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

9512260293 951130
PDR NUREG
CR-5884 R PDR

210173

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

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 Battelle Memorial Institute, nor any of their employees, **makes any warranty, expressed or implied, or assumes any legal 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**. The views expressed in this report are not necessarily those of the U.S. Nuclear Regulatory Commission.

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

Page

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 $)	(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 $\$50/ft^3$, $\$100/ft^3$, $\$300/ft^3$, $\$500/ft^3$, and $\$1000/ft^3$. The associated disposal facility fees, surcharges, and taxes were held constant. All other parameters of the CECP calculation were also held constant. The results of the analysis showed that the total cost for DECON increased almost linearly with increased disposal cost, from $138.72 million for the $\$50/ft^3$ rate to $506.27 million for the $\$1000/ft^3$ 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

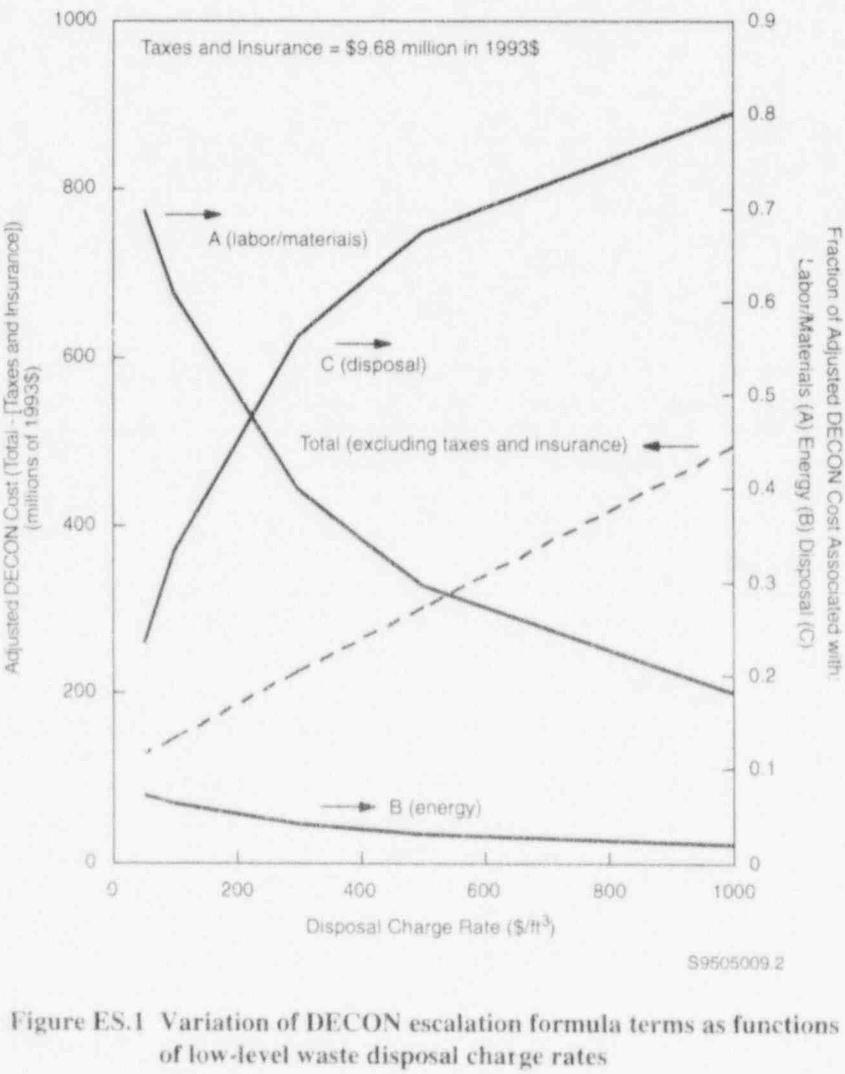


Figure ES.1 Variation of DECON escalation formula terms as functions of low-level waste disposal charge rates

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).

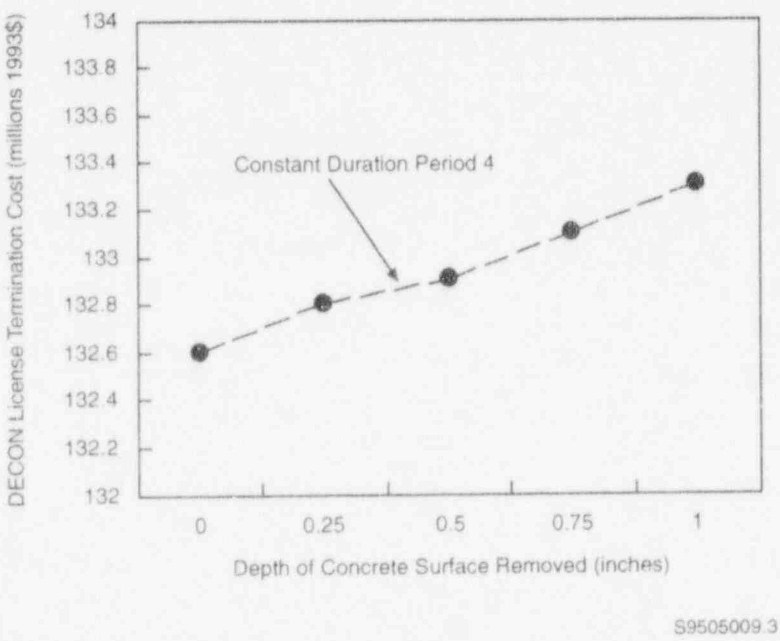


Figure ES.2 Sensitivity of license termination cost to varying depths of contaminated concrete removal during DECON

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.

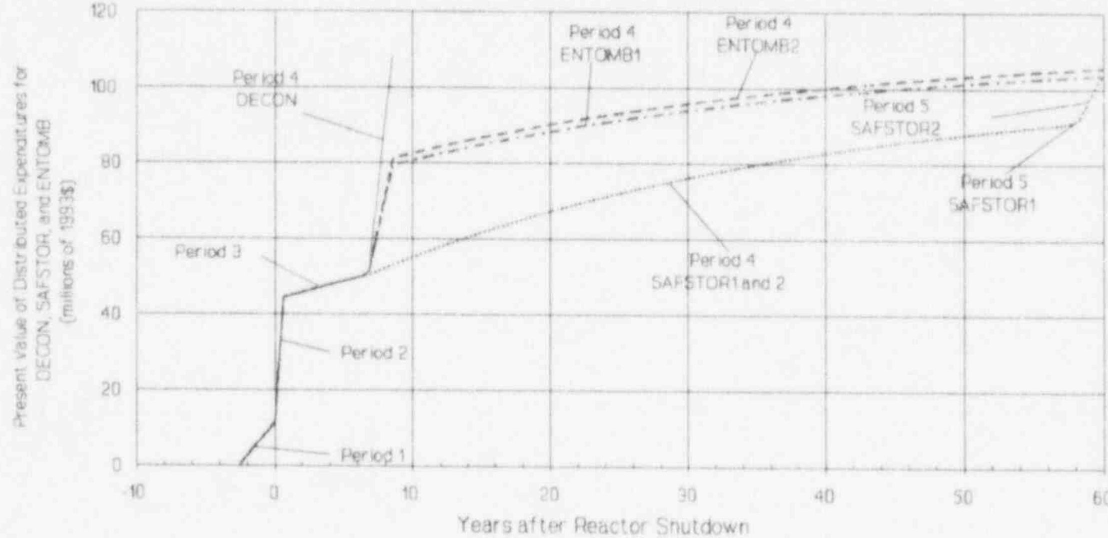


Figure ES.3. Present value of time-distributed expenditures for DECON, SAFSTOR, AND ENTOMB

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

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.

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.

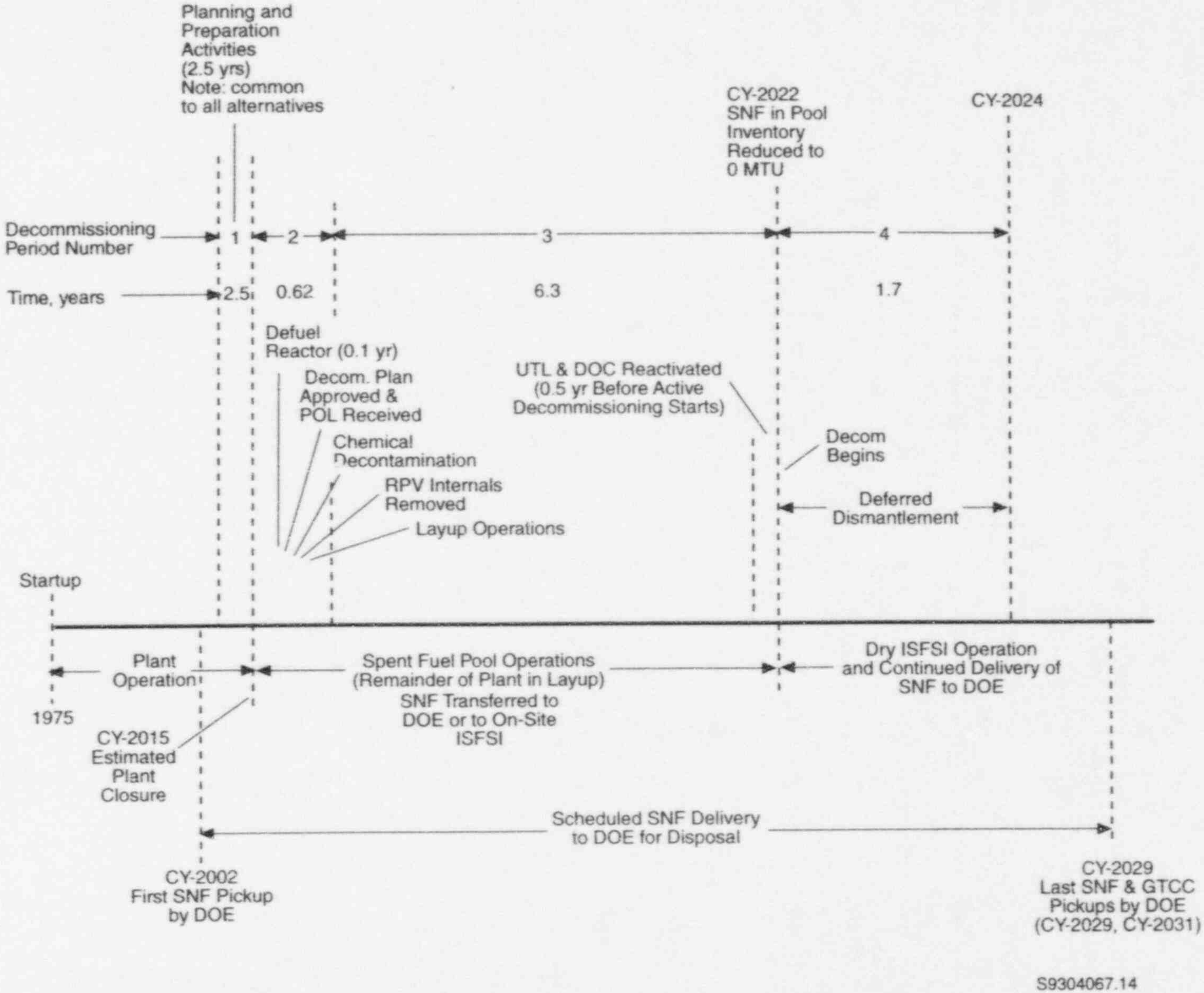


Figure 3.1 Schedule of activities during the four periods of DECON

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

Position	Annual salary[a]	Person-years per period and period costs in 1993 dollars							
		Period 1 (2.5 yr)		Period 2 (0.62 yr)		Period 3[b] (6.3 yr)		Period 4 (1.7 yr)	
Project Manager	220,272	2.5	550,680	--	--	0.5	110,136	1.7	374,462
Asst. Project Manager	178,275	2.5	445,688	--	--	0.5	89,138	1.7	303,068
Secretary/Clerk	47,829	12.5	597,863	--	--	2.5	119,573	13.6	650,474
Planner/Schedule Engineer	127,101	--	--	--	--	--	--	5.1	648,215
Quality Assurance Supvr.	147,653	--	--	--	--	--	--	1.7	251,010
Quality Assurance Engineer	83,825	2.5	209,563	--	--	0.5	41,913	1.7	142,503
Quality Assurance Tech.	76,580	--	--	--	--	--	--	6.0	459,480
Health Physics Supvr.	148,643	--	--	--	--	--	--	1.7	252,693
H. P. ALARA Planner	124,228	--	--	--	--	--	--	1.7	211,188
Sr. Health Physics Tech.	124,228	--	--	--	--	--	--	5.1	633,563
Health Physics Tech.	76,580	--	--	--	--	--	--	21.0	1,608,180
D&D Operations Supervisor	147,653	--	--	--	--	--	--	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.

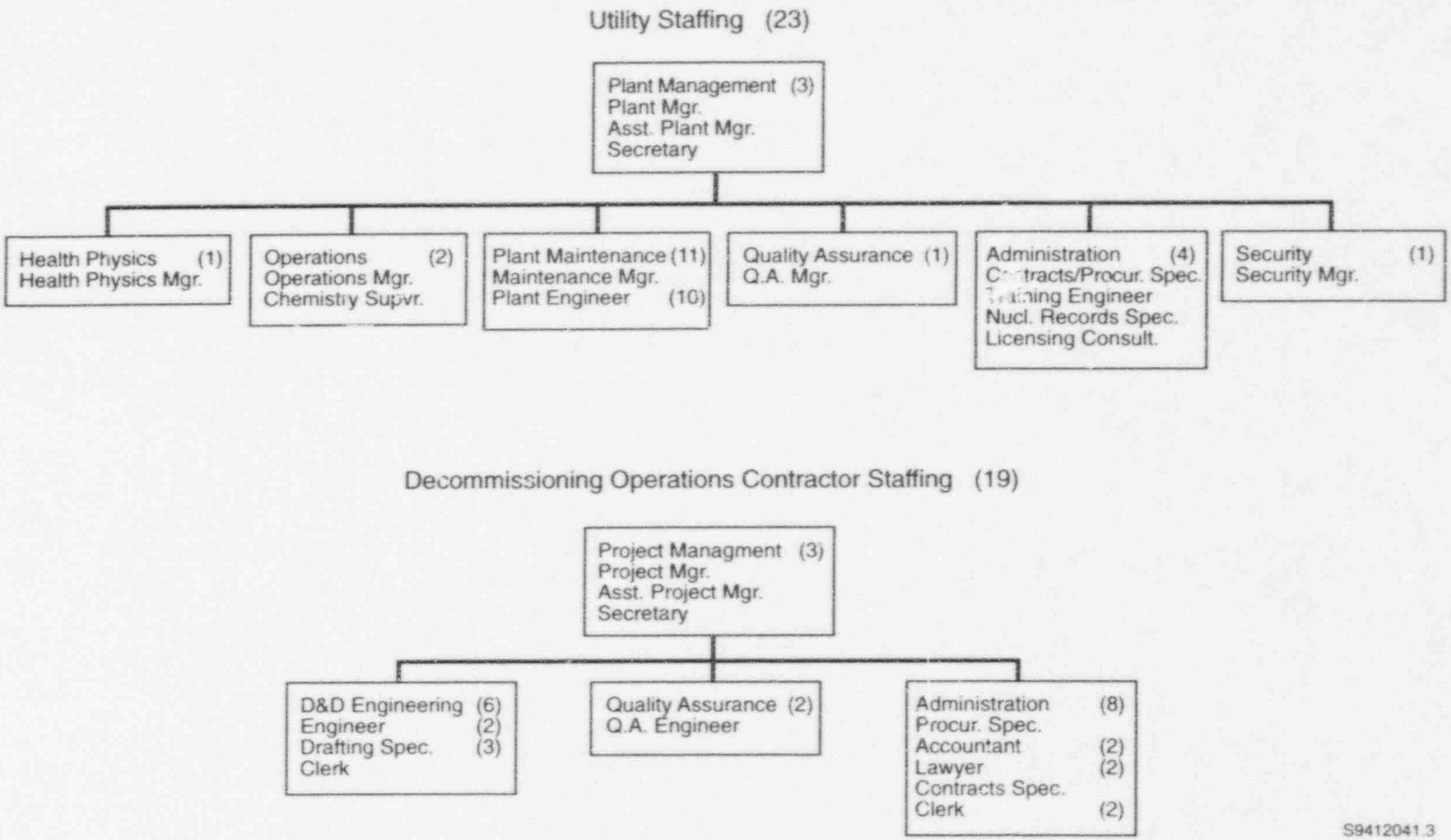


Figure 3.2 Utility and DOC staff structure and staffing levels during pre-decommissioning: Period 1

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.

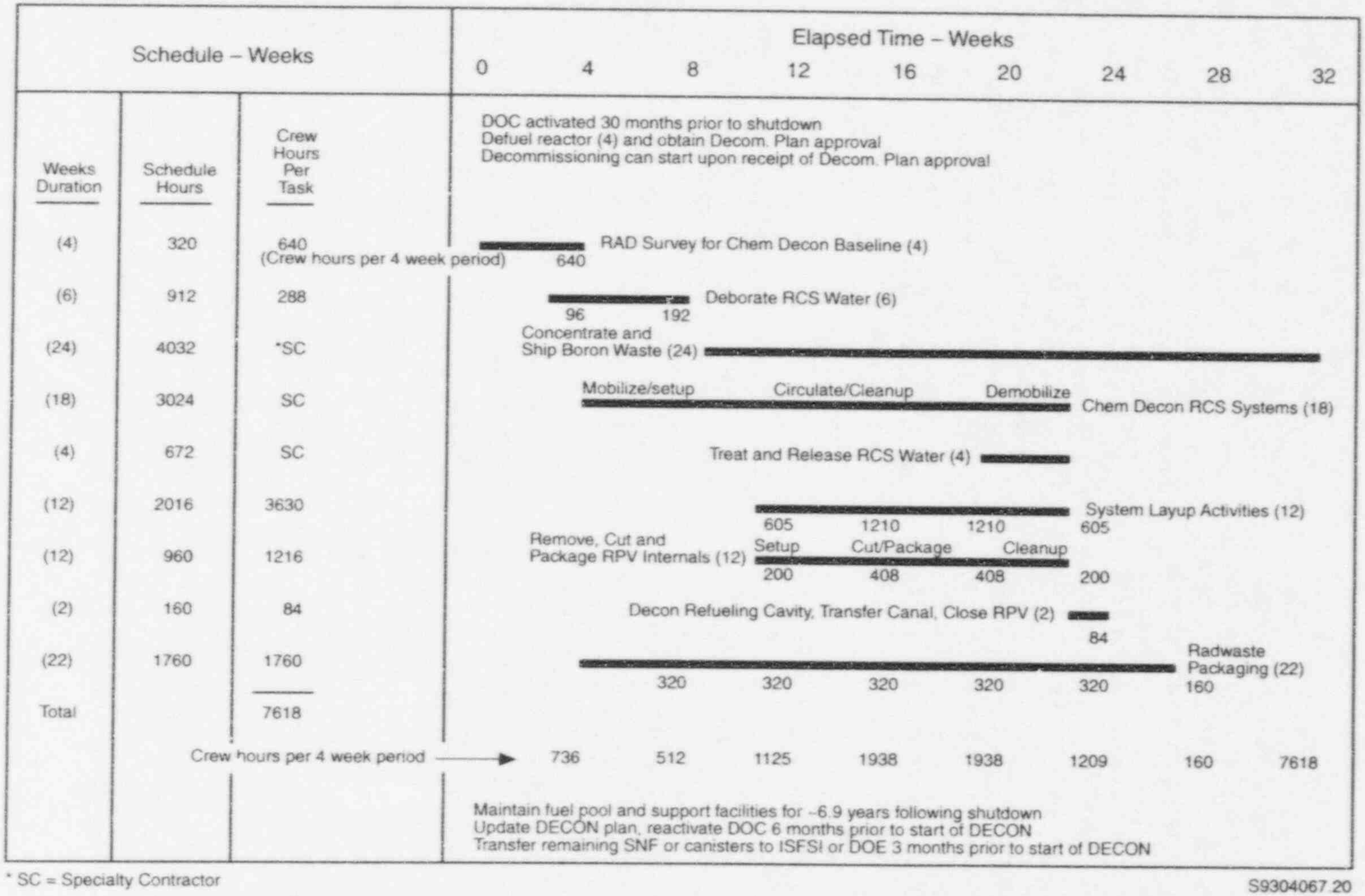


Figure 3.3 Schedule of activities during deactivation: Period 2

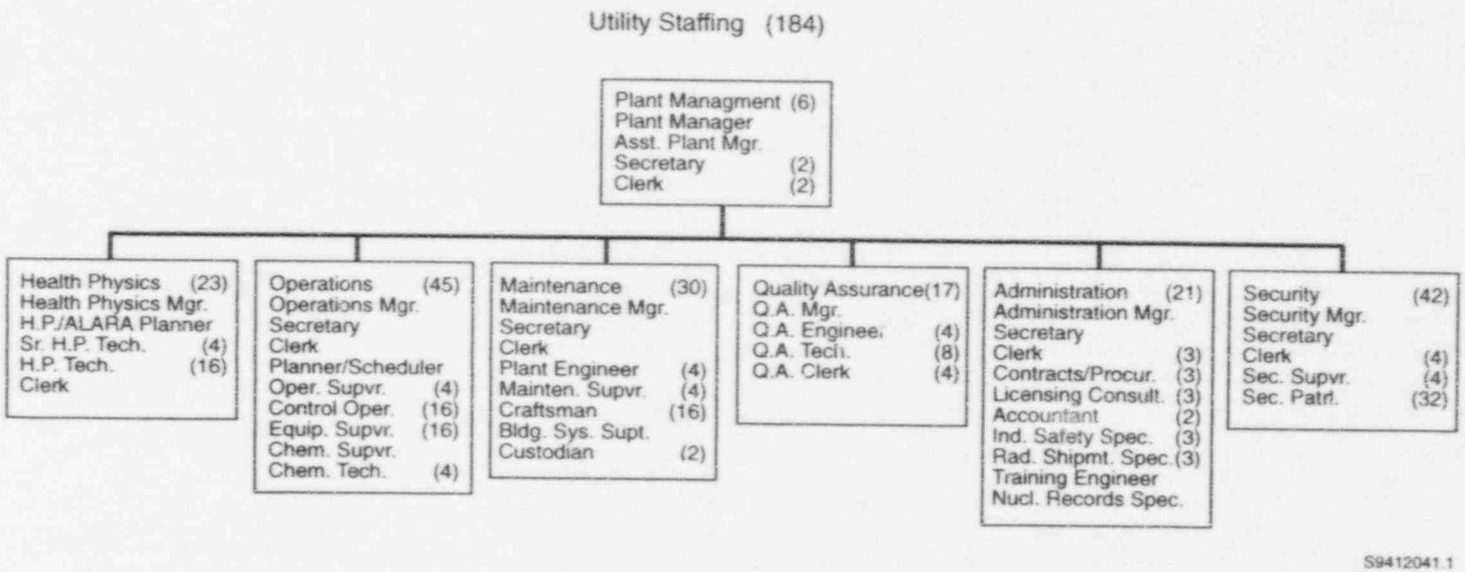


Figure 3.4 Utility staffing structure and levels following receipt of possession-only license: Period 2

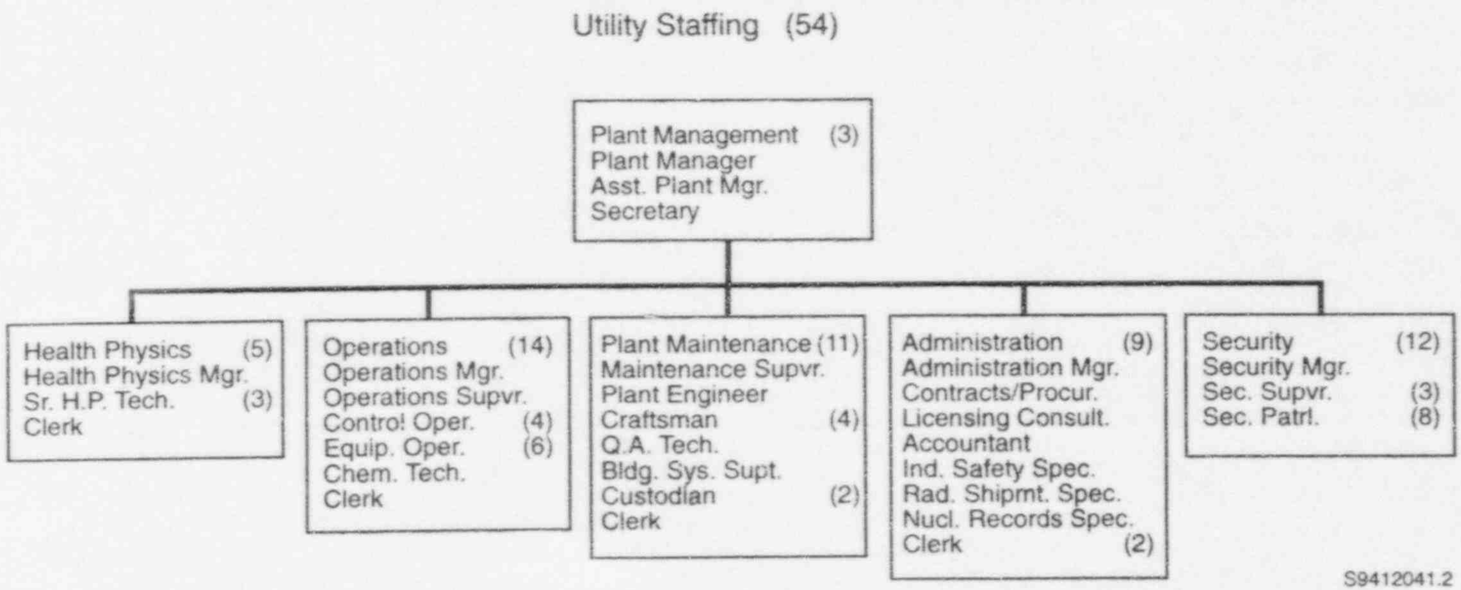


Figure 3.5 Utility staffing structure and levels during safe storage/SNF pool operations: Period 3

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.

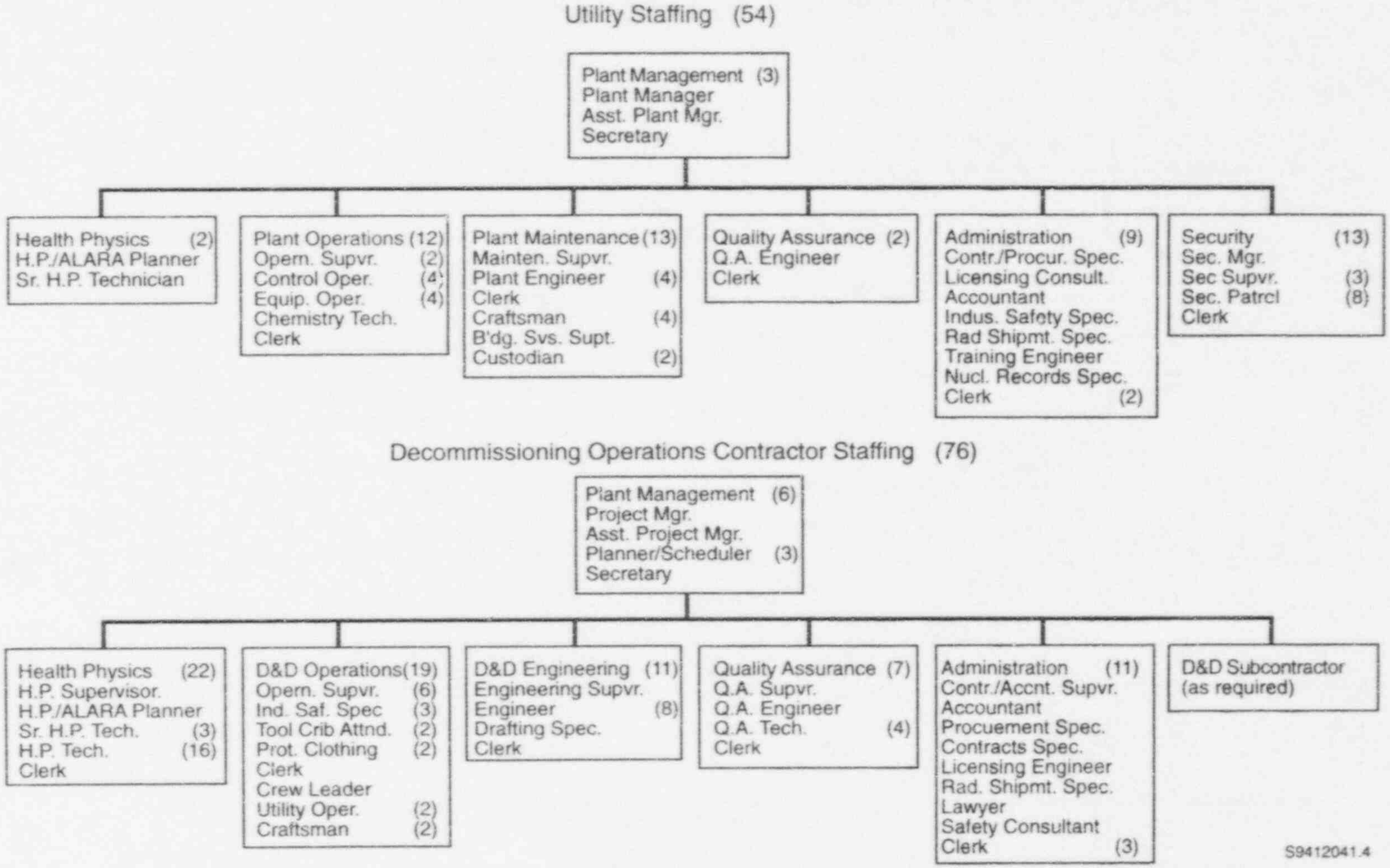
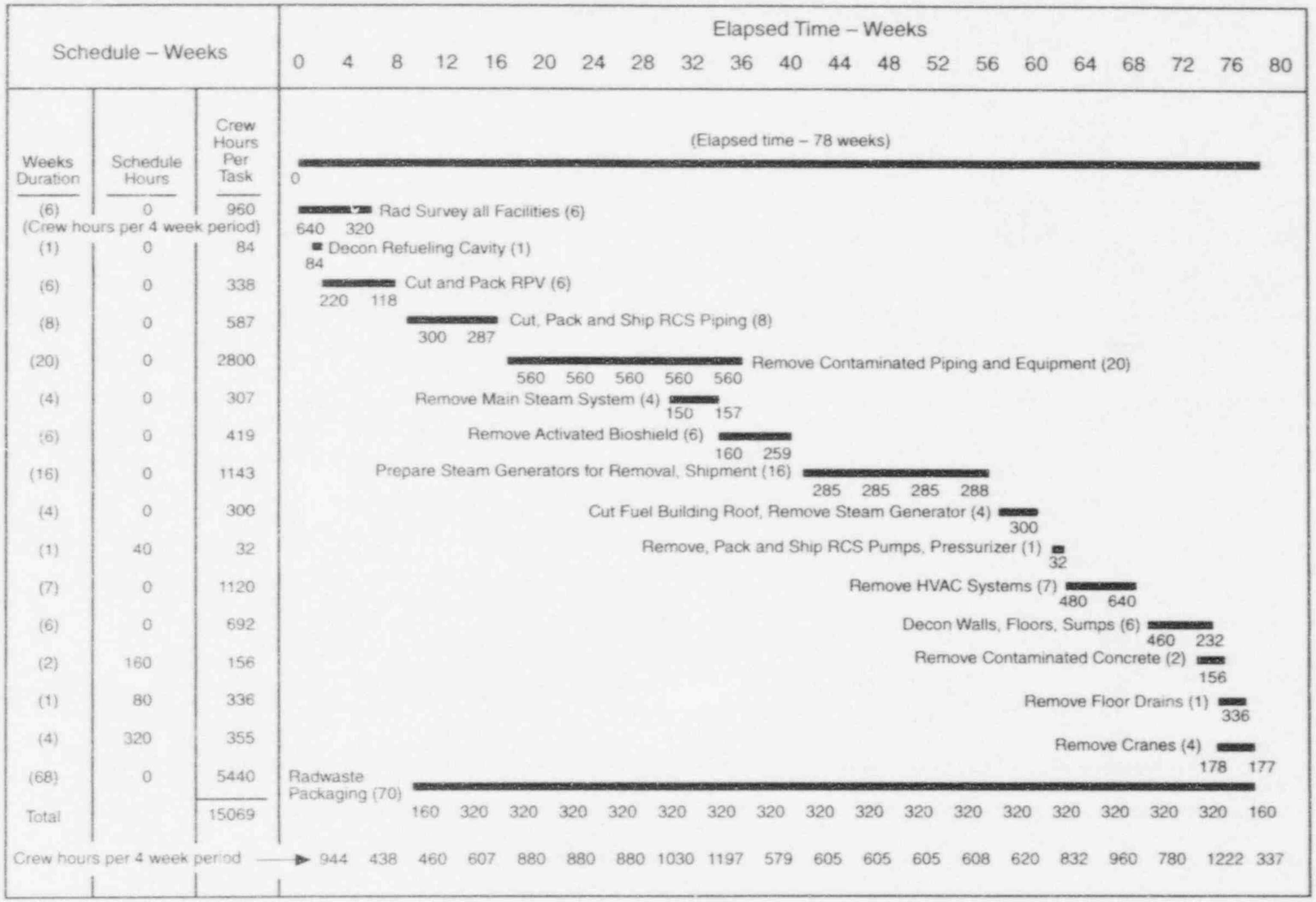
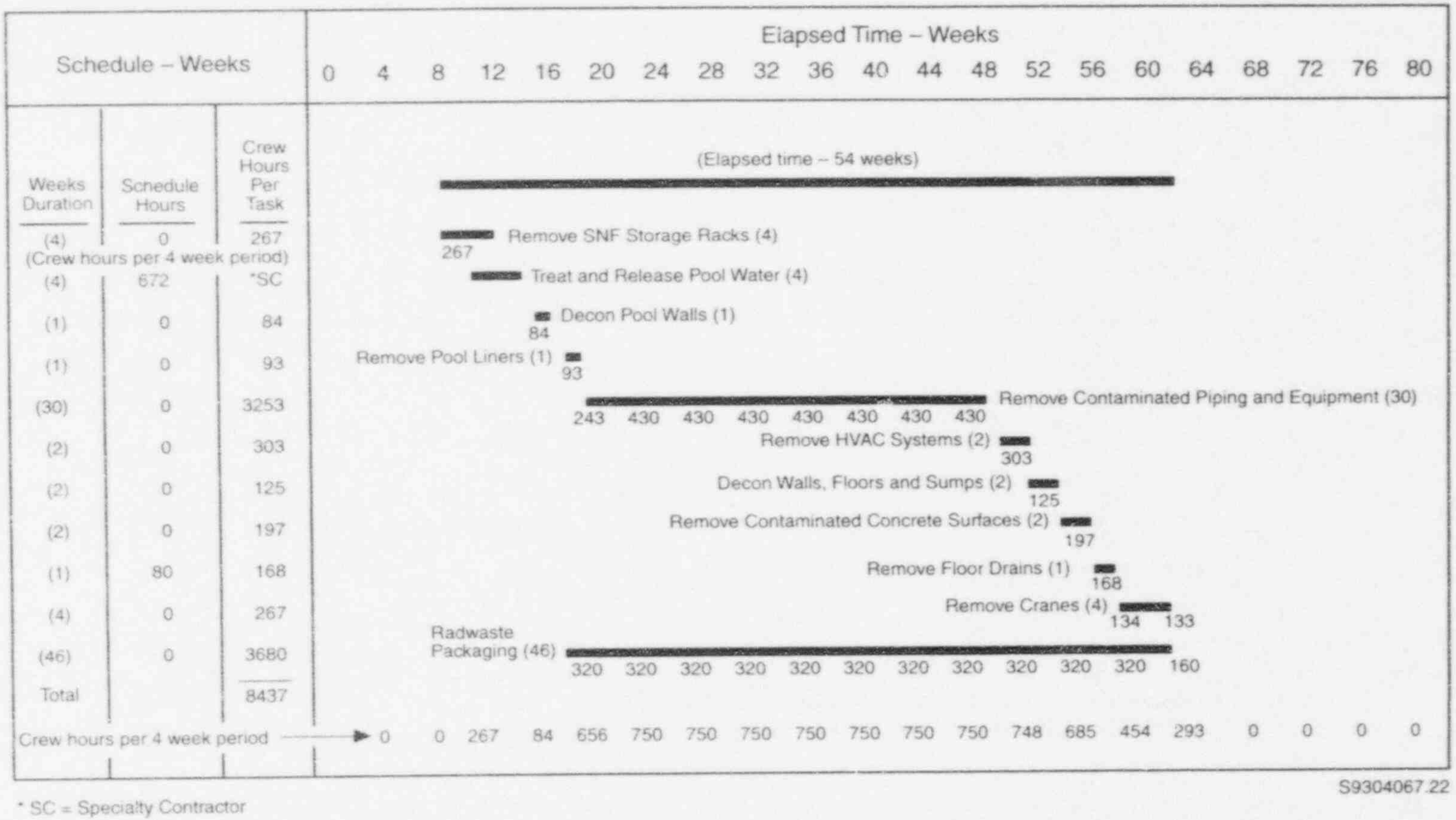


Figure 3.6 Utility and DOC staff structures and staffing levels during dismantlement: Period 4



S9304067.21

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



* SC = Specialty Contractor

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

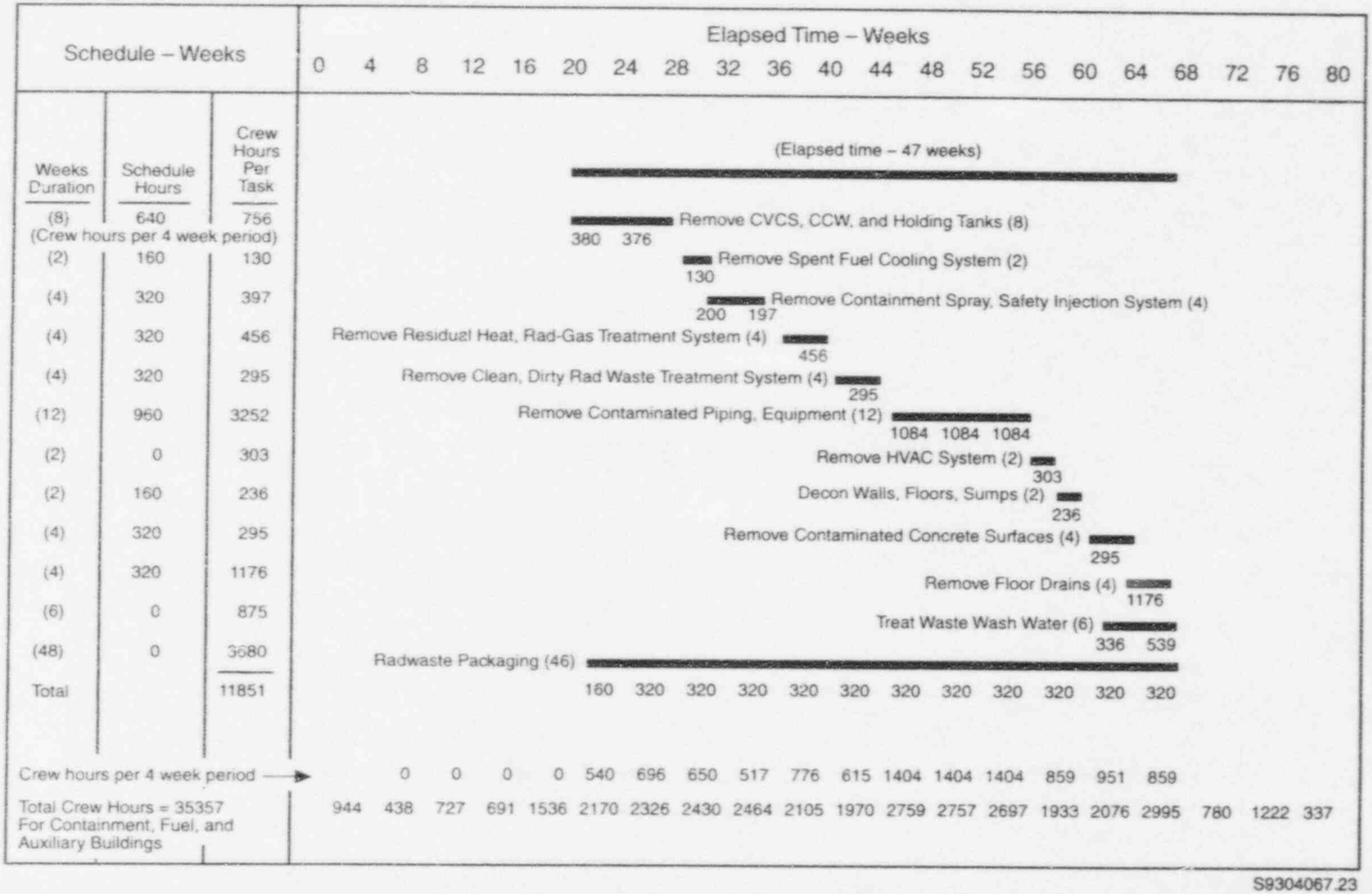


Figure 3.9 Schedules and staffing for dismantlement activities in the Auxiliary Building

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 re-racking 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

	Estimated costs (1993 $)		
Cost element	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		Total cost ($)
					Volume (ft³)	Cost ($)(b)	
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/m³ attributable to ^{152}Eu was about the same as the Ci/m³ 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

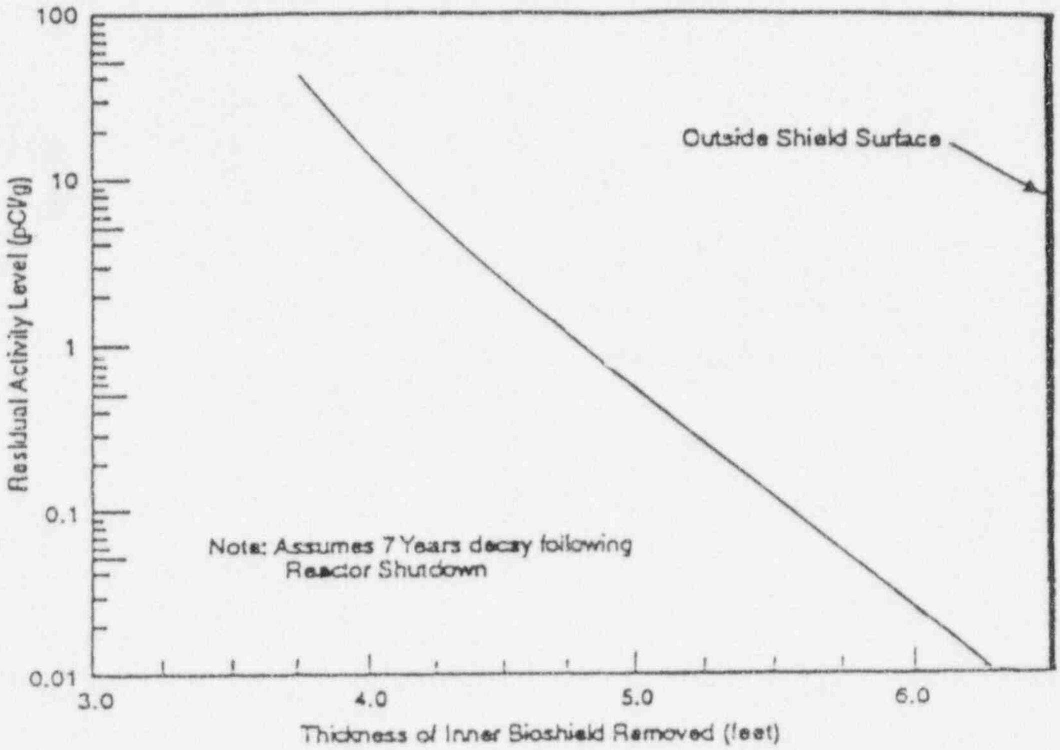


Figure 3.10 Residual radioactivity in the activated concrete bioshield as a function of the depth of concrete removed during DECON

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 [illegible] 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 [illegible]55, 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 $4[illegible]

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 cost 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.

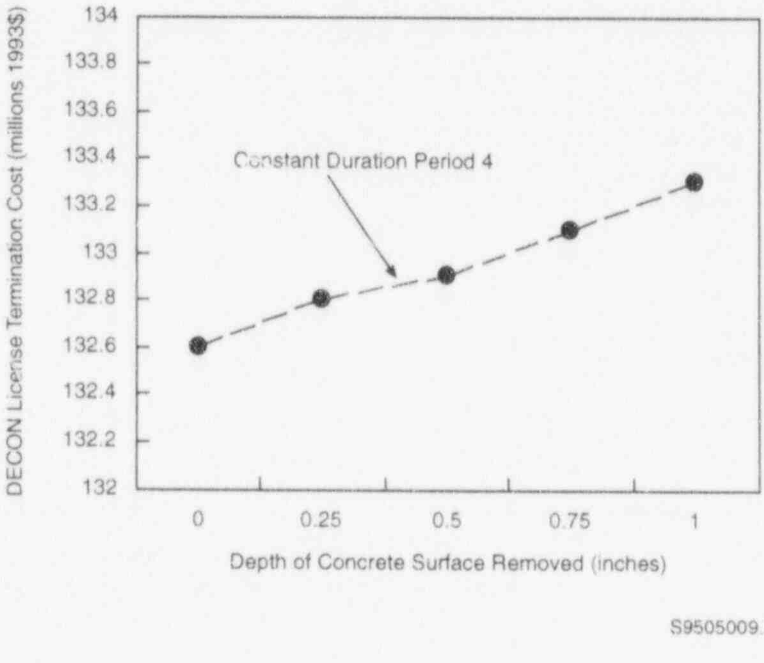


Figure 3.11 Sensitivity of license termination cost to varying depths of contaminated concrete removal during DECON

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 Radiac-wash™ (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/ft^3, $100/ft^3, $300/ft^3, $500/ft^3, and $1000/ft^3. The associated disposal facility fees, surcharges, and taxes were held constant. All other parameters of the CECP calculation were also held constant. The results of the analysis showed that the total cost for DECON increased almost linearly with increased disposal cost, from $138.72 million for the $50/ft^3 rate to $506.27 million for the $1000/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]

Disposal charge rate ($/ft^3)	Costs, with contingency (millions of 1993 $)		Terms for LLW disposal cost escalation formula[b]			
	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.

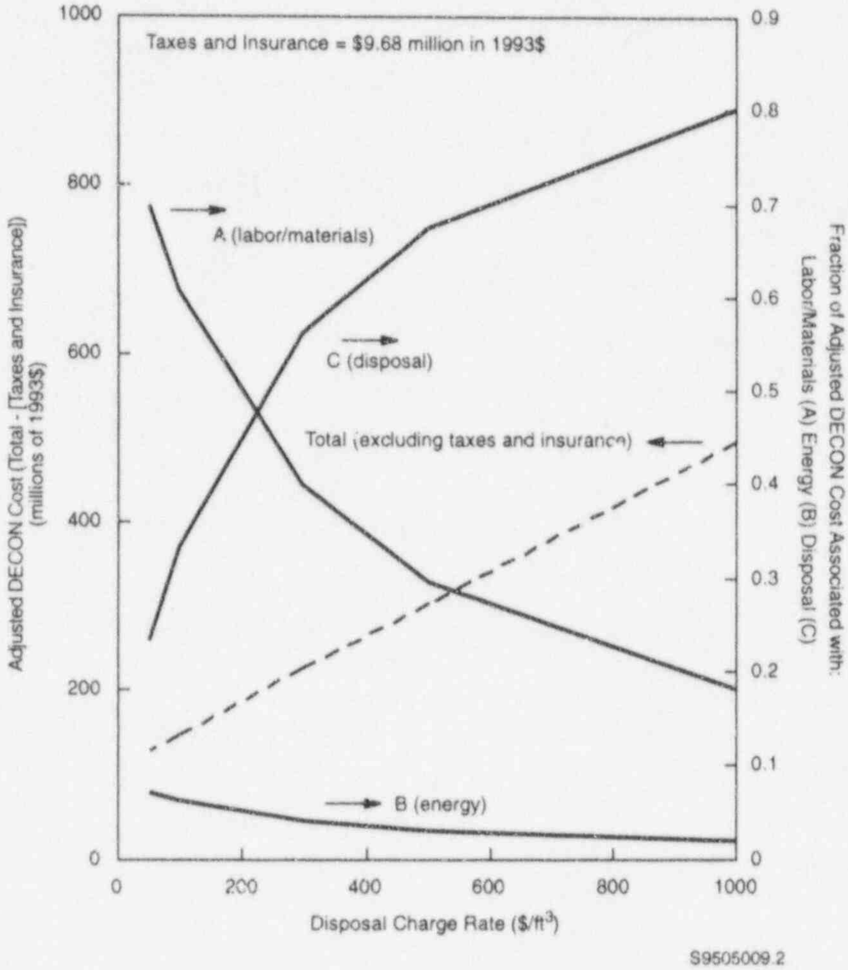


Figure 3.12 Variation of DECON escalation formula terms as functions of low-level waste disposal charge rates

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:

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

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:

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

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

$[\text{Total Cost} - (T \,\&\, I\ \text{Cost})]_{(1993\,\$)}$ = \$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[11]). 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

Period number	Estimated costs (1993 $) 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.

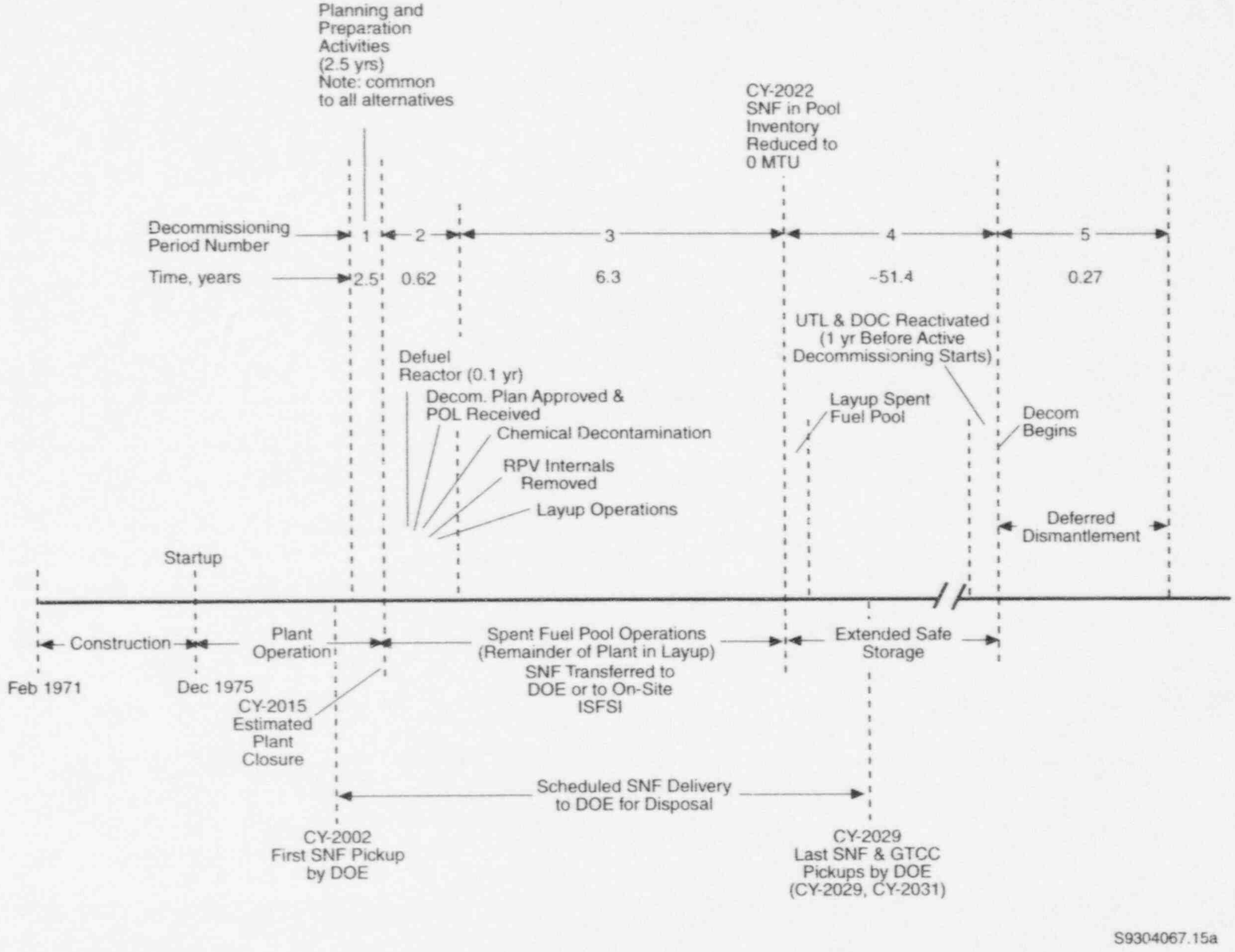


Figure 4.1 Schedule of activities during the five decommissioning periods of SAFSTOR1

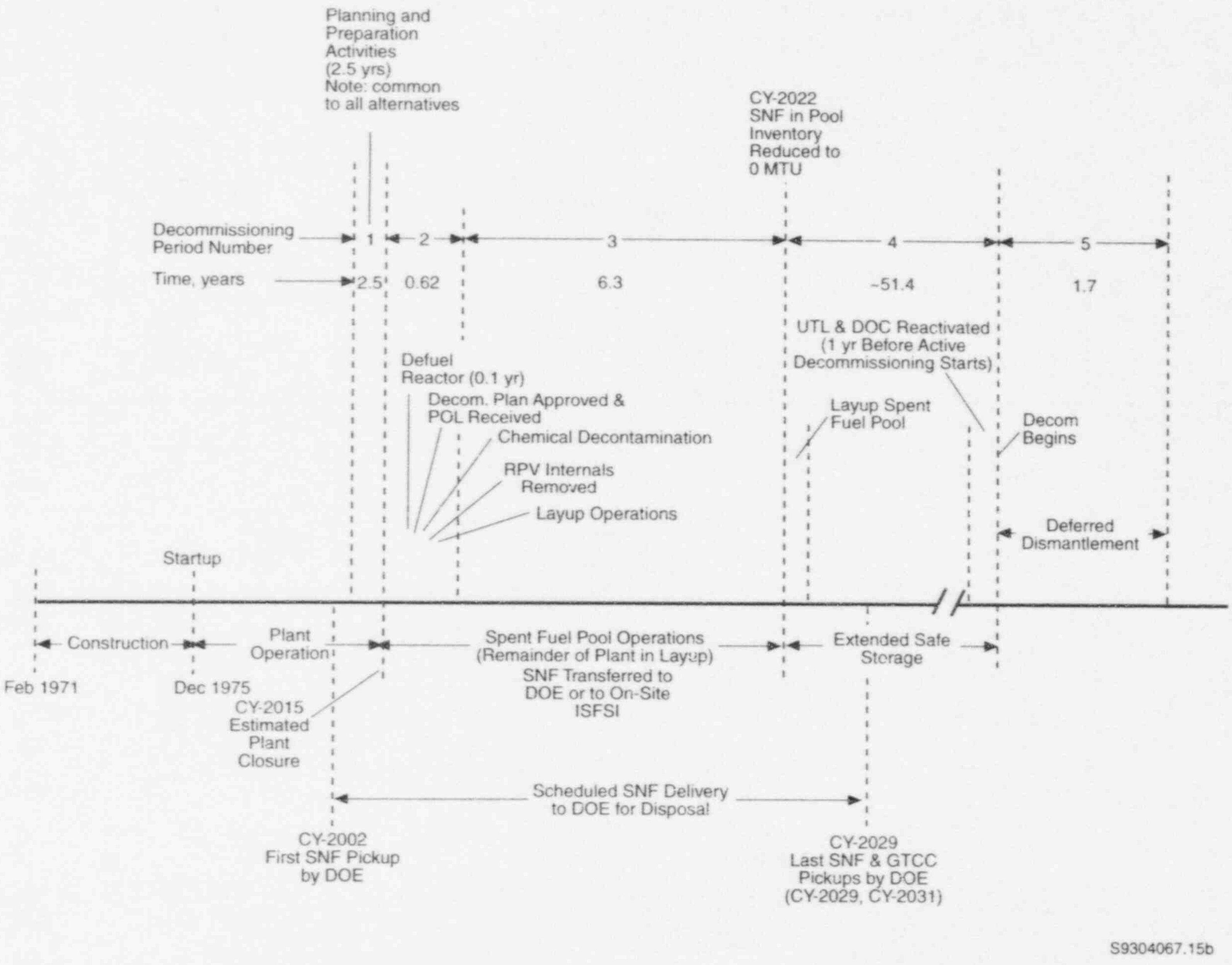


Figure 4.2 Schedule of activities during the five decommissioning periods of SAFSTOR2

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.

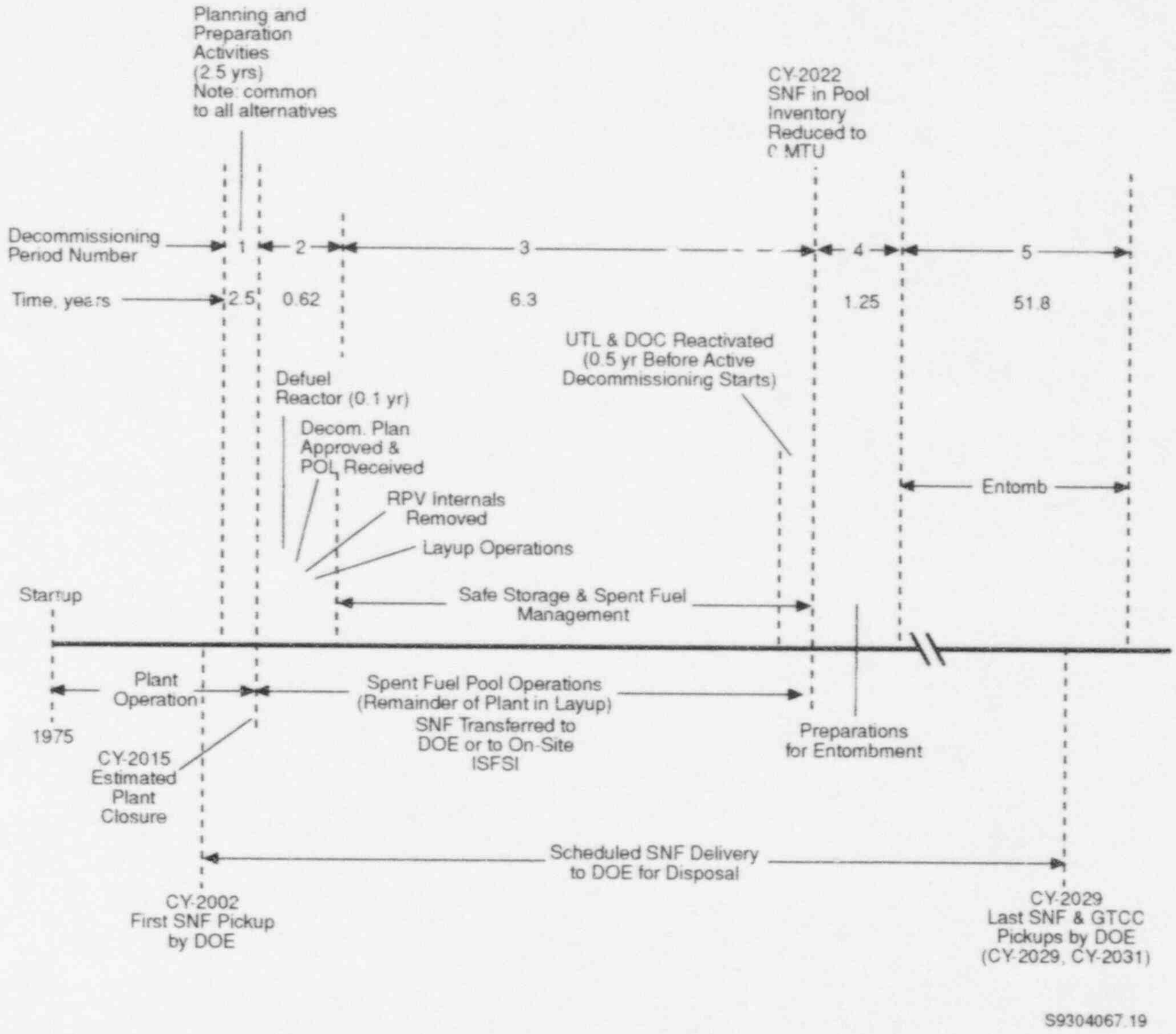


Figure 5.1 Schedule of activities during the five decommissioning periods of ENTOMB

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.

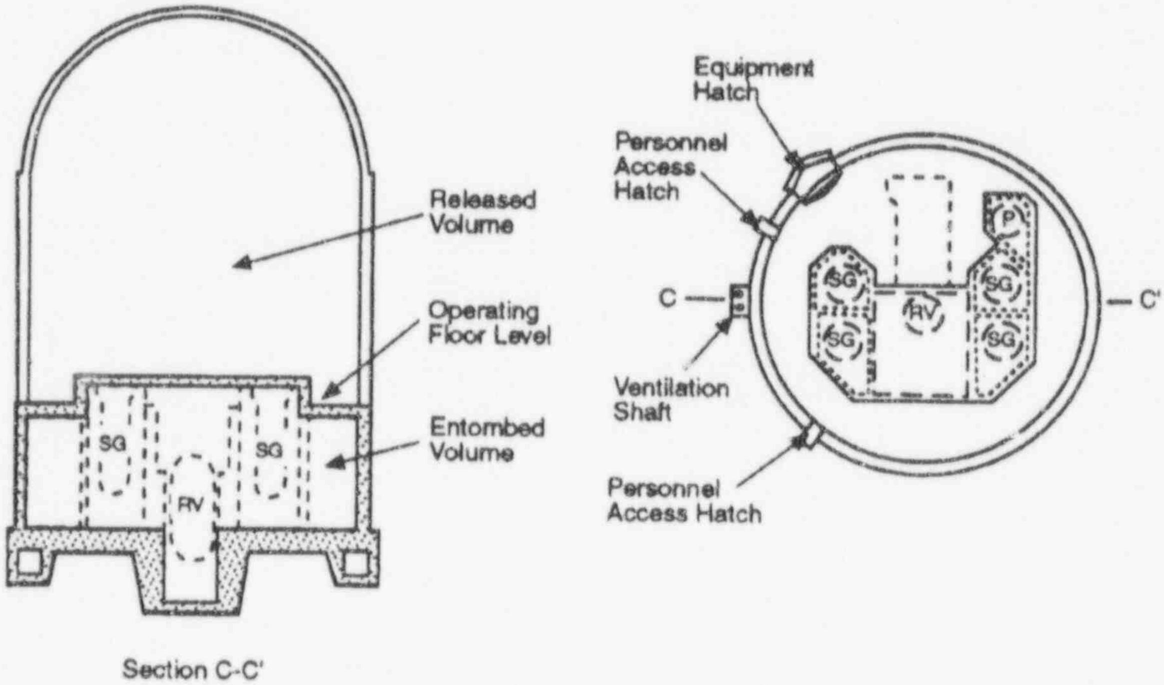


Figure 5.2 Illustration of the entombment barrier

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 x 10^{10} Bq.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Curie (Ci): (a) Formerly, a special unit of radioactivity. One Curie equals 3.7×10^{10} disintegrations per second exactly or $1\ Ci = 3.7 \times 10^{10}\ Bq$. (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 = 2.58×10^{-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

NRC FORM 335 (2-89)

Printed
on recycled
paper

Federal Recycling Program

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS MAIL
POSTAGE AND FEES PAID
USNRC
PERMIT NO. G-67