantling ("active" decommissioning) is taking place. This conclusion (the strong incentive to perform DECON on multiple shifts is correct, but should not be overemphasized, as it does not necessarily follow that DECON should be done as soon as possible (as this report asserts elsewhere). Once final decontamination and dismantling is begun, then multiple shifts are more economic.

Response: PNL does not disagree with the above statement.

018-87 Comment: Page 6.1, 3rd paragraph: The LLW disposal costs in this report are primarily a function of waste volume charges. There is no basis given in this report for the conclusion that LLW volume disposal charges "can only increase with time." The rest of this conclusion is unsupported.

Response: Based on historical trends and predicted charge rates at yet-to-be-built regional compact LLW disposal facilities.

Comment: Waste costs are not just disposal costs. Waste costs include transportation, activity surcharges, weight surcharges, packaging costs, and labor costs. Waste burial costs are indeed a major portion of the total. Separating disposal costs from the rest of the waste costs and lumping the rest of the waste costs into "undistributed costs" is inappropriate as it conceals the effect of much of the waste handling costs.

Response: The costs of packaging, transport, and disposal are all estimated explicitly for each major task. One can choose whichever and how many to include in waste costs as he chooses. See Table C.1 in Appendix C.

Comment: Battelle has not evaluated the effect of using intermediate waste handling companies on the costs of decommissioning. These companies recycle some wastes and perform significant volume reduction on the rest. See general comment #4. Use of these companies may obviate the need for "aggressive decontamination efforts" that increase worker radiation dose and result in waste forms that are more easily mobilized after disposal.

Response: Consideration of waste brokers and recycling was expressly omitted by NRC direction.

018-88 Comment: Page 6.2, 1st paragraph: The insurance and security assumptions used in this report were not identified earlier as "conservative." Conservative assumptions are not appropriate for this report. These costs are not, however, conservative. These costs must include the insurance and security of spent fuel that has been assumed to be in dry storage. These costs do not go away simply because the plant has placed this risks into a new structure. The hazards from spent fuel are far higher than hazards from the retired plant (activated and contaminated material). See general comments #1 and #5.

Response: The objective of this comment is not obvious. No response.

Comment: The NRC and decommissioning licensees do not have any control over determining "appropriate levels" of insurance. This statement is a non-sequitur. It is only insurance companies that set levels of insurance.

Response: NRC can require certain levels of insurance coverage. The insurance companies determine what the premium is for insuring against the risks.

Comment: Security labor costs can indeed be reduced by relying more on electronic systems. This was done in the original NUREG/CR-0130 reports. However, security costs must be based upon the decommissioning hazards -- the spent fuel that exists as a true decommissioning cost whether it is in the spent fuel pool or in dry storage.

Response: Current NRC policy does not include SNF storage costs in those costs included in the funding assurance requirement.

018-89 Comment: Page 6.2,2nd paragraph: This report provided no basis for the 3% net <u>interest</u> rate (not discount rate) used for present value costs. Obviously, a different assumed net interest rate will result in a different cost order. The order of cost differences is of less importance than the quantification of those costs. A summary table here would improve this section tremendously.

Response: The 3% net discount rate was a study assumption, based on historical values over long periods of past experience.

018-90 Comment: Page 6.2,3rd paragraph: The present value method of comparison was expressly denied during the development of the Decommissioning Rule. The present value method requires strong support for the assumed interest rates, tax rates, and inflation rates to be used. None of this supporting information is provided in this report.

Response: See the response to Comment 003-3.

Comment: The costs given ignore major portions of costs of decommissioning. This report has ignored ("allocated") $32 million in Period 3 and 4 labor costs alone (Table 3.2 & 3.3). This report has also improperly ignored all costs associated with movement and storage of spent fuel. No estimate of spent fuel cost was provided in these totals. See general comment #1.

Response: These so-called "ignored" costs are not D&D costs under current NRC policy. They are presented in the report for completeness, but not included in the estimated total cost of license termination.

018-91 Comment: Page 6.3, 1st paragraph: The standard occupational exposures are not "large" when compared with operating plants. This does not reflect whether these doses are large for decommissioning. The pipe length assumption used in this report (15 feet) is evaluated on page 3.28 to show a radiation dose of up to 1910 person rem instead of the 931 person rem. This difference is identified to be absorbed by a work crew of 42 people. The additional 1,000 person rem is a large radiation dose. To determine a "large" dose, one must indicate the staff over which the exposure is spread.

Response: As discussed in the response to Comment 018-63, if the work is increased, more staff are needed to stay on schedule. Thus, more persons to absorb the additional dose.

018-92 Comment: Page B.5,Table B.1: These positions are not in the same order as Tables 3.2 and 3.3.

Response: Statement is true. Has no effect on the analyses.

018-93 Comment: Page B.6,Table B.1: Typographical error. Utility Overhead Position should be DOC. HP Technician should be included in Dedicated Decontamination Workers.

Response: The typo was fixed. In this analysis, the HP staff are members of the DOC staff. However, each work crew has an HP attached at least part-time.

018-94 Comment: Page B.7,Section B.3: The escalation factor of 2.11 is not appropriate for an item of this size and importance (2.5% of listed total). Nuclear utility construction costs have changed significantly from 1978 (when plant construction was common) to 1993 (when no US plants are under construction). This item should be re-estimated.

Response: Labor and materials costs have escalated at about that rate. There is no reason to use any other factor.

018-95 Comment: Page B.24,section B.7.2: The "industry expert" used should be identified here. There is no avoiding the speculative nature of repository costs. I recommend that these costs be derived from DOE spent fuel disposal contract rates.

Response: The repository disposal rates were derived from analysis of repository life-cycle-costs (LCC), performed for DOE-OCRWM several years ago. The LCC estimates may have changed since the value used in this report was calculated, but probably not by very much.

018-96 Comment: Page B.32,Table B.7: Note (b) indicates that some insurance costs are "not" decommissioning costs. Per general comment #1, these are definitely decommissioning costs. After contingency this adds $10.7 million to the cost of DECON.

Response: Not included in NRC's costs that define decommissioning financial assurance requirements.

018-97 Comment: Page B.48,2nd paragraph: Licensing costs for decommissioned (shut down) reactors are decommissioning costs per general comment #1. These fees, or a fraction thereof must be included in these estimates. Assuming NRC fees would drop to 25% of the fees for an operating plant, this would be a yearly cost of $0.7 million, while spent fuel is on site. This adds another $4.9 million over 7 years ($6. 1 million with contingency).

Response: Based on review of the regulations and discussions with NRC staff, it appears that the Part 171 fees don't apply to a shutdown reactor. Costs for services rendered by NRC staff are applicable.

018-98 Comment: Page D.2,2nd paragraph: This paragraph implies that calculations are performed for 14 year delays while maintaining spent fuel in the fuel pool. This is not done. Only the 7 year delay coupled with the ISFSI is identified in the main report.

Response: The paragraph has been rephrased to improve clarity. Only the 7-year pool storage was examined in the main report. The 14-year delay, attributable to DOE's acceptance schedules and when the pool SNF inventory reaches zero, was not examined in detail.

018-99 Comment: Page D.14, 4th paragraph: There is no requirement for a minimum of 5 years storage of spent fuel. Fuel stored less than 5 years is non-standard, but acceptable per Part 192, Appendix E.

Response: The statement is correct. However, the probability of acceptance of non-standard fuel into the OCRWM system early in the acceptance queue seems unlikely.

018-100 Comment: Page D.15, last paragraph: There should be no annual license fee or labor cost difference between a license under part 72 or a modified part 50 license, as license conditions would be based on safety considerations that should be independent of the specific NRC regulation.

Response: No response. The comment is a statement.

018-101 Comment: Page D.17,section D.4.3: Present-value costs are not appropriate for this cost estimate (see general comment #6). Use constant 1993 dollars.

Response: PNL disagrees. For SNF storage, the present value analyses are made over relatively short periods of time, and involve normal types of costs, not disposal costs. This technique is normally used to compare alternative paths to the same endpoint, especially when the time-distribution of expenditures differ between the alternatives.

018-102 Comment: Page D.18, Table D.4: Error in table. ISFSI total should be 680,901 not 761,901. Total Annual Operating costs should be 1,945,582 not 2,026,582.

Response: The error in the table has been corrected. Property taxes were inadvertently omitted from the table. $761,901 is the correct value.

Comment: Footnote (c). Entire cost is decommissioning cost. See general comment #1.

Response: See response to Comment 018-1.

Comment: Footnote (g). Describe <u>how</u> values were derived from Table 3.2 It is not self-evident.

Response: Divide the totals of columns 8 and 12 by 6.3.

081-103 Comment: Page D.19, last paragraph: The method for estimating decommissioning costs (10% of construction costs) is not appropriate for nuclear facilities. The ISFSI will be contaminated. LLW will be generated. Highly radioactive SNF will be handled. Decommissioning of typical ISFSIs have been estimated to run $7 million, not $2.6 million.

Response: The level of difficulty is a function of the storage system used. If the proposed multipurpose canister were employed, there would be little or no contamination with which to deal. Only clean concrete structures would remain after the canistered fuel had been shipped. Other types of storage systems could have some contaminated components, such as the drywell tubes and the fuel handling machine in a vault system. The 10% of construction costs is probably an adequate estimate for most of the simple systems.

018-104 Comment: Page D.22, last paragraph: Typographical error. The reference number for DATING is 21, not 20.

Response: The reference number has been corrected.

018-105 Comment: Page D.23, 1- paragraph: What is the source of the "safety factor" used for allowable values?

Response: Engineering judgement.

018-106 Comment: Page D.26, 2nd paragraph: Spent fuel storage is not unrelated to decommissioning as indicated in this evaluation. See general comment #1.

Response: NRC does not currently include SNF storage costs in those costs included in determining the amount of funding assurance required.

018-107 Comment: Page F.3,2nd paragraph: This section mentions the sectioning of steam generators as well as the barge shipment of whole steam generators. No mention is made of the first alternative in the main report. The cost information for sectioning should be made the standard cost, since barge shipment is not available at most reactor sites.

Response: This statement refers to comparing the intact removal approach to the sectioned approach suggested in NUREG/CR-0130. No detailed trade-off study has been documented.

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER *(Assigned by NRC. Add Vol., Supp., Rev., and Addendum Numbers, if any.)*
NUREG/CR-5884
Vol. 2

2. TITLE AND SUBTITLE
Revised Analysis of Decommissioning for the
Reference Pressurized Water Reactor Power Station

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

3. DATE REPORT PUBLISHED

MONTH	YEAR
November	1995

4. FIN OR GRANT NUMBER
B2902

5. AUTHOR(S)
G. J. Konzek, R. I. Smith, M. C. Bierschbach, P. N. McDuffie

6. TYPE OF REPORT
Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION – NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*
Battelle-Pacific Northwest Laboratory
Richland, WA 99352

9. SPONSORING ORGANIZATION – NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*
Division of Regulatory Applications
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES G.J. Mencinsky, NRC Project Manager

11. ABSTRACT *(200 words or less)*

With the issuance of the final Decommissioning Rule (July 27, 1988), owners and operators of licensed nuclear power plants are required to prepare, and submit to the U.S. Nuclear Regulatory Commission (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 provide some of the needed bases documentation.

This report contains the results of a review and reevaluation of the 1978 PNL decommissioning study of the Trojan nuclear power plant (NUREG/CR-0130), including all identifiable factors and cost assumptions which contribute significantly to the total cost of decommissioning the nuclear power 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 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, and to different depths of contaminated concrete surface removal within the facilities is also examined.

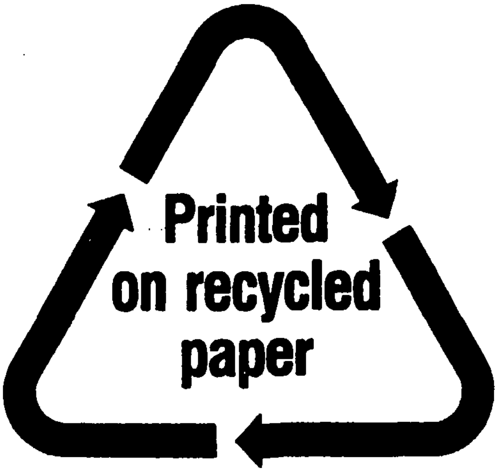
12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*
pressurized water reactor (PWR)
decommissioning
cost/dose/sensitivity

13. AVAILABILITY STATEMENT
Unlimited

14. SECURITY CLASSIFICATION
(This Page)
Unclassified
(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE



Federal Recycling Program