Enclosure 3

Draft PNNL Study

Assessment of the Adequacy of the 10 CFR 50.75(c) Minimum Decommissioning Fund Formula

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

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Assessment of the Adequacy of the 10 CFR 50.75(c) Minimum Decommissioning Fund Formula

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) requires nuclear power plant licensees to provide reasonable assurance that funds will be available for the decommissioning of their plants. An element of this assurance is the requirement for licensees to provide a minimum decommissioning fund per the formula defined in 10 CFR 50.75(c). The minimum decommissioning fund formula was established in 1988 and is based on studies performed in the late 1970s and early 1980s. The requirement in 10 CFR 50.75(c) also defines a process for updating the formula to current-year dollars. The NRC staff uses the formula and updating process to biannually assess the adequacy of the decommissioning funds established by nuclear power plant licensees.

Subsequent to the establishment of the minimum decommissioning fund formula, the studies used to provide the technical basis for the formula were updated in the early 1990s to reflect changes in decommissioning technology and decommissioning experience gained since the original studies were completed. Furthermore, several nuclear power plants have completed decommissioning since the formula was established, providing a practical experience-base that was not available at the time of the original NRC decommissioning studies. Also, for various regulatory reasons, several nuclear power plant licensees have over the last several years submitted to the NRC site-specific cost estimates to decommission their reactors, providing a basis to benchmark the formula against. Lastly, the available options and cost structure for the treatment and disposal of low-level waste has changed significantly since the formula was developed. In recognition of the significantly expanded nuclear power plant decommissioning experience and knowledge-base, and the evolution in decommissioning technology and practice since the development of the minimum decommissioning fund formula, the NRC commissioned a study to re-evaluate the adequacy of the minimum decommissioning fund requirement specified by the formula. This report summarizes the results of this re-evaluation, including making a recommendation on how the formula should be updated to reflect the current state-of-knowledge in nuclear power plant decommissioning.

EXECUTIVE SUMMARY

Nuclear power reactor licensees are required by 10 CFR 50.75(c) to update annually the estimated cost to decommission their nuclear plants for the purpose of demonstrating reasonable assurance that adequate funds are available for decommissioning. Also included in 10 CFR 50.75(c) is a formula that specifies the minimum decommissioning fund that licensees must retain to demonstrate reasonable assurance. These requirements were implemented with the issuance of the final Decommissioning Rule on July 27, 1988 and have not been updated since. Furthermore, the technical basis for the minimum decommissioning fund formula is based on two studies, referred to as the Original Studies, performed in the 1976-1980 time frame to assess the technology, safety, and costs of decommissioning pressurized water reactors (PWRs) and boiling water reactors (BWRs).

Subsequent to the establishment of the minimum decommissioning fund formula, two studies were performed in the 1993-1996 time frame to update the technical bases for the Nuclear Regulatory Commission (NRC) staff's review of the reasonableness of licensee-submitted decommissioning cost and radiation dose estimates associated with PWR and BWR license termination activities. The results of these studies, which are referred to in this report as the Updated Studies, were not used to update the minimum decommissioning fund formula in 10 CFR 50.75(c).

The purpose of this study is to reassess the technical basis that supported the development of the minimum decommissioning fund formula over 20 year ago and to develop an update to the formula if deemed necessary. The primary approach in this reassessment is to determine how the decommissioning cost estimates from both the Updated Studies and the Original Studies compare with estimates prepared by licensees and with reported decommissioning costs for nuclear power plants that have completed decommissioning. The major factors considered in this reassessment are as follows:

- Review and consideration of advances in decommissioning technology and processes, including one-piece removal and disposal of the reactor pressure vessel (RPV) and improved decontamination/decommissioning processes.

- Compilation and review of power reactor decommissioning experience and successful license termination activities, including consideration of the lessons learned experience gained from the decommissioning of several large nuclear power reactors.

- Evaluation of the detailed decommissioning cost estimates submitted by nuclear power reactor licensees to the NRC for review, including those which have been submitted by licensees of nuclear power reactors that have permanently ceased operation and those submitted by licensees for nuclear power reactors that are within five years of potentially ceasing operation.

- Assessment of improvements and changes in low-level waste (LLW) management and disposal practices to reduce costs.

- Evaluation of the impact on estimated decommissioning costs due to the unavailability of LLW disposal facilities, including impacts from having to provide interim storage of Class B and C LLW for an indeterminant time period.

The first task of this reassessment was to update the decommissioning cost estimates for the reference PWR and BWR plants developed in the Updated Studies to current-year (2010) dollars. At this early phase it was assumed that component inventories and LLW volumes were not changed so that basic cost escalation principles were applied to escalate from 1993 dollars to 2010 dollars. Decommissioning methods, labor and staffing levels, work durations, and work difficulty factors are also assumed to not have changed. Thus the only variables which were assumed to have changed since 1993 were unit costs of labor, regulations, taxes, commodities, energy, and services. This minimal update of “old” cost estimates provided the foundation from which to later revise the estimates for the reference plants to incorporate new information. Estimated decommissioning costs for immediate dismantlement (DECON) increased from $133.3 million (1993) to $271.1 million (2010) for the reference PWR plant and from $164.6 million (1993) to $333.6 million (2010) for the reference BWR plant.

Site-specific decommissioning cost and LLW volume estimates submitted by licensees to the NRC were then reviewed, and relevant information compiled into a database, for the purpose of developing comparisons by cost categories and identify, to the extent possible with the available information, the key differences in cost drivers. Site-specific cost estimates for 19 different reactor sites, representing 27 reactors and 60 decommissioning scenarios, were evaluated. All licensee-developed costs were updated to 2010 dollars so that the comparisons could be made on the same dollar basis. Estimated decommissioning costs for DECON scenarios, in 2010 dollars, ranged from a low of $458 million to a high of $746 million for PWRs and for BWRs ranged from a low of $530 million to a high of $616 million.

The actual experience from the decommissioning of four large nuclear plants that have completed radiological decommissioning was also reviewed. The four nuclear plants reviewed were Haddam Neck, Maine Yankee, Trojan, and Rancho Seco, all PWRs. No large BWRs have yet completed decommissioning. The decommissioning experience for each of the four plants were evaluated to identify important cost drivers, including potentially the decommissioning strategy and release criteria implemented, significant decommissioning issues addressed, LLW volumes and activities generated and dispositioned, and significant environmental remediation. The actual reported decommissioning costs were updated to 2010 dollars so that cost comparisons could be made on the same dollar basis. Reported decommissioning costs were $323.8 million for Trojan, $512.4 million for Rancho Seco, $575.2 million Maine Yankee, and $918.5 million (Haddam Neck). Significant contaminated soil requiring remediation and very stringent cleanup criteria appeared to be the main drivers for the high cost to decommission Haddam Neck. Low LLW disposal costs and one-piece removal and disposal of the RPV, and most reactor internals, appeared to be the main drivers for the low cost to decommissioning Trojan.

The LLW volume and decommissioning cost information developed in the tasks described above were then compared to one another and to corresponding estimates developed using the 10 CFR 50.75(c) minimum decommissioning fund formula. The comparison was developed by reactor type (i.e., PWR and BWR) for the DECON scenario only. The Original and Updated decommissioning studies have previously concluded that DECON is generally the highest cost strategy on a discounted cost basis, for discount rates as low as three percent. Both the licensee-developed and actual-reported decommissioning costs and LLW volumes were compared to the corresponding cost estimates for the Original and Updated Studies. This evaluation concluded the following:

1. There LLW volume estimates from the Original Studies are in relatively good agreement with actual-reported (PWR) and licensee-developed (BWR) volumes and so no revision to the LLW volumes is necessary.

2. The formula, or cost estimates from the Original Studies, are significantly underestimating project management, decontamination and removal, and insurance and regulatory costs and so each needs to be increased from 100-250 percent.

3. The formula should continue to not include an estimate for property taxes. Property taxes are not considered decommissioning costs by many licensees.

4. The formula estimate is overestimating energy and unit LLW packaging costs and so these costs need to be reduced by 10-70 percent.

5. The formula estimate is overestimating unit LLW transportation costs and so needs to be reduced by 10–60 percent.

6. The formula estimate is significantly overestimating unit LLW disposal costs and so needs to be reduced by 50-75 percent.

Based on the above results, the cost estimates for the reference PWR and BWR plants were revised. In general, the approach taken to revise the cost estimates was to develop scaling factors by cost category that resulted in a revised cost estimate for the reference plants that was in the low end-to-below average of the estimated/actual costs reviewed in this study, with a greater emphasis placed on actual reported costs when available. The revised cost estimates were significant enough to result in a proposed change to the 10 CFR 50.75(c) formula for both cost escalation and plant size.

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1 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) requires nuclear power plant licensees to provide reasonable assurance that funds will be available for the decommissioning of their plants. An element of this assurance is the requirement for licensees to provide a minimum decommissioning fund that was established in the Code of Federal Regulations (CFR) in 1988. The purpose of this report is to assess the adequacy of the current minimum decommissioning fund requirement.

1.1 Historical Context for Minimum Decommissioning Fund

To provide reasonable assurance of adequate decommissioning funds, licensees must submit to the NRC biannually a report that contains a certification that financial assurance for decommissioning has been provided in an amount that may be more but not less than the following amount (in January 1986 dollars) stated in 10 CFR 50.75(c)(1), where P is the thermal capacity in megawatt-thermal (MWth) of the reactor:

For a pressurized water reactor (PWR) –
- Greater than or equal to 3400 MWth……………………….$105 million
- Between 1200 MWth and 3400 MWth…………………..$(75+0.0088P) million
- Less than 1200 MWth……………………………………..$85.56 million

For a boiling water reactor (BWR) –
- Greater than or equal to 3400 MWth……………………….$135 million
- Between 1200 MWth and 3400 MWth…………………..$(104+0.009P) million
- Less than 1200 MWth……………………………………..$114.8 million

Licensees must annually adjust the estimate of the cost (in dollars of the current year) by using the following adjustment factor from 10 CFR 50.75(c)(2):

$$0.65L + 0.13E + 0.22B$$

where L, E, and B are escalation factors for labor, energy, and low-level waste (LLW) burial, respectively. The L and E adjustment factors are to be taken from regional data of the U.S. Department of Labor Bureau of Labor Statistics (BLS). The B adjustment factor is to be taken from the NRC report NUREG-1307, "Report on Waste Burial Charges," which is updated biannually. The last update of NUREG-1307 was made in the year 2010 and is referred to as Revision 14 (Reference 1).

The minimum decommissioning fund formula in 10 CFR 50.75(c) is based on two studies performed by Pacific Northwest National Laboratory (PNNL) for NRC in 1978 and 1980:

1. NUREG/CR-0130, June 1978, "Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station" (Reference 2), and associated Addendum 4, "Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule" (Reference 3). This study developed a detailed

decommissioning cost estimate for a reference PWR, the Trojan Nuclear Power Plant (TNP), which has since been decommissioned.

2. NUREG/CR-0672, June 1980, "Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station" (Reference 4), and associated Addendum 3, "Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule" (Reference 5). This study developed a detailed decommissioning cost estimate for a reference BWR, the Columbia Generating Station (CGS), formerly Washington Nuclear Power Unit 2 (WNP-2).

Both studies were part of an extensive NRC effort at the time to understand the requirements for decommissioning nuclear facilities in preparation for revising the regulatory requirements for decommissioning, and were based on decommissioning technology and experience from that time period. At the time, experience was limited to the decommissioning of research and development-size reactors, not the large base-load power generation plants in use today.

In addition to the addenda previously mentioned, both of these reports were supplemented by other addenda to address 1) the effects on decommissioning due to an inability to dispose of LLW and spent fuel offsite, 2) the classification of LLW from decommissioning consistent with 10 CFR 61, which was promulgated in 1982, 3) updating the decommissioning cost estimates from the two original studies to 1986 dollars and assessing the decommissioning cost of post-TMI-2 backfits, and 4) comparing the decommissioning cost estimate from the NRC methodology with that developed by a nuclear industry consultant.

These original studies were subsequently updated by PNNL for the NRC in the early 1990s to reflect changes in decommissioning technology and decommissioning experience gained since the original studies were completed. The purpose of these studies was to provide the NRC staff with the bases needed to review site-specific decommissioning cost estimates submitted by licensees and to potentially revise the formula in 10 CFR 50.75(c). The updated studies are documented in the following reports:

1. NUREG/CR-5884, November 1995, "Revised Analyses of Decommissioning for the Reference Pressurized Water Reactor Power Station" (Reference 6). This study also developed a detailed decommissioning cost estimate for the reference PWR or the Trojan Nuclear Power Plant.

2. NUREG/CR-6174, July 1996, "Revised Analyses of Decommissioning for the Reference Boiling Water Reactor Power Station" (Reference 7). This study also developed a detailed decommissioning cost estimate for the reference BWR or the Columbia Generating Station.

These studies included 1) an interim 5-7-year spent fuel cooling period after plant shutdown and prior to major disassembly operations or extended safe storage; 2) an estimate of the cost to demolish "clean" structures on the site and to restore the site to a "green field" condition; 3) termination of the 10 CFR Part 50 license within 60 years after permanent reactor shutdown; 4) packaging and disposal requirements for greater-than-Class C (GTCC) waste; 5) one-piece removal and disposal of steam generators; 6) updated decommissioning cost estimates to

1993 dollars; and 7) sensitivity of decommissioning costs to various analysis assumptions, including LLW disposal rates. No change in the 10 CFR 50.75(c) minimum decommissioning fund formula was made as a result of these studies, and so the formula continues to reflect the original decommissioning studies performed in the late 1970s.

1.2 Basis for Reassessing the Minimum Decommissioning Fund

Since the development of the original decommissioning studies, the following changes have occurred that could significantly impact the cost of decommissioning nuclear power plants:

- The technical basis for the formula is based on studies that were performed more than 30 years ago. Decommissioning technology and practices in use today are significantly different than assumed in the original studies. Specifically, the formula does not reflect the one-piece removal of large components (e.g., steam generators) commonly in use today and the more efficient decontamination/decommissioning processes that potentially significantly reduce, relative to that assumed in the original studies, the volume of LLW requiring disposal. These technology advances were reflected in the updated studies.

- A significant amount of experience has been gained since the original studies were conducted over 30 years ago. Specifically, the NRC has approved either the termination of the 10 CFR Part 50 licensee or the removal of most of the land from the 10 CFR Part 50 license for several decommissioned "large" nuclear power plants including Fort St. Vrain, Shoreham, Trojan, Yankee Rowe, Main Yankee, Haddam Neck, and Rancho Seco.

- Nuclear power plant licensees have submitted to the NRC, over the last several years, site-specific decommissioning cost estimates for "large" aging nuclear power plants that 1) are within 5 years of potentially ceasing operation per 10 CFR 50.75(f)(2) or 2) have permanently ceased operation per 10 CFR 50.82(a)(8)(iii). Site-specific decommissioning cost estimates have also been submitted to the NRC for other reasons, including as part of a request to an exemption from 10 CFR 50.82(a)(8). This type of information was not available when the original studies were conducted. Specifically, the NRC has received site-specific decommissioning cost estimates for, among others, the following nuclear power plants: Oyster Creek, Surry, Vermont Yankee, Pilgrim, Indian Point, Prairie Island, Kewaunee, Zion, LaSalle, Byron, Braidwood, South Texas Project, Diablo Canyon, Kewaunee, Palisades, Three Mile Island 1, Cooper, Duane Arnold, Salem, and Hope Creek.

- The cost of LLW management and disposal has increased dramatically since the original studies. LLW management and disposal accounted for 22% of the total decommissioning cost in the 10 CFR 50.75(c) decommissioning fund formula. As of Revision 14 of NUREG-1307 (Reference 1), this percentage had increased to at least 50%, and as high as 75%, of the total decommissioning cost as estimated by the formula.

- The management of LLW generated during decommissioning is highly uncertain relative to that assumed in the original studies. Specifically, since there currently is no disposal capacity available for Class B and C LLW, 1) the volume of Class B and C LLW requiring disposal during decommissioning may be substantially higher than originally assumed (i.e., plants must now store waste generated during operations) and 2) the cost of disposal of LLW, especially Class B and C LLW, may increase substantially once new LLW disposal sites become available.

For these reasons, the technical basis that supported the minimum decommissioning formula development needs to be re-evaluated.

1.3 Study Objective and Report Organization

The purpose of this study is to re-evaluate the adequacy of the minimum decommissioning fund formula in light of the above factors and to determine if the formula needs to be updated to assure that it reflects the current costs associated with decommissioning nuclear power reactors. To accomplish this objective, subsequent sections of this report provide the following analysis results:

1. Section 2. The estimated decommissioning costs from NUREG/CR-5884 (Reference 6) and NUREG/CR-6174 (Reference 7) are updated to current-year dollars, including changes in LLW disposal rates. Included in this update is an assessment of significant changes in decommissioning technology and process since the time period when these studies were performed.

2. Section 3. Site-specific decommissioning cost estimates submitted by licensees to the NRC, as described in the previous section, are reviewed to develop comparisons by cost categories and identify, to the extent possible with the available information, the key differences in cost drivers.

3. Section 4. The actual decommissioning experience from four nuclear plants that have completed radiological decommissioning is reviewed. The four nuclear plants reviewed are Haddam Neck, Maine Yankee, Trojan, and Rancho Seco. Each review includes a summary of the decommissioning strategy implemented, a description of the decommissioning approach and significant issues addressed, an assessment of the LLW volumes and activities generated during decommissioning, and an evaluation of the actual cost of decommissioning incurred based on the level-of-detail available.

4. Section 5. The LLW volume and decommissioning cost information provided in Sections 2 through 4 are compared to one another and to corresponding estimates developed using the 10 CFR 50.75(c) minimum decommissioning fund formula. The comparison is provided by reactor type (i.e., PWR and BWR).

5. Section 6. The results of the comparisons in Section 5 are used to develop a proposed update to the 10 CFR 50.75(c) minimum decommissioning fund formula.

1.4 References

1. U.S. Nuclear Regulatory Commission (NRC). 2010. *Report on Waste Burial Charges*. NUREG-1307, Revision 14, November 2010. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1307/r14/sr1307r14.pdf; accessed on October 19, 2011.

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

6. Konzek, G. J., R. I. Smith, M. C. Bierschbach, and P. N. McDuffie. 1995. *Revised Analyses of Decommissioning for the Reference Pressurized Water Reactor Power Station*. NUREG/CR-5884, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

7. Smith, R. I., M. C. Bierschbach, G. J. Konzek, and P. N. McDuffie. 1996. *Revised Analyses of Decommissioning for the Reference Boiling Water Reactor Power Station*. NUREG/CR-6174, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2 UPDATE OF ESTIMATED DECOMMISSIONING COSTS FOR THE REFERENCE PWR AND BWR

This section updates the estimated decommissioning costs for the reference PWR from NUREG/CR-5884 (Reference 6) and for the reference BWR from NUREG/CR-6174 (Reference 7) to current-year dollars, including changes in LLW disposal rates. Included in this update is an assessment of significant changes in decommissioning technology and process since the time period when these studies were performed.

2.1 Background

The NRC requires the licensees of nuclear power plants to annually adjust the estimate of the cost (in dollars of the current year) of decommissioning their plants as part of the process of providing reasonable assurance to the NRC that adequate funds for decommissioning will be available when needed. The cost estimate is specified in 10 CFR 50.75 by a formula that depends on the sum of the cost components for energy, labor, and offsite low-level waste (LLW) disposal to a licensed facility.

The decommissioning fund requirement formula in 10 CFR 50.75(c) is based on two studies, described in References 1 and 2, that were performed by PNNL for the NRC in the late 1970s. The Reference 1 study developed a detailed decommissioning cost estimate for a reference PWR, the Trojan Nuclear Power Plant, which has since been decommissioned. Similarly, the Reference 2 study developed a detailed decommissioning cost estimate for a reference BWR, the Columbia Generating Station (formerly WNP-2).

Both studies were part of an extensive NRC effort to understand the requirements for decommissioning nuclear facilities in preparation for revising the regulatory requirements for decommissioning, and were based on decommissioning technology and experience from that time period. At the time, experience was limited to the decommissioning of research and development-size reactors, not the large base-load power generation plants in use today.

These original studies were subsequently updated by PNNL for the NRC in the early 1990s to reflect changes in decommissioning technology and decommissioning experience gained since the original studies were completed. The purpose of these studies was to provide the NRC staff with the bases needed to review site-specific decommissioning cost estimates submitted by licensees and to potentially revise the formula in 10 CFR 50.75(c). The revised studies are documented in Reference 3 (the Trojan Nuclear Power Plant) and Reference 4 (the Columbia Generating Station).

The revised studies included: 1) an interim 5-7 year spent fuel cooling period after plant shutdown and prior to major disassembly operations or extended safe storage, 2) an estimate of the cost to demolish “clean” structures on the site and to restore the site to a “green field” condition, 3) termination of license within 60 years after permanent reactor shutdown, 4) packaging and disposal requirements for greater-than-Class C (GTCC) waste, 5) one-piece removal and disposal of steam generators, 6) updated decommissioning cost estimates to

1993 dollars, and 7) sensitivity of decommissioning costs to various analysis assumptions, including LLW disposal rates. In these revised studies, a computer model, the Cost-Estimating Computer Program (CECP), was used to estimate the total cost of decommissioning the two reference reactors.

2.2 Cost Updating Methodology

To update estimated costs from NUREG/CR-5884 and NUREG/CR-6174 to current-year (2010) dollars, the cost estimates from the CECP are escalated from 1993 dollars to 2010 dollars. Cost escalation is a reasonable approach for this section of the report because it is assumed that inventories and waste volumes for the two reference reactor sites are the same as in the revised studies. Furthermore, decommissioning methods, labor and staffing levels, work durations, and work difficulty factors are also assumed to be the same. Whether these assumptions are reasonable is the subject of later sections of this report. Thus the only variables which are assumed to have changed since 1993 are unit costs of labor, regulations, taxes, commodities, energy, and services.

The CECP cost estimates fall naturally into several categories (labor, overhead, energy, burial, regulation, taxes, etc.). For each category an escalation factor is developed. The escalation factor for each of these categories comes from various sources, as indicated below. Escalation factors depend on indexes prepared by the Bureau of Labor Statistics (BLS).

Labor. In addition to plant and decommissioning operations contractor (DOC) staff, this category includes overhead and contracted services such as laundry services. The labor escalation factor is based on labor adjustment factors (L_x) that are discussed in References 5 and 6. The labor adjustment factors are derived from employment cost indexes (ECI) provided by the BLS. The value of L_x for a particular region is the value of the ECI for that region for the current year divided by the value of the same ECI for the reference year (1986). For this report the labor escalation factor is the value of L2010 for the West region, obtained from Reference 6 (2.29), divided by the corresponding value of L1993 (1.373). The escalation factor is thus 2.29/1.373 = 1.67.

Energy. Energy includes both PWR and BWR power usage during decommissioning. The energy escalation factor is based on energy adjustment factors (E_x) that are discussed in References 5 and 6. The value for E_x is a weighted average of two producer price indexes (PPIs): industrial electrical power (WPU0543) and light fuel oils (WPU0573). A PWR has a different weighting factor than a BWR. The value of E_x is the weighted summation of the value of WP0543 for the current year divided by the value for WPU0543 for the reference year (1986), and the value of WPU0573 for the current year divided by the value for WPU0573 for the reference year (1986). The energy escalation factor is therefore E2010 from Reference 6, divided by E1993 from Reference 5. The escalation factor for Trojan is 2.139/0.965 = 2.22, and for the Columbia plant it is 2.181/0.949 = 2.30.

LLW Burial. To escalate LLW burial costs, the values of B_x from References 5 and 6 are used, where B_x is the ratio of waste burial costs in the current year to waste burial costs in the reference year 1986. To find the burial escalation from 1993 to 2010, the ratios of B_x for those years are calculated: B2010/B1993. The B_x value depends on the type of reactor and on the burial site. In 1993, the burial site was postulated to be the US Ecology site in Washington State. In 2010, a generic site was used (Reference 6). For the reference PWR, the escalation factor is 6.588/1.997 = 3.30. For the reference BWR, it is 5.458/1.938 = 2.82. Both of these escalation factors assume disposal of most Class A LLW at the Energy*Solutions* facility.

Tools and Equipment. This category includes hand tools and consumables as well as larger specialized equipment, such as plasma arc cutting systems, submersible pumps, and man-lifts. The escalation factor for these items is derived from the BLS PPI index WPU112 (construction machinery and equipment, not seasonally adjusted). The escalation factor is WPU112 (2010 Average)/WPU112 (1993 Average) = 191.4/132.0 = 1.45.

LLW Packaging Materials. This category includes materials used in the fabrication of waste containers. The escalation factor for these items is derived from the BLS PPI index WPU10 (metals and metal products, not seasonally adjusted). The escalation factor is WPU10 (2010 average)/WPU10 (1993 average) = 207.6/119.2 = 1.74.

Regulatory Costs. Included in this category are onsite inspections by state and NRC representatives, licensing fees, resolution and response to NRC review of the decommissioning plan, and NRC license termination confirmatory surveys. It was decided that a reasonable, conservative, indicator of overall regulatory cost increase can be approximated by the cost increase of a professional staff hour (10 CFR 170.20) from $132/hour (hr) (1993) to $273/hr (2010). The escalation factor is therefore 273/132=2.07. Note: In 1993 it was the conclusion of the revised studies that the annual fees of 10 CFR Part 171 were not applicable to reactors with possession-only licenses and such fees were not included. Currently, 10 CFR 171 requires a reactor in a decommissioning status to pay a $148,000 annual fee. This annual fee has been included in the update.

LLW Transportation. This is the cost of shipping LLW by truck to an LLW burial site. Transportation costs are difficult to estimate but in rough terms transportation depends on labor and fuel costs per mile. Fuel cost escalation can be estimated by the BLS producer price index for No. 2 diesel fuel (Series Id=WPS057303). Fuel cost escalation from 1993 to 2010 would then be WPS057303 (2010 Average)/WPS057303 (1993 Average) = 233.1/60.5 = 3.85 ≈ 4. It would be reasonable to assign a value of 2 to labor escalation, as suggested by the discussions of this factor above. A rough estimate of 3 for the transportation escalation factor is therefore considered reasonable.

For the Reference PWR, the steam generators were transported to the LLW site by barge. Because barging operations are highly labor intensive, the labor escalation factor (1.67) calculated earlier in this section was chosen.

Property Taxes and Nuclear Liability Insurance. Lacking sufficient data to derive specific escalation factors for these categories, it was decided to use a 3% annual cost of living adjustment. Over the seventeen-year period from 1993 to 2010, this adjustment results in an escalation factor of 1.65.

Cost escalation factors for the reference PWR nuclear plant are summarized in Table 2.1; those for the reference BWR nuclear plant are summarized in Table 2.2.

Table 2.1. Cost Escalation Factors for the Reference PWR – Escalation from 1993$ to 2010$

Category	Element	Escalation Factor	Basis
Burial	LLW Disposal	3.30	Ratio of Bx in NUREG-1307 (Rev. 14, 2010) to Bx in NUREG-1307 (Rev. 3, 1993) = 6.588/1.997
Energy	Chemical Decontamination/Deboration Energy	2.22	Ratio of Ex in NUREG-1307 (Rev. 14, 2010) to Ex in NUREG-1307 (Rev. 3, 1993) = 2.139/0.965
Energy	Plant Power Usage	2.22	Ratio of Ex in NUREG-1307 (Rev. 14, 2010) to Ex in NUREG-1307 (Rev. 3, 1993) = 2.139/0.965
Insurance	Nuclear Liability Insurance	1.65	Cost of living (3% for 17 years)
Labor	Decontamination	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Labor	Contaminated Equipment Removal	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Labor	Steam Generator--Undistributed Costs	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Overhead	DOC Mobilization Costs	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Overhead	DOC Mobilization/Demobilization Costs	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Overhead	Staff Salary	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Packaging Material	LLW Containers	1.74	BLS Series Id=WPU10 (Metals & Metal Products): Ratio of 2010 Annual to 1993 Annual = 207.6/119.2
Regulation	Environmental Monitoring Costs	2.07	10 CFR 170.20: 2010 value to 1993 value (used in NUREG/CR-5884 and -6174) = 273/132
Regulation	Regulatory Costs	2.07	10 CFR 170.20: 2010 value to 1993 value (used in NUREG/CR-5884 and -6174) = 273/132
Regulation	Termination Survey Cost	2.07	10 CFR 170.20: 2010 value to 1993 value (used in NUREG/CR-5884 and -6174) = 273/132
Services	Laundry Services	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Shipping	LLW Shipment	3	Engineering estimate based on labor rates and diesel fuel costs
Shipping	Steam Generator Barging	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Taxes	Property Taxes	1.65	Cost of living (3% for 17 years)
Tools/Equipment	Maintenance Allowance	1.45	BLS Series Id=WPU112 (Construction Machinery and Equipment): Ratio of 2010 Annual to 1993 Annual = 191.4/132.0
Tools/Equipment	Small Tools and Minor Equipment	1.45	BLS Series Id=WPU112 (Construction Machinery and Equipment): Ratio of 2010 Annual to 1993 Annual = 191.4/132.0
Tools/Equipment	Special Tools and Equipment	1.45	BLS Series Id=WPU112 (Construction Machinery and Equipment): Ratio of 2010 Annual to 1993 Annual = 191.4/132.0

Table 2.2. Cost Escalation Factors for the Reference BWR – Escalation from 1993$ to 2010$

Category	Element	Escalation Factor	Basis
Burial	LLW Disposal	2.82	Ratio of Bx in NUREG-1307 (Rev. 13, 2010) to Bx in NUREG-1307 (Rev. 3, 1993) = 5.458/1.938
Energy	Chemical Decontamination Energy	2.30	Ratio of Ex in NUREG-1307 (Rev. 13, 2010) to Ex in NUREG-1307 (Rev. 3, 1993) = 2.181/0.949
Energy	Plant Power Usage	2.30	Ratio of Ex in NUREG-1307 (Rev. 13, 2010) to Ex in NUREG-1307 (Rev. 3, 1993) = 2.181/0.949
Insurance	Nuclear Liability Insurance	1.65	Cost of living (3% for 17 years)
Labor	Decontamination	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Labor	Contaminated Equipment Removal	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Overhead	DOC Mobilization Costs	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Overhead	DOC Mobilization/Demobilization Costs	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Overhead	Staff Salary	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Packaging Material	LLW Containers	1.74	BLS Series Id=WPU10 (Metals & Metal Products): Ratio of 2010 Annual to 1993 Annual = 207.6/119.2
Regulation	Environmental Monitoring Costs	2.07	10 CFR 170.20: 2010 value to 1993 value (used in NUREG/CR-5884 and -6174) = 273/132
Regulation	Regulatory Costs	2.07	10 CFR 170.20: 2010 value to 1993 value (used in NUREG/CR-5884 and -6174) = 273/132
Regulation	Termination Survey Cost	2.07	10 CFR 170.20: 2010 value to 1993 value (used in NUREG/CR-5884 and -6174) = 273/132
Services	Laundry Services	1.67	Ratio of Lx in NUREG-1307 (Rev. 14, 2010) to Lx in NUREG-1307 (Rev. 3, 1993) = 2.29/1.373
Shipping	LLW Shipment	3	Engineering estimate based on labor rates and diesel fuel costs
Taxes	Property Taxes	1.65	Cost of living (3% for 17 years)
Tools/Equipment	Maintenance Allowance	1.45	BLS Series Id=WPU112 (Construction Machinery and Equipment): Ratio of 2010 Annual to 1993 Annual = 191.4/132.0
Tools/Equipment	Small Tools and Minor Equipment	1.45	BLS Series Id=WPU112 (Construction Machinery and Equipment): Ratio of 2010 Annual to 1993 Annual = 191.4/132.0
Tools/Equipment	Special Tools and Equipment	1.45	BLS Series Id=WPU112 (Construction Machinery and Equipment): Ratio of 2010 Annual to 1993 Annual = 191.4/132.0

2.3 Cost Assumptions

Key assumptions in the updated decommissioning cost analysis are as follows:

- This cost update is for the Reference PWR Station (Trojan) and Reference BWR Station (Columbia). Cost escalation would be somewhat different for other reactors, both because of geographical location and reactor-specific characteristics.

- NUREG/CR-5884 and NUREG/CR-6174 both assumed that GTCC waste was disposed of in a geologic repository at a cost based on that for disposal of spent nuclear fuel at the Yucca Mountain Repository. However, since the Yucca Mountain Repository is no longer being considered by the U.S. Department of Energy (DOE) and the disposal pathway for GTCC has not yet been decided on by the U.S. Congress, the cost of GTCC disposal is highly uncertain. Also, licensees of decommissioned nuclear power plants are currently treating GTCC waste the same as spent nuclear fuel (SNF) by placing GTCC waste into SNF storage casks for long-term interim storage. For these reasons, this cost update assumes that GTCC waste is essentially the same as SNF and its disposal is not treated as a decommissioning cost.

- Interim storage of spent nuclear fuel either in the pool or in a dry cask storage facility is not considered a decommissioning activity. Therefore, the costs associated with the preparation of the spent fuel storage pool for loading spent fuel storage containers, loading the spent fuel storage containers into storage casks, interim storage of spent fuel, and the eventual shipment of spent fuel to the national repository are not included in the estimated decommissioning costs.

- As in the revised studies, it is assumed that 10% of the cost of plant and spent nuclear fuel pool operations after permanent plant shutdown and prior to completion of defueling of the pool will be charged to decommissioning; the remaining 90% will be charged to spent fuel management/plant operations. In other words, during the defueling period, it is assumed that about 10% of the work effort of plant staff is on decommissioning planning and preparation, including conducting radiation surveys, preparing the post-shutdown decommissioning activities report (PSDAR), development of a detailed work breakdown structure for decommissioning activities, and development of requests-for-proposals and award of decommissioning subcontracts.

- The demolition of non-radiological facilities or the demolition of radiological facilities that have been decontaminated to below the license termination criteria, is not considered a decommissioning activity and so the associated costs are not included in the estimated decommissioning costs.

- Decontamination and remediation activities to achieve a more restrictive cleanup criteria than the NRC license termination criteria are not considered decommissioning activities and are therefore not included in the estimated decommissioning costs.

- Since no LLW disposal facility currently exists for disposal of Class B/C LLW for many nuclear power plant licensees, it is assumed that the cost of disposal of this “stranded” Class B/C LLW generated during decommissioning is the same as that for the Barnwell disposal facility. It is also assumed that a disposal facility for Class B/C LLW is available at the time of decommissioning.

- Similarly, Class B/C LLW that continues to be generated during normal plant operations is currently being stored by licensees that do not have access to a disposal facility for this waste. This waste will continue to be interim stored until a disposal facility becomes available. It is possible that this “stranded” waste generated during plant operations will not be disposed of until the plant is decommissioned and thus be included in the cost of decommissioning. The cost of disposal of this "stranded" LLW is not included in this cost update. This issue is addressed further in Sections 4 and 6 of this report.

2.4 Survey of Decommissioning Technology and Experience Since the Early 1990s

A literature search was performed for improved decontamination and decommissioning (D&D) technologies that were developed since the revised studies were performed. By far the most complete and up-to-date source of information was the Electric Power Research Institute (EPRI) report of Reference 7. Since this report addressed the same topics that were to be covered in this study, the EPRI report was the primary source of the information used in this section. A discussion of each of the main topics from the EPRI report is presented below.

Adoption of Bulk Removal Approach. The EPRI report explains that the availability of the Class A LLW disposal facility at Clive, Utah (Energy*Solutions* facility), has resulted in cost reductions because of lower waste disposal rates at that facility and because bulk removal and shipment to that facility has "…also reduced final survey costs, where the complete removal of structures (as assumed radioactive waste) has been found to be much less expensive than the time and labor intensive process of performing final status surveys." The impact of the availability of this facility has been accounted for in the B_x factors reported in NUREG-1307, Rev. 14 (Reference 6), which was used as the basis for updating the costs in this section. The updated costs reported in this section are provided for two scenarios: 1) disposal at the full-service US Ecology disposal facility since both of the reference plants are located in the Northwest LLW Compact and 2) disposal of most Class A LLW at the Energy*Solutions* disposal facility and the disposal of the remaining LLW at a full-service disposal facility having a cost structure similar to that applied at the Barnwell facility, referred to as the "Generic LLW Disposal Facility" case.

Improved Primary System Decontamination. While the EPRI report mentions that there have been improvements in primary system decontamination techniques, it does not indicate what these improvements are. Nor does it indicate the comparative cost reductions that could be affected by employing these techniques. The literature search did not locate any publicly-available documents that presented actual cost benefit or dose reduction data resulting from recent decontamination experience. However, one report (Reference 8) was reviewed that discussed the chemical decontamination of the main coolant system (MCS) and other subsidiary systems at Yankee Nuclear Power Station in 1995 (Reference 8). This report is contemporaneous with the revised decommissioning cost estimates of References 3 and 4. At the time Reference 8 was released (May 1996) no actual savings had been realized from the reduction of disposal costs or radiological doses to workers. No waste had been disposed of, and so no data exists for actual cost savings. Another EPRI report, Reference 9, provides a review of the decontamination of the reactor coolant systems during the decommissioning of the Maine Yankee and Haddam Neck plants. This experience is discussed further in Section 4 of this report where the results of actual nuclear power plant decommissioning experience is reviewed.

Improved Contracting Practices. The revised decommissioning cost estimates of References 3 and 4 assume that D&D operations are handled efficiently and that there is little utility oversight of the DOC. Also, the revised estimates of DOC costs generally err on the low side when compared with what industry typically assumes in their D&D cost estimates (this is discussed further in Section 5 of this report). Each of the four recently nuclear power plant decommissioning projects reviewed in Section 4 of this report self-performed the plant decommissioning rather than contract with a DOC, however two of these projects initially contracted with a DOC and then switched later to self-performing the decommissioning. This is experience is further discussed in Section 4 of this report.

Improved Removal Techniques for Large Components. The EPRI report explains that "one-piece removal of large components, such as reactor pressure vessels and steam generators, in lieu of segmentation, has reduced labor costs and shortened schedules. This has also reduced waste disposal, packaging and transportation costs through averaging of radioactivity over a large single mass, thereby allowing components to be disposed of as less expensive Class A waste, and transported as their own containers." The revised decommissioning cost estimate for the reference PWR station in Reference 3 already assumes that the steam generators are removed intact and shipped as their own containers to the LLW disposal site or processing facility. However, the reactor pressure vessel (RPV) is assumed to be segmented and packaged prior to disposal.

Most power reactor decommissioning projects to-date (e.g., Yankee Rowe, Maine Yankee, Connecticut Yankee or Haddam Neck, Big Rock Point, Trojan, etc.) have removed and shipped the RPV intact for disposal at either the Barnwell or US Ecology full-service LLW disposal facilities. However, the Rancho Seco RPV was segmented and packaged for disposal and, in fact, the Ranch Seco steam generators were cut in half before being shipped for disposal. The difference between the Rancho Seco approach and the other decommissioning projects being that the Rancho Seco RPV and steam generators were transported overland via rail, which introduced weight limitations, for disposal at the Energy*Solutions* disposal facility whereas the other decommissioning projects were able to use barge transport (which weren't weight limited). Barge transportation to the Energy*Solutions* facility in Utah is not an option. Since barge transport for disposal of the RPV is not an option for most operating nuclear plants today, the revised cost estimates for the reference PWR and BWR stations have not been adjusted to reflect one-piece RPV removal and disposal at this time. Potential cost savings/differences of intact transit and burial versus segmentation are further considered in Section 4 of this report where the actual experience at four completed nuclear power plant decommissioning projects is reviewed.

Groundwater Contamination and Soil Remediation. Radiological release criteria for sites are established by a number of entities, including the NRC, state regulatory agencies, and local stakeholders. To meet these criteria decommissioning plans must include costs for monitoring groundwater and performing soil remediation, if required. For three sites detailed in the EPRI report these costs ranged from about 2% of total decommissioning costs (where only monitoring was required) to about 9% of total costs (where both monitoring and remediation were required).

The revised decommissioning cost estimates for the reference PWR and BWR stations in References 3 and 4 do not include any significant environmental remediation. The need for significant environmental remediation is very site-specific since it is dependent on plant-specific operational practices and the cleanup criteria applied during decommissioning. For these reasons, the revised decommissioning cost estimates assume minimal environmental remediation is required. This issue is addressed extensively in Section 4 of this report, where one of the four completed decommissioning projects reviewed required extensive environmental remediation during decommissioning.

2.5 Cost Update Results

The cost updates are presented in Tables 2.3 through 2.6. In column 5 of these tables, the original estimates (1993 $) are shown. For these original estimates the LLW burial site is the US Ecology facility in Washington State. The revised cost estimates (2010 $) in column 6 also assume disposal of all LLW at the US Ecology facility. In addition, the “Grand Total” for column 6 for the DECON scenarios also includes a revised cost estimate (2010 $) that assumes disposal at the “Generic LLW Site” described in Reference 6 and discussed above. The DECON scenario is used as the basis for this study as discussed further in Section 5 of this report.

The DECON and SAFSTOR cases for the Reference PWR Station (Trojan) are presented in Tables 2.3 and 2.4. The same cases for the Reference BWR Station (Columbia) are provided in Tables 2.5 and 2.6. The SAFSTOR cases used from References 3 and 4 for this update are the higher cost “SAFSTOR 2” cases. In “SAFSTOR 2” it is postulated that the nature of the contaminants are such that radioactivity will not have decayed to unrestricted release levels within 60 years following reactor shutdown. This means that essentially all decontamination, removal, packaging, transport, and disposal activities that were done in the final period of DECON will still be required in the final period of SAFSTOR.

The relative contributions of each of the cost categories to the total decommissioning costs are presented in Tables 2.7 through 2.10. LLW burial and project overhead costs, consisting primarily of the management costs of the licensee and DOC, are the major cost drivers in all four cases. As is to be expected, overhead costs are more dominating in the SAFSTOR cases.

In the revised studies cost estimates for non-radioactive demolition and site restoration of the two reference reactor plants were provided. Updated cost estimates for these non-decommissioning activities are shown in Table 2.11. A simple labor escalation of 1.67 is used.

Table 2.3. DECON Case for Reference PWR (Trojan)

Period	Period Name	Duration (years)	Cost Category	Cost ($ Millions) Original Estimate (1993 $)	Updated Estimate (2010 $)
1	Planning and Preparation	2.5	Overhead	5.4	9.1
			Regulation	0.4	0.7
			Tools/Equipment	3.3	4.8
2	Defuel and Layup	0.6	Burial	3.4	11.3
			Energy	1.0	2.3
			Insurance	1.7	2.8
			Labor	14.8	24.7
			Overhead	6.0	10.0
			Packaging Material	0.1	0.2
			Regulation	0.4	0.9
			Services	0.3	0.5
			Shipping	1.1	3.3
			Tools/Equipment	0.0	0.0
3	Spent Fuel Pool Operations	6.3	Energy	0.0	0.1
			Insurance	3.8	6.2
			Overhead	2.9	4.8
			Regulation	0.1	1.0
			Services	0.1	0.1
			Taxes	0.1	0.1
4	Deferred Dismantlement	1.7	Burial	16.2	53.3
			Energy	2.0	4.5
			Insurance	2.0	3.4
			Labor	14.4	24.0
			Overhead	18.1	30.2
			Packaging Material	2.2	3.8
			Regulation	2.3	5.1
			Services	0.9	1.5
			Shipping	3.2	7.4
			Taxes	0.2	0.3
			Tools/Equipment	0.3	0.4
Grand Total				**106.6**	**217.0**
Grand Total with 25% Contingency				**133.3**	**271.3**
Grand Total with 25% Contingency (Generic LLW Disposal Site)				**Not Applicable**	**361.3**

Table 2.4. SAFSTOR Case for Reference PWR (Trojan)

Period	Period Name	Duration (years)	Cost Category	Cost ($ Millions) Original Estimate (1993 $)	Updated Estimate (2010 $)
1	Planning and Preparation	2.5	Overhead	5.4	9.1
			Regulation	0.4	0.7
			Tools/Equipment	3.3	4.8
2	Defuel and Layup	0.6	Burial	3.4	11.3
			Energy	1.0	2.3
			Insurance	1.7	2.8
			Labor	14.8	24.7
			Overhead	6.0	10.0
			Packaging Material	0.1	0.2
			Regulation	0.4	0.9
			Services	0.3	0.5
			Shipping	1.1	3.3
			Tools/Equipment	0.0	0.0
3	Spent Fuel Pool Operations	6.3	Energy	0.0	0.1
			Insurance	3.8	6.2
			Overhead	1.9	3.2
			Regulation	0.1	1.0
			Services	0.1	0.1
			Taxes	0.1	0.1
4	Extended Safe storage	51.4	Burial	0.1	0.3
			Energy	0.6	1.3
			Insurance	30.8	50.9
			Labor	0.8	1.3
			Overhead	43.5	72.6
			Packaging Material	0.1	0.1
			Regulation	4.0	15.9
			Services	0.6	1.0
			Shipping	0.0	0.0
			Taxes	4.6	7.6
			Tools/Equipment	0.9	1.3
5	Deferred Dismantlement	1.7	Burial	15.8	52.1
			Energy	2.0	4.5
			Insurance	2.0	3.4
			Labor	13.6	22.7
			Overhead	18.1	30.2
			Packaging Material	2.1	3.7
			Regulation	2.3	5.1
			Services	0.9	1.5
			Shipping	3.2	7.4
			Taxes	0.2	0.3
			Tools/Equipment	0.3	0.4
Grand Total				**190.3**	**365.0**
Grand Total with 25% Contingency				**237.9**	**456.3**

Table 2.5. DECON Case for Reference BWR (Columbia)

Period	Period Name	Duration (years)	Cost Category	Cost ($ Millions) Original Estimate (1993 $)	Updated Estimate (2010 $)
1	Planning and Preparation	2.5	Overhead	5.7	9.5
			Regulation	0.4	0.7
			Tools/Equipment	3.4	5.0
2	Defuel and Layup	1.2	Burial	3.4	9.7
			Energy	1.4	3.2
			Insurance	3.2	5.3
			Labor	14.0	23.4
			Overhead	16.7	27.8
			Packaging Material	0.1	0.2
			Regulation	0.5	1.2
			Services	0.5	0.9
			Shipping	0.8	2.4
			Tools/Equipment	0.0	0.0
3	Spent Fuel Pool Operations	3.4	Energy	0.0	0.0
			Insurance	2.0	3.4
			Overhead	2.4	4.0
			Regulation	0.1	0.7
			Services	0.0	0.1
4	Deferred Dismantlement	1.7	Burial	33.2	93.6
			Energy	1.6	3.7
			Insurance	2.0	3.4
			Labor	14.3	23.8
			Overhead	18.9	31.6
			Packaging Material	3.5	6.1
			Regulation	1.8	3.9
			Services	1.1	1.8
			Shipping	0.3	1.0
			Tools/Equipment	0.3	0.4
Grand Total				**131.7**	**266.7**
Grand Total with 25% Contingency				**164.6**	**333.4**
Grand Total with 25% Contingency (Generic LLW Disposal Site)				**Not Applicable**	**516.9**

Table 2.6. SAFSTOR Case for Reference BWR (Columbia)

Period	Period Name	Duration (years)	Cost Category	Cost ($ Millions) Original Estimate (1993 $)	Updated Estimate (2010 $)
1	Planning and Preparation	2.5	Overhead	5.7	9.5
			Regulation	0.4	0.7
			Tools/Equipment	3.4	5.0
2	Defuel and Layup	1.2	Burial	3.4	9.7
			Energy	1.4	3.2
			Insurance	3.2	5.3
			Labor	14.0	23.4
			Overhead	16.7	27.8
			Packaging Material	0.1	0.2
			Regulation	0.5	1.2
			Services	0.5	0.9
			Shipping	0.8	2.4
			Tools/Equipment	0.0	0.0
3	Spent Fuel Pool Operations	3.4	Energy	0.0	0.0
			Insurance	2.0	3.4
			Overhead	1.4	2.4
			Regulation	0.1	0.7
			Services	0.0	0.1
4	Extended Safe Storage	53.7	Burial	0.1	0.1
			Energy	0.5	1.1
			Insurance	32.2	53.2
			Labor	0.5	0.8
			Overhead	65.3	109.0
			Packaging Material	0.0	0.0
			Regulation	16.8	42.7
			Services	0.6	1.0
			Shipping	0.0	0.1
			Tools/Equipment	0.9	1.4
5	Deferred Dismantlement	1.7	Burial	32.8	92.5
			Energy	1.6	3.7
			Insurance	2.0	3.4
			Labor	13.8	23.1
			Overhead	19.9	33.2
			Packaging Material	3.5	6.1
			Regulation	1.8	3.9
			Services	1.2	2.0
			Shipping	0.3	0.9
			Tools/Equipment	0.3	0.4
Grand Total				**247.7**	**474.2**
Grand Total with 25% Contingency				**309.6**	**592.8**

Table 2.7. DECON Case for Reference PWR (Trojan) – Cost Categories

Cost Category	Original Estimate (1993)	Updated Estimate w/Class A LLW Site (2010)
Overhead	30.4%	24.9%
Labor	27.3%	22.4%
Burial	18.4%	29.8%
Insurance	7.1%	5.7%
Shipping	4.0%	4.9%
Tools/Equipment	3.4%	2.4%
Regulation	2.9%	3.6%
Energy	2.9%	3.2%
Packaging Material	2.2%	1.9%
Services	1.2%	1.0%
Taxes	0.2%	0.2%
Grand Total	**100.0%**	**100.0%**

Table 2.8. SAFSTOR Case for Reference PWR (Trojan) – Cost Categories

Cost Category	Original Estimate (1993)	Updated Estimate w/Class A LLW Site (2010)
Overhead	39.3%	34.3%
Insurance	20.2%	17.3%
Labor	15.3%	13.3%
Burial	10.1%	17.5%
Regulation	3.8%	6.5%
Taxes	2.5%	2.2%
Tools/Equipment	2.4%	1.8%
Shipping	2.2%	2.9%
Energy	1.9%	2.2%
Packaging Material	1.2%	1.1%
Services	1.0%	0.9%
Grand Total	**100.0%**	**100.0%**

Table 2.9. DECON Case for Reference BWR (Columbia) – Cost Categories

Cost Category	Original Estimate (1993)	Updated Estimate w/Class A LLW Site (2010)
Overhead	33.2%	27.3%
Burial	27.8%	38.7%
Labor	21.5%	17.7%
Insurance	5.5%	4.5%
Tools/Equipment	2.8%	2.0%
Packaging Material	2.8%	2.4%
Energy	2.3%	2.6%
Regulation	2.1%	2.4%
Services	1.2%	1.0%
Shipping	0.8%	1.3%
Grand Total	**100.0%**	**100.0%**

Table 2.10. SAFSTOR Case for Reference BWR (Columbia) – Cost Categories

Cost Category	Original Estimate (1993)	Updated Estimate w/Class A LLW Site (2010)
Overhead	44.0%	38.4%
Insurance	15.9%	13.7%
Burial	14.6%	21.6%
Labor	11.4%	10.0%
Regulation	7.9%	10.4%
Tools/Equipment	1.9%	1.4%
Packaging Material	1.5%	1.3%
Energy	1.4%	1.7%
Services	0.9%	0.8%
Shipping	0.4%	0.7%
Grand Total	**100.0%**	**100.0%**

Table 2.11. Cost of Site Demolition and Return to Green Field Conditions ($ Millions)

Reactor Plant	Original Estimate (1993 $)	Updated Estimate (2010 $)
Reference PWR	38.1	64.0
Reference BWR	48.2	80.0

2.6 References

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3 REVIEW OF SITE-SPECIFIC DECOMMISSIONING COST ESTIMATES

This section reviews site-specific decommissioning cost estimates submitted by licensees to the U.S. Nuclear Regulatory Commission (NRC). These cost estimates are organized into cost categories to allow direct comparison to 1) the reference pressurized water reactor (PWR) and boiling water reactor (BWR) cost estimates used to develop the minimum decommissioning fund formula discussed in Section 1 of this report and 2) the revised reference PWR and BWR cost estimates discussed in Section 2 of this report. This section also discusses the major cost drivers for the licensee-submitted site-specific cost estimates.

3.1 Background for Decommissioning Cost Estimates

Over the last several years many licensees have submitted to the NRC estimates of the cost to decommission their nuclear power plants. Licensees submitted these estimates to the NRC principally for the following two reasons:

1. Per 10 CFR 50.75(f)(3), a utility is required to submit a preliminary decommissioning cost estimate for a nuclear power plant that is within about 5 years of potentially ceasing operations.

2. Per 10 CFR 50.82(a)(8)(iii), a utility is required to submit a site-specific decommissioning cost estimate for a nuclear power plant within 2 years following permanent cessation of operations.

However, plant-specific decommissioning cost estimates have been submitted to the NRC for other reasons, including as part of a request to an exemption from 10 CFR 50.82(a)(8). The purpose of this section of the report is to examine several of these submitted decommissioning cost estimates, update the estimates to 2010 dollars, and compare these updated estimates.

Most of the site-specific decommissioning cost estimates were developed by TLG Services, Inc. The estimates developed by TLG were sufficiently detailed to make comparisons between one power plant and another across many cost elements. These cost elements include decontamination, removal, packaging, transportation, waste disposal, program management, energy, and regulatory costs. A few site-specific decommissioning cost estimates were developed by Energy*Solutions*. The estimates provided by Energy*Solutions* were categorized by total costs of major activities performed over time (for example, “SAFSTOR Planning and Design Prior to Shutdown,” “Major Component Removal,” “Site Decontamination,” etc.) rather than by the cost elements used by TLG. Thus it was not possible to make detailed comparisons between the TLG estimates and the Energy*Solutions* estimates.

As shown in Table 3.1, some licensees included more than one decommissioning alternative in their estimates to the NRC. Entergy Nuclear Operations, Inc., for example, provided four distinct DECON and four distinct SAFSTOR estimates for their Vermont Yankee plant in 2006. Summary descriptions of the decommissioning alternatives for the plants listed in Table 3.1 are provided in Section 3.3.

Table 3.1. Decommissioning Cost Document by Licensee and Power Plant

Reference[a]	Licensee and Year of Estimate	Plant Name	Type	Capacity (MWe)	Decommissioning Alternatives[b]	Estimate Provided By[c]
1	AmerGen Energy Company (2003)	Oyster Creek	BWR	619	DECON, Delayed DECON, SAFSTOR	TLG
2	Commonwealth Edison (1996)	Zion 1	PWR	1040	DECON	TLG
	Commonwealth Edison (1996)	Zion 2	PWR	1040	DECON	
3	Consumers Energy (2003)	Palisades	PWR	778	SAFSTOR	TLG
4	Dominion Energy Kewaunee, Inc. (2008)	Kewaunee	BWR	556	SAFSTOR	ES
5	Entergy Nuclear Operations, Inc. (2006)	Vermont Yankee	BWR	620	DECON, SAFSTOR (4 cases each)	TLG
6	Entergy Nuclear Operations, Inc. (2007)	Pilgrim	BWR	685	SAFSTOR	TLG
7	Exelon Generation (2009)	Braidwood 1	PWR	1178	DECON, Delayed DECON, SAFSTOR	TLG
	Exelon Generation (2009)	Braidwood 2	PWR	1152	DECON, Delayed DECON, SAFSTOR	
8	Exelon Generation (2009)	Byron 1	PWR	1164	DECON, Delayed DECON, SAFSTOR	TLG
	Exelon Generation (2009)	Byron 2	PWR	1136	DECON, Delayed DECON, SAFSTOR	
9	Exelon Generation (2009)	LaSalle 1	BWR	1118	DECON, Delayed DECON, SAFSTOR	TLG
	Exelon Generation (2009)	LaSalle 2	BWR	1120	DECON, Delayed DECON, SAFSTOR	
10	Exelon Generation (2008)	Three Mile Island 1	PWR	819	DECON, Delayed DECON, SAFSTOR	TLG
11	FPL Energy Duane Arnold, LLC (2008)	Duane Arnold	BWR	580	DECON, SAFSTOR (2 Cases each)	ES
12	STP Nuclear Operating Company (2004)	South Texas 1	PWR	1280	DECON	TLG
	STP Nuclear Operating Company (2004)	South Texas 2	PWR	1280	DECON	
13	Nuclear Management Company, LLC (2008)	Prairie Island 1	PWR	551	DECON	TLG
	Nuclear Management Company, LLC (2008)	Prairie Island 2	PWR	545	DECON	
14	Pacific Gas and Electric (2002)	Diablo 1	PWR	1122	DECON, SAFSTOR	TLG
	Pacific Gas and Electric (2002)	Diablo 2 & Common	PWR	1118	DECON, SAFSTOR	

Table 3.1. (contd)

Reference[(a)]	Licensee and Year of Estimate	Plant Name	Type	Capacity (MWe)	Decommissioning Alternatives[(b)]	Estimate Provided By[(c)]
15	Nebraska Public Power District	Cooper	BWR	758	DECON, Delayed DECON, SAFSTOR (2 cases each)	TLG
16	Entergy Nuclear Operations, Inc. (2010)	Indian Point 3	PWR	1041	SAFSTOR	TLG
17	Nuclear Management Company, LLC (2005)	Monticello	BWR	572	DECON	TLG
18	PSEG Nuclear (2002)	Salem 1[(d)]	PWR	1174	DECON	TLG
	PSEG Nuclear (2002)	Salem 2	PWR	1130	DECON	
19	PSEG Nuclear (2008/2002)[(e)]	Hope Creek	BWR	1061	SAFSTOR	PSEG, TLG

(a) Numbers in this column correspond to the references in Section 3.6.
(b) Descriptions of the decommissioning alternatives for each power plant are provided in Section 3.3 of this report.
(c) TLG is TLG Services, Bridgewater, Connecticut. ES is Energy*Solutions*, Inc., Commercial Decommissioning Services Division, 143 West Street, Unit E, New Milford, Connecticut.
(d) Detailed cost data were not available for Salem 1.
(e) Summary information was available in 2008 dollars; detailed information in 2002 dollars.

3.2 Analysis Methodology

The available decommissioning cost estimates that will be discussed in this report are identified in Table 3.1. Of the many cost estimates that examined, only the ones listed in the table contained enough detail to permit meaningful comparisons between one estimate and another. All estimates are plant-specific estimates submitted to the NRC in accordance with the NRC regulations discussed previously. The estimates were prepared either by TLG Services, Inc. (TLG) or by Energy*Solutions*, Inc. (ES) as indicated in the table.

3.2.1 Decommissioning Activities

The plant-specific decommissioning cost estimates developed by TLG and Energy*Solutions* generally include the total cost to restore the site of the nuclear power plant to its original or green-field state. Hence, these estimates include activities, such as spent fuel management and site restoration, which are beyond those required to obtain termination of the 10 CFR Part 50 license by the NRC. The decommissioning activities included in these estimates generally include the following:

- License Termination – includes decommissioning activities required to remove and dispose of all contaminated systems and structures so that the plant's operating license can be terminated by the NRC (10 CFR 50.82). These activities can be funded by the plant's decommissioning fund.

- Spent Fuel Management – includes activities required to safely manage the plant's spent fuel until it is transferred to the U.S. Department of Energy (DOE) for final disposition (10 CFR 50.54(bb)). Since a program to manage and fund these activities is required by NRC regulations separate from 10 CFR 50.82, these activities are not funded by the plant's decommissioning fund.

- Site Restoration – includes activities performed after license termination to restore the plant site to its original or green-field state, such as demolition and disposal of uncontaminated structures and site regarding and re-vegetation. The NRC has no regulatory authority over these activities and so these activities are not funded by the plant's decommissioning fund.

While this report is only concerned with the cost of activities required to obtain license termination, since the costs associated with the other two activities are significant and are generally included in the plant-specific decommissioning cost estimates, they are included in this report for completeness.

Based on its review of the available decommissioning cost estimates, it was determined that the TLG license termination costs could readily be divided into 15 unique cost elements. Eight of these elements pertain to direct decommissioning activities and three to management activities. The remaining four elements did not readily fit into any particular category and so were assigned to a group called "other." The classification scheme is provided in Table 3.2. Because of the nature of the cost breakdown of the estimates furnished by Energy*Solutions*, the TLG and

Energy*Solutions* estimates can only be compared at the license termination/spent fuel management/site restoration level. The authors chose to primarily rely on the TLG estimates because, as indicated in Table 3.1, all but two of the available plant-specific decommissioning cost estimates were developed by TLG.

Table 3.2. Cost Breakdown Hierarchy and Cost Escalation Factors for TLG Estimates

Activity	Major Cost Category	Cost Element	Annual Escalation Factor
License Termination 10 CFR 50.75	Direct Costs	Decontamination	1.0306
		Removal	1.0306
		Packaging	1.0331
		Transportation	1.0668
		Waste Disposal	1.046
		Waste Processing	1.046
		Spent Fuel Pool Isolation	1.0306
		Miscellaneous Equipment	1.0221
	Management Costs	Program Management	1.0306
		Spent Fuel Management (non 10 CFR 50.54(bb) activities)	1.0306
		Site Operations and Management	1.0306
	Other Costs	Insurance and Regulatory	1.0437
		Energy	1.0723
		Characterization and Licensing	1.0437
		Property Taxes	1.03
Spent Fuel Management – 10 CFR 50.54(bb)			1.0306
Site Restoration			1.0306

3.2.2 Escalation of Estimates to Current-Year Dollars

In order to make sensible comparisons between decommissioning cost estimates, each estimate must be converted to current-year (2010) dollars. The first step in this process is to determine an annual escalation factor for each of the cost elements in Table 3.2. In Section 2 of this report, escalation factors for each of the cost elements in Table 3.2 were developed for the 17-year period from 1993 to 2010. To obtain a yearly estimate, it is necessary to take the seventeenth root of each of these factors. For example, the decontamination escalation factor is 1.67 for the 17-year period. Converting this to an annual value yields

$$Decontamination\ escalation = 1.67^{1/17} = 1.0306.$$

This is the escalation factor shown in the first line of Table 3.2. The other annual escalation factors shown in Table 3.2 are obtained in a similar manner (except for the waste disposal and waste processing escalation factors described below). Once the yearly escalation has been obtained it is a simple matter to calculate the escalation for a different period of time. For example, the decontamination escalation for the 6-year period from 2004 to 2010 is $(1.0306)^6$ = 1.1982.

The waste disposal and waste processing escalation factors (assumed to be equal for simplicity) were obtained by calculating the average yearly increase in B_x (the LLW burial/disposition cost adjustment) for direct disposal at the Barnwell disposal site in South Carolina for the years 1998 through 2010. The Barnwell Site is considered to be the generic LLW burial site for lack of a better alternative at this time. It is also assumed in this report that the escalation factors for disposal of Class A waste at the Energy*Solutions* facility in Clive, Utah, are the same as for the Barnwell site.

3.3 Decommissioning Costs

A summary of each cost analysis performed by TLG or Energy*Solutions*, as identified in Table 3.1, is provided in this section. Each analysis assumes the eventual removal of all contaminated and activated plant components and structural materials, such that the licensee may then have unrestricted use of the site with no further requirement for an operating license.

AmerGen Energy Company (Oyster Creek)

Three decommissioning alternatives were evaluated by TLG, as follows:

Alternative 1 – DECON: The operating license expires in April 2009. The first alternative assumes that the total duration of the physical dismantling process is minimized. The existing independent spent fuel storage installation (ISFSI) is expanded to accommodate any residual spent fuel remaining from plant operations so as to facilitate the decontamination and dismantling of the power block structures. Spent fuel storage operations continue at the site until the transfer of fuel to the DOE is complete, assumed to be in the year 2027.

Alternative 2 – Delayed DECON: In the second alternative, the unit is prepared for an abbreviated period of storage. The spent fuel discharged to the storage pool, once operations cease, remains in the pool until it can be transferred to a DOE facility, i.e., an ISFSI is not used to offload the pool. Decommissioning is delayed until the transfer of the fuel to the DOE is complete, i.e., in the year 2027. The unit is then decommissioned.

Alternative 3 – SAFSTOR: The unit is placed into safe-storage in the third alternative. However, decommissioning is deferred beyond the fuel storage period to the maximum extent possible; termination of the license would conclude within the maximum required 60-year period. Spent fuel remaining in the spent fuel storage pool after a minimum cooling period of 5 years is transferred to the ISFSI for interim storage.

Commonwealth Edison (Zion Units 1 and 2)

The analysis performed by TLG assumes that Commonwealth Edison chooses a Delayed DECON decommissioning alternative which involves removal of all radioactive material from the site commencing at the original license expiration date of Zion Station and ending with the shipment of spent fuel from the site. At this point, the owner would have unrestricted use of the site with no further requirement for a license. The analysis further assumes that a number of plant systems and structures onsite affected by the decontamination effort are dismantled to the extent necessary to support NRC license termination, allowing the remaining structures onsite to be available for alternative use. The analysis was submitted to Commonwealth Edison in February 1999. Although this is after the 1998 permanent shutdown of the units, the analysis was in preparation before that time and does not reflect the permanent shutdown. The analysis is based on 1996 dollars.

TLG did not supply enough information in its estimate to allow a detailed analysis. Consequently, only license termination costs and utility/DOC staffing costs for Zion are discussed in this report.

Consumers Energy (Palisades)

This SAFSTOR cost estimate was analyzed by TLG. The estimate assumes the eventual removal of all contaminated and activated plant components and structural materials to the point that the facility operator may then have unrestricted use of the site with no further requirement for an operating license. Delayed decommissioning is accomplished within the 60-year period required by current NRC regulations. In the interim, the spent fuel remains in storage at the site in the storage pool and/or an ISFSI until such time that the transfer to a DOE facility can be completed. Once the transfer is complete, the storage facilities are also decommissioned.

Dominion Energy Kewaunee, Inc. (Kewaunee)

The original site-specific decommissioning cost analysis for Kewaunee, which analyzed six different decommissioning alternatives, was not available. However, a revision to Alternative 2 of that original report was available. The revision, prepared by Energy*Solutions*, was necessitated by a delay in the planned opening of Yucca Mountain and by the fact that Barnwell would be closed to non-Atlantic compact utilities after July 2008, thereby leaving Kewaunee without access to a disposal facility for Class B and C wastes.

The revision to Alternative 2 analyzes a DECON alternative. The specific details used in the analysis are as follows:

- No license extension with shutdown on December 21, 2013.
- Terminate spent fuel pool operation seven years after permanent unit shutdown.
- Spent fuel will be stored in Multi-Purpose Canisters (MPCs) at an ISFSI to be built in the future.
- A dry transfer facility will not be necessary.
- Yucca Mountain spent fuel repository opens in 2017.

This alternative incorporated the spent fuel schedule, developed by Dominion, modified to include the disposition of one MPC containing greater-than-Class C (GTCC) waste. The

10 CFR Part 50 license is terminated by 2021 with the 10 CFR Part 72 ISFSI license being terminated by 2048. The cost of a 10 CFR Part 72 ISFSI site-specific license and renewal was included.

Entergy Nuclear Operations, Inc. (Vermont Yankee)

Eight scenarios based on two decommissioning alternatives were identified by TLG for evaluation. As shown in Table 3.3, the eight scenarios evaluate a combination of shutdown dates (scheduled and anticipated), decommissioning alternative (DECON or SAFSTOR), and expectations of DOE's performance in transferring spent fuel from the site to a federal repository (EntergyVY versus Vermont Department of Public Service).

Table 3.3. Eight Decommissioning Scenarios

Scenario	Shutdown	Alternative	First Spent Fuel Assembly Pickup	Last Spent Fuel Assembly Pickup
1	2012	DECON	2017	2042
2	2032	DECON	2017	2057
3	2012	DECON	2057	2082
4	2032	DECON	2042	2082
5	2012	SAFSTOR	2017	2042
6	2032	SAFSTOR	2017	2057
7	2012	SAFSTOR	2057	2082
8	2032	SAFSTOR	2042	2082

The analysis assumes that an ISFSI is constructed within the protected area (PA) to support continued plant operations. If the plant operates until 2032 and the DOE initiates pickup in 2017, this facility will be able to accommodate the fuel remaining in the storage pool after the required cooling period. However, in a scenario where the plant ceases operation in 2012 or the DOE fails to initiate transfer in 2017, a supplemental ISFSI is assumed to be constructed. The following is assumed for each scenario:

Scenario	ISFSI Assumptions
1, 3, 4, 5, 7, 8	New ISFSI constructed to support decommissioning operations. Fuel relocated from the PA ISFSI to the ISFSI at shutdown.
2, 6	The PA pad constructed during plant operations can accommodate the fuel present in the storage pool at the time of decommissioning

Once the reactor building's storage pool is emptied, the building can be either decontaminated and dismantled or prepared for long-term storage. The ISFSI will operate under an independent license once the plant's operating license is terminated.

The earliest completion of fuel removal from the site is 2042 (Scenarios 1 and 5). The latest completion date, as proposed by the Vermont Department of Public Service, would be 2082 (Scenarios 3, 4, 7, and 8).

Entergy Nuclear Operations, Inc. (Pilgrim)

The SAFSTOR alternative was analyzed by TLG. In the analysis, Pilgrim is assumed to cease operations in June 2012 after 40 years of operations. The unit would then be placed in safe-storage, with the spent fuel relocated to an ISFSI to await the transfer to a DOE facility. Based on a 2017 start date for the pickup of spent fuel from the commercial industry, Entergy anticipates that the removal of the Pilgrim fuel from the site could be completed by the year 2042. At that time, the plant would be decommissioned and the site released for alternative use without restriction.

Exelon Generation (Braidwood Units 1 & 2, Byron Units 1 & 2, and LaSalle Units 1 & 2)

In 2009, TLG performed a DECON, Delayed DECON, and SAFSTOR decommissioning cost analysis for each of these units.

Braidwood: Operating licenses were issued on October 17, 1986, for Unit 1 and December 18, 1987, for Unit 2. TLG assumed a sixty year operating lifetime for the analysis. The cessation of operations would then be October 17, 2046, and December 18, 2047, for Units 1 and 2, respectively. For each decommissioning scenario, TLG assumed continued operation of the plant's spent fuel pool for a minimum of 5½ years following the cessation of operations for continued cooling of the assemblies. For the DECON and SAFSTOR scenarios, the ISFSI is expanded to accommodate the spent fuel, once sufficiently cooled, until such time as DOE can complete the transfer of the assemblies to its repository. The spent fuel remains in the storage pool in the Delayed-DECON alternative.

Byron: Operating licenses were issued on October 31, 1984, for Unit 1 and November 6, 1986, for Unit 2. TLG assumed a 60-year operating lifetime for the analysis. The cessation of operations would then be October 31, 2044, and November 6, 2046, for Units 1 and 2, respectively. For each decommissioning scenario, TLG assumed continued operation of the plant's spent fuel pool for a minimum of 5½ years following the cessation of operations for continued cooling of the assemblies. For the DECON and SAFSTOR scenarios, the ISFSI is expanded to accommodate the spent fuel, once sufficiently cooled, until such time as the DOE can complete the transfer of the assemblies to its repository. The spent fuel remains in the storage pool in the Delayed-DECON alternative.

LaSalle: Operating licenses were issued on April 17, 1982, for Unit 1 and on December 16, 1983, for Unit 2. TLG assumed a 60-year operating lifetime for the analysis. The cessation of operations would then be April 17, 2042, and December 16, 2043, for Units 1 and 2, respectively. For each decommissioning scenario, TLG assumed continued operation of the plant's spent fuel pool for a minimum of 5½ years following the cessation of operations for continued cooling of the assemblies. For the DECON and SAFSTOR scenarios, the ISFSI is expanded to accommodate the spent fuel, once sufficiently cooled, until such time as the DOE can complete the transfer of the assemblies to its repository. The spent fuel remains in the storage pool in the Delayed-DECON alternative.

Exelon Generation, Inc. (Three Mile Island, Unit 1)

TLG analyzed three alternatives. For each alternative, it was assumed that the unit would operate until 2034.

Alternative 1 – DECON: In this alternative, an ISFSI is constructed onsite to permit offloading of the spent fuel in the fuel storage facilities so as to facilitate decontamination and dismantling activities within the fuel handling building. The unit is then promptly decommissioned as an integrated activity. Spent fuel storage operations continue at the site until the transfer of fuel to, the DOE is complete, assumed to be in the year 2048.

Alternative 2 – Delayed DECON: In the second alternative, the unit is shut down and prepared for an abbreviated period of storage prior to the actual start of field activities. The spent fuel discharged to the storage pool once operations cease remains in the pool until it can be transferred to a DOE facility. Decommissioning is delayed until the transfer of the fuel to the DOE is completed (i.e., in the year 2048). The unit is then decommissioned.

Alternative 3 – SAFSTOR: The unit is also placed into storage for 60 years. An ISFSI is constructed onsite to permit offloading of the spent fuel in the fuel storage facilities; spent fuel remaining in the spent fuel storage pool after a minimum cooling period is transferred to the ISFSI for interim storage. The unit remains in safe-storage after the fuel has been removed from the site until decommissioning operations. As with the first two alternatives, decommissioning activities are sequenced and integrated so as to minimize the total duration of the physical dismantling process.

FPL Energy Duane Arnold, LLC (Duane Arnold)

Two DECON alternatives and two SAFSTOR alternatives were analyzed by Energy*Solutions*.

DECON (No License Extension): For this alternative the following assumptions are made:

- No license extension, with shutdown on February 21, 2014.
- Terminate spent fuel pool operation five years after permanent unit shutdown.
- Spent fuel will be stored at the existing ISFSI.
- Class B and C waste will be temporarily stored in an onsite interim waste storage facility to be built during decommissioning. Class B and C waste are assumed to be stored onsite until 2025, which is the assumed date a licensed facility would be available to receive these wastes.
- The DOE Yucca Mountain repository, or other approved method of spent fuel disposition, will be available starting in 2025.

SAFSTOR (No License Extension): This alternative makes the same assumptions as the DECON alternative except that Class B and C waste generated during operations and SAFSTOR preparations will be stored in the existing Low-Level Radwaste Storage Building until 2025, which is the assumed date a licensed facility would be available to receive these wastes.

DECON (Twenty-Year License Extension): This alternative is identical to the first DECON alternative with the exception of a 20-year license extension, and therefore no onsite interim waste storage facility is required for Class B and C waste. All legacy Class B and C waste generated during operations, and stored until a licensed facility is available to accept these wastes, is assumed to be disposed of during operations.

SAFSTOR (Twenty-Year License Extension): This alternative is identical to the first SAFSTOR alternative with the exception of a 20-year license extension, and therefore no onsite interim waste storage facility is required for Class B and C waste. All legacy Class B and C waste generated during operations, and stored until a licensed facility is available to accept these wastes, is assumed to be disposed of during operations.

Nuclear Management Company, LLC (Prairie Island Units 1 and 2)

The analysis relies upon site-specific, technical information from an earlier evaluation prepared in 2005, updated to reflect current assumptions. A detailed cost estimate was developed utilizing the DECON decommissioning alternative. Unit 1 and Unit 2 are assumed to permanently cease to operate in August 2013 and October 2014, respectively. The ISFSI will continue to operate under a site-specific license as authorized by 10 CFR Part 72. Assuming the DOE begins to remove fuel from the Prairie Island site in 2028, the process is not expected to be completed until 2053.

Pacific Gas and Electric (Diablo Canyon Units 1 and 2)

TLG analyzed a DECON and a SAFSTOR alternative. A major underlying assumption for the DECON alternative is that DOE will begin receipt of spent fuel from Diablo Canyon in 2018. It also assumes construction of an ISFSI prior to final plant shutdown in order to support continued plant operations. For both alternatives, the fuel will remain in wet storage in the existing fuel pool(s) for 12 years following shutdown of each unit. During this time, the existing ISFSI will be expanded to accept the inventory of fuel from the pools. All fuel will be transferred to the ISFSI within 12 years of final unit shutdown. The last spent fuel shipment is expected to occur in 2040.

The primary difference between the sequences anticipated for the DECON and SAFSTOR alternatives is the absence, in the latter, of any constraint on the availability of the Fuel Handling Buildings for decommissioning. The timing for the SAFSTOR alternative is such that the spent fuel inventory has been removed from the site prior to the initiation of decontamination and dismantling activities, eliminating a significant scheduling hindrance. Any GTCC material generated in the segmentation of the reactor vessel internals is assumed to be directly routed to DOE's geological facility, without the need to provide for interim storage onsite.

STP Nuclear Operating Company (South Texas Units 1 and 2)

This analysis by TLG is an update (in 2004 dollars) of that company's previous 1998 DECON cost study. The analysis assumes that Unit 1 will be shutdown in 2027 and Unit 2 in 2028. The DECON period would run from about 2030 to 2036 for both units, with spent fuel being transferred from the ISFSI to DOE during the period from 2037 to 2047.

TLG did not supply enough information in its estimate to allow PNNL to perform a detailed analysis. Consequently, only license termination costs and utility/DOC staffing costs for South Texas are discussed in this report.

Nebraska Public Power District (Cooper)

TLG analyzed six different decommissioning alternatives, as shown in Table 3.4. The first three alternatives assume the plant operates until its current license expires. The second three assume that a 20-year license extension is granted.

Table 3.4. Six Decommissioning Alternatives Analyzed by TLG

Alternative	Shutdown Date	Option	Spent Fuel Transfer Completed	Operating License Terminated
1	2014	DECON	2046	2020
2	2014	Delayed DECON	2046	2053
3	2014	SAFSTOR	2046	2074
4	2034	DECON	2061	2040
5	2034	Delayed DECON	2061	2068
6	2034	SAFSTOR	2061	2094

The Nebraska Public Power District has 1,054 spent fuel assemblies from Cooper in storage at General Electric's wet-pool ISFSI in Morris, Illinois. TLG assumes that this inventory will be preferentially transferred to the DOE, starting in 2022. The first assemblies removed from the Cooper site are assumed to be in 2027. With an estimated rate of transfer of 3,000 metric tons of uranium per year, fuel is projected to be removed from the site by 2046 for a 2014 shutdown and 2061 for a 2034 shutdown.

Cooper's ISFSI is available to support continued plant operations and future decommissioning. This facility will accommodate the dry storage modules needed to empty the wet storage pool so that dismantling activities can proceed. Once emptied, the Reactor Building can be either decontaminated and dismantled or prepared for long-term storage.

Entergy Nuclear Operations, Inc. (Indian Point 3)

TLG analyzed a SAFSTOR alternative for the decommissioning of Indian Point 3 (IP-3). For purposes of this analysis, TLG assumed DOE will begin accepting commercial spent fuel in 2020. The first IP-3 spent fuel assemblies are assumed to be removed from the site in 2023. With an estimated rate of transfer of 3,000 metric tons of uranium (MTU)/year all fuel would be removed from the site by 2047, assuming shutdown of IP-3 in 2015 (and a transfer of approximately 30 additional MTUs in 2047 should IP-3 require refueling in 2015, prior to the cessation of operations).

TLG included costs associated with the removal and disposition of approximately 2.4 million cubic feet of potentially contaminated soil on the IP-3 site. This volume includes soil contaminated by IP-1 located within the boundaries of the IP-3 site.

Nuclear Management Company, LLC. (Monticello)

TLC analyzed a DECON alternative for Monticello. At the time of the estimate (2006), the NRC operating license for Monticello was due to expire in September 2010, at which time decommissioning activities were assumed to begin. The analysis also assumed that an onsite ISFSI would be built to store spent fuel before the permanent plant shutdown. It was further assumed that spent fuel in the storage pool would be shipped to DOE or placed into the ISFSI within 5½ years of shutdown to facilitate decontamination and dismantling activities within the fuel handling area of the reactor building. Spent fuel storage operations would continue at the site until the transfer of the fuel to the DOE is complete, assumed to be in the year 2039.

PSEG Nuclear (Salem Units 1 and 2)

TLG analyzed a DECON alternative for the two Salem units, based on an assumed scheduled shutdown in 2016 for Unit 1 and 2020 for Unit 2. The analysis assumed that fuel will be removed from the spent fuel pool, starting in 2020, with the transfer complete by the end of year 2046. An ISFSI would be available to support decommissioning so that decommissioning could begin on the fuel handling buildings. While general cost information was available for both units, detailed cost breakdowns were available for Salem 2 only.

PSEG Nuclear (Hope Creek)

In 2009, PSEG personnel updated the original 2002 TLG SAFSTOR analysis. The TLG analysis assumed that the spent fuel would be removed from the plant and placed in an ISFSI beginning in the year 2015. The rate at which the fuel is removed is assumed to be 3,000 metric tons per year. Fuel transfer would be completed in 2046.

In addition to converting from 2002 to 2008 dollars, the PSEG update included two other significant changes from the 2002 TLG Report. The first change shifted the initial costs for preparing the plant for decommissioning from the start of the seven-year decommissioning and dismantlement period to a point just preceding the start of the SAFSTOR period. These up-front costs would be incurred in three years immediately following termination of operations. The second major change was adding a forty-year period of safe storage prior to final decommissioning.

3.4 Analysis of Licensee-Provided Decommissioning Cost Estimates

Results of the analysis conducted for nineteen cost estimates comprising some 60 decommissioning cases are presented in this section.

3.4.1 Total Decommissioning Costs

As discussed in previously, the decommissioning cost estimates provided by licensees include three cost elements: license termination, spent fuel management, and site restoration. Table 3.5 presents the costs for these three elements for each of the 60 decommissioning cost estimate cases available for this study. The information in the table is presented in order from the plant scenario having the lowest license termination cost to the plant scenario having the highest license termination cost. For comparison purposes, Table 3.3 also includes license termination cost estimates derived from NRC's independent analyses of current decommissioning funding reports. These reports are submitted by licensees to the NRC in accordance with 10 CFR 50.75(f)(1).

3.4.2 License Termination Costs

License termination costs for the plants listed in Table 3.1 are presented in Table 3.5. For completeness, spent fuel management costs and site restoration costs are also provided.

The license termination costs for the plants and decommissioning alternatives shown in Table 3.5 are also plotted in Figure 3.1. The data shown on the graph suggests the following:

- There is significant variability in the license termination costs for plant having similar capacities. For example:
    - The BWR DECON cases having about 600 MWe capacity have license termination costs ranging from about $550M to about $630M.
    - Similarly, the BWR SAFSTOR cases having about 600 MWe capacity have license termination costs ranging from about $530M to almost $800M.
- License termination costs do not, in general, appear to increase with plant capacity. However:
    - The PWR DECON cases show some indication of increasing cost with increasing plant electric capacity, but clearly this is not indicated for all cases.
    - The SAFSTOR cases especially show considerable scatter; however, there is a general trend of lower cost with smaller electric capacity to higher cost with higher electric capacity for the BWR SAFSTOR cases.

The report sections below attempt to better understand the reasons for the wide variability in license termination costs by identifying the important assumptions that are driving the cost estimates.

Figure 3.2 presents license termination costs for 42 separate cost estimates, categorized by DECON, SAFSTOR, and Delayed DECON decommissioning scenarios. For each decommissioning scenario, cost estimates for each decommissioning case are arranged by decreasing costs.

The license termination cost for each case is split into direct decommissioning cost, decommissioning management cost, and "other" costs. These three categories are defined in Section 3.2 and are composed of the cost elements indicated in Table 3.2.

Figure 3.3 is similar to Figure 3.2 but shows license termination costs broken down by percent contributions of direct, management and other costs. Wide fluctuations in the percentages of these costs are evident.

Table 3.5. Plant-Specific Decommissioning Costs (Millions of 2010 Dollars) Listed in Order of Increasing License Termination Costs

Plant/Type/Capacity (MWe)/Alternative[a]	Cost Estimator	Year of Original Estimate	NRC Estimate[b]	License Termination 10 CFR 50.75	Spent Fuel Management 10 CFR 50.54[b]	Site Restoration	Total
Kewaunee/PWR/556/DECON	Energy*Solutions*	2008	408	404	342	23	769
Byron 1/PWR/1164/Delayed DECON	TLG	2009	473	434	138	70	642
Braidwood 1/PWR/1178/Delayed DECON	TLG	2009	473	439	142	69	650
Braidwood 1/PWR/1178/DECON	TLG	2009	473	458	123	68	648
Byron 1/PWR/1164/DECON	TLG	2009	473	464	112	68	644
Cooper/BWR/758/Delayed DECON (2014 SD)	TLG	2008	573	510	329	40	878
Cooper/BWR/758/Delayed DECON (2034 SD)	TLG	2008	573	510	271	40	821
Three Mile Island 1/PWR/819/Delayed DECON	TLG	2008	448	511	163	81	755
LaSalle 1/BWR/1118/Delayed DECON	TLG	2009	616	513	99	51	663
Duane Arnold/BWR/580/DECON LIC EXT	Energy*Solutions*	2008	553	517	249	43	809
Byron 2/PWR/1136/Delayed DECON	TLG	2009	473	517	117	93	728
Vermont Yankee/BWR/620/SAFSTOR (2012 SD/2057 SFPU)	TLG	2006	564	518	565	45	1,128
Prairie Island 1/PWR/551/DECON	TLG	2008	404	522	213	34	768
Vermont Yankee/BWR/620/SAFSTOR (2032 SD/2017 SFPU)	TLG	2006	564	524	249	47	820
Vermont Yankee/BWR/620/SAFSTOR (2012 SD/2017 SFPU)	TLG	2006	564	526	344	47	917
Braidwood 2/PWR/1152/Delayed DECON	TLG	2009	473	529	126	93	748
Duane Arnold/BWR/580/DECON NO LIC	Energy*Solutions*	2008	553	530	296	43	869
Monticello/BWR/572/DECOM	TLG	2005	548	531	220	32	783
Oyster Creek/BWR/619/Delayed DECON	TLG	2003	565	531	217	56	804
LaSalle 2/BWR/1120/Delayed DECON	TLG	2009	616	534	128	68	730
Byron 2/PWR/1136/DECON	TLG	2009	473	539	122	92	753
Vermont Yankee/BWR/620/SAFSTOR (2032 SD/2042 SFPU)	TLG	2006	564	539	474	49	1,062
Vermont Yankee/BWR/620/DECON (2012 SD/2017 SFPU)	TLG	2006	564	540	247	45	833
Vermont Yankee/BWR/620/DECON (2012 SD/2057 SFPU)	TLG	2006	564	540	434	45	1,019

Table 3.5. (contd)

Plant/Type/Capacity (MWe)/Alternative[a]	Cost Estimator	Year of Original Estimate	NRC Estimate[b]	License Termination 10 CFR 50.75	Spent Fuel Management 10 CFR 50.54[b]	Site Restoration	Total
Three Mile Island 1/PWR/819/DECON	TLG	2008	448	540	169	78	787
Vermont Yankee/BWR/620/DECON (2032 SD/2042 SFPU)	TLG	2006	564	540	346	45	931
Vermont Yankee/BWR/620/DECON (2032 SD/2017 SFPU)	TLG	2006	564	540	160	50	751
Cooper/BWR/758/DECON (2014 SD)	TLG	2008	573	543	246	37	826
Cooper/BWR/758/DECON (2034 SD)	TLG	2008	573	543	194	37	773
Braidwood 2/PWR/1152/DECON	TLG	2009	473	547	122	91	760
LaSalle 1/BWR/1118/DECON	TLG	2009	616	566	109	50	725
Prairie Island 2/PWR/545/DECON	TLG	2008	404	575	217	55	847
LaSalle 2/BWR/1120/DECON	TLG	2009	616	593	116	67	776
South Texas 1/PWR/1280/DECON	TLG	2004	467	600	115	54	769
Byron 1/PWR/1164/SAFSTOR	TLG	2009	473	608	114	70	791
Pilgrim/BWR/685/SAFSTOR	TLG	2007	569	610	360	39	1,009
Duane Arnold/BWR/580/SAFSTOR LIC EXT	Energy*Solutions*	2008	553	614	245	44	903
Duane Arnold/BWR/580/SAFSTOR NO LIC	Energy*Solutions*	2008	553	614	291	44	949
Oyster Creek/BWR/619/DECON	TLG	2003	565	616	175	52	844
Braidwood 1/PWR/1178/SAFSTOR	TLG	2009	473	619	117	69	806
Zion 1/PWR/1040/Delayed DECON	TLG	1996	--[c]	620	--[d]	--[e]	620
South Texas 2/PWR/1280/DECON	TLG	2004	467	629	187	115	931
Salem 1/PWR/1174/DECOM	TLG	2002	467	647	86	41	773
Byron 2/PWR/1136/SAFSTOR	TLG	2009	473	660	135	94	888
LaSalle 2/BWR/1120/SAFSTOR	TLG	2009	616	674	129	68	871
Braidwood 2/PWR/1152/SAFSTOR	TLG	2009	473	676	125	93	894
LaSalle 1/BWR/1118/SAFSTOR	TLG	2009	616	688	124	51	863
Diablo 2 & Common/PWR/1118/SAFSTOR	TLG	2002	473	718	--[d]	86	803
Salem 2/PWR/1130/DECOM	TLG	2002	467	718	68	68	855
Diablo 1/PWR/1122/DECON	TLG	2002	473	719	--[d]	39	759
Cooper/BWR/758/SAFSTOR (2014 SD)	TLG	2008	573	722	208	40	969
Cooper/BWR/758/SAFSTOR (2034 SD)	TLG	2008	573	724	169	40	932
Diablo 1/PWR/1122/SAFSTOR	TLG	2002	473	725	--[d]	39	764

Table 3.5. (contd)

Plant/Type/Capacity (MWe)/Alternative[a]	Cost Estimator	Year of Original Estimate	NRC Estimate[b]	License Termination 10 CFR 50.75	Spent Fuel Management 10 CFR 50.54[b]	Site Restoration	Total
Three Mile Island 1/PWR/819/SAFSTOR	TLG	2008	448	740	189	81	1,010
Palisades/PWR/778/SAFSTOR	TLG	2003	439	743	368	97	1,208
Diablo 2 & Common/PWR/1118/DECON	TLG	2002	473	746	--[d]	88	835
Zion 2/PWR/1040/Delayed DECON	TLG	1996	--[c]	759	--[d]	--[e]	759
Oyster Creek/BWR/619/SAFSTOR	TLG	2003	565	775	243	56	1,074
Indian Point 3/PWR/1041/SAFSTOR	TLG	2010	474	836	228	77	1,142
Hope Creek/BWR/1061/SAFSTOR	TLG	2008	609	924	50	125	1,098

(a) The decommissioning alternatives for each plant are discussed in Section 3.
(b) NRC independent analysis of 2010 decommissioning funding reports submitted as required by 50.75(f)(1)
(c) Plant not operating. NRC independent analysis not available.
(d) Spent fuel management costs were not provided in original estimate.
(e) Site restoration costs were not provided in original estimate.

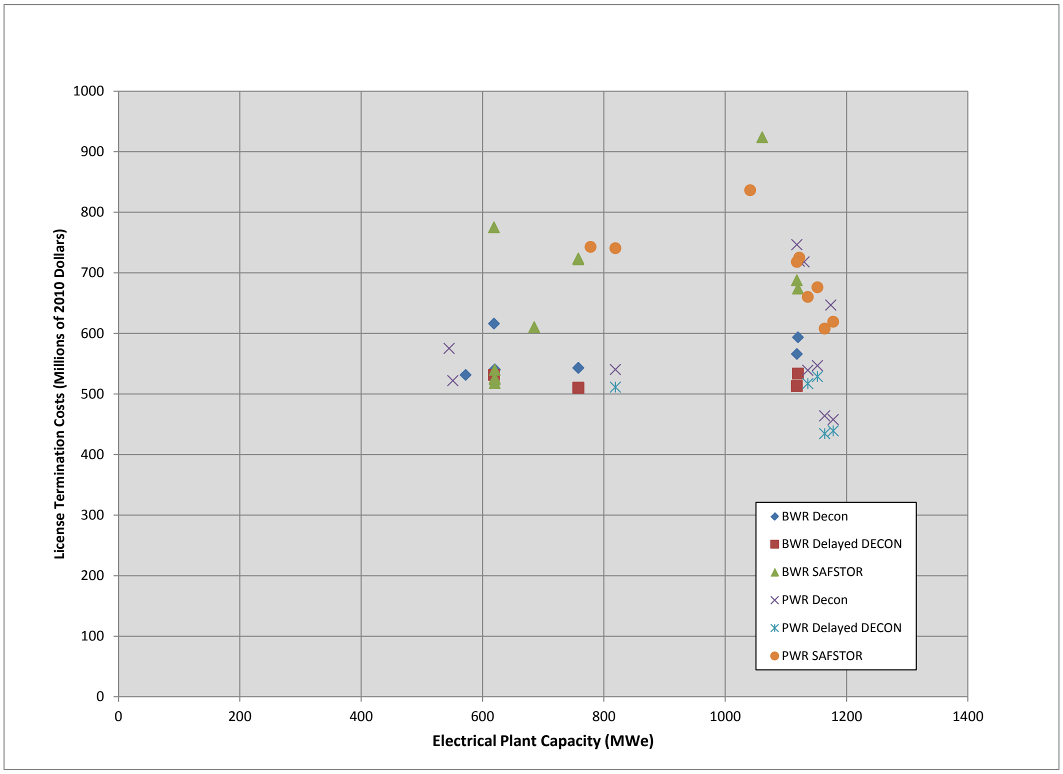

Figure 3.1. License Termination Costs vs. Plant Capacity

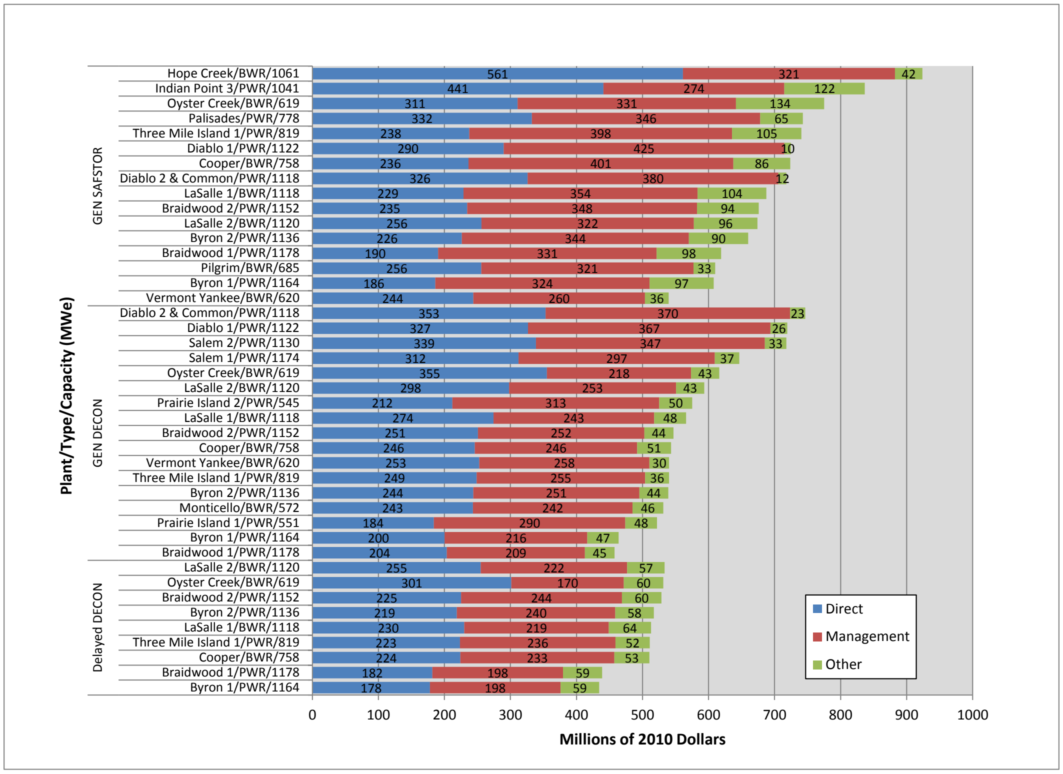

Figure 3.2. License Termination Cost Breakdown

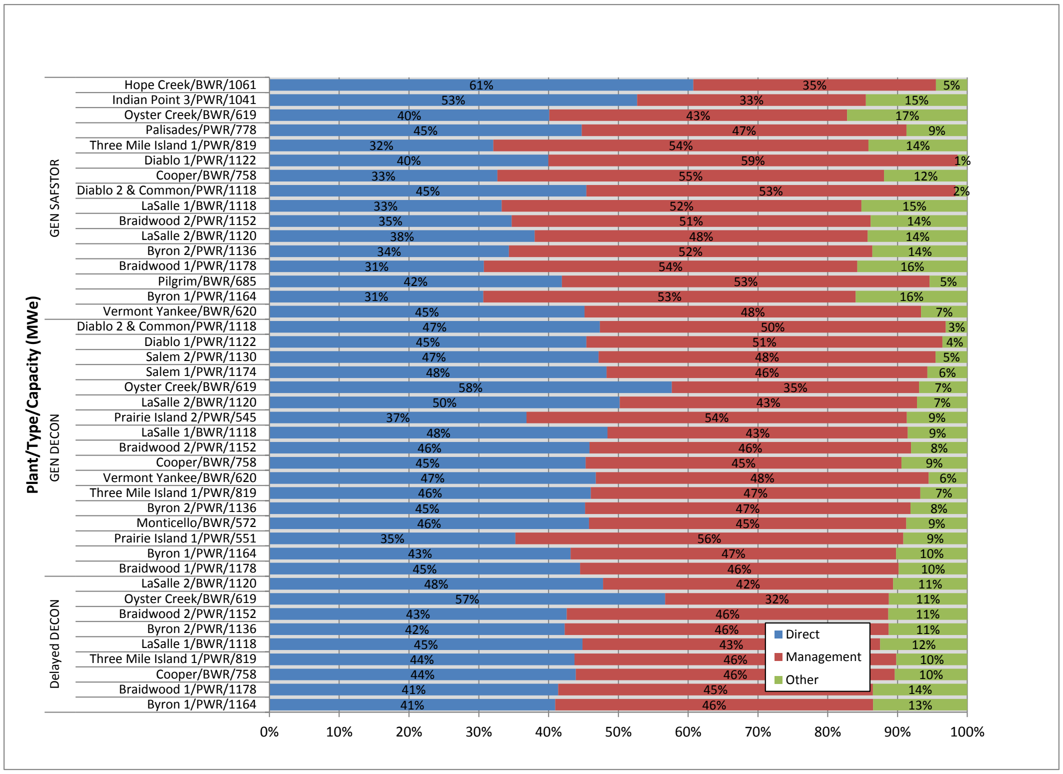

Figure 3.3. License Termination Costs Breakdown by Percent of Total

Of the eight decommissioning cost estimates submitted by Vermont Yankee, only Cases 4 and 8 (i.e., DECON 4 and SAFSTOR 4) are included in the figure. These two cases represent the licensee's application to extend the operating license by 20 years by assuming a later shutdown of 2032 (as opposed to 2012) and assuming that an ISFSI will be required.

Not included in the graphs are the three cost estimates prepared by Energy*Solutions*. As indicated earlier in this report, Energy*Solutions* uses a different method of grouping costs that is incompatible with the cost groupings used by TLG. Since the majority of the available decommissioning cost estimates were prepared by TLG, the TLG cost groupings are used in this report. Tables 3.6 and 3.7 summarize the license termination costs for the cases shown in Figures 3.2 and 3.3.

It is interesting that average of the direct decommissioning costs comprise practically the same percentage of license termination costs for each decommissioning scenario: 46%, 45%, and 40% for DECON, Delayed DECON, and SAFSTOR, respectively.

Table 3.6. Average License Termination Costs (Millions of 2010 Dollars)

Alternative	Reactor Type	Direct Costs	Management Costs	Other Costs	Total
DECON	BWR	278	243	44	565
	PWR	261	288	39	589
	DECON Average	**267**	**272**	**41**	**580**
Delayed DECON	BWR	253	211	58	522
	PWR	205	223	58	486
	Delayed DECON Average	**226**	**218**	**58**	**502**
SAFSTOR	BWR	299	330	76	705
	PWR	274	352	77	703
	SAFSTOR Average	**285**	**343**	**76**	**704**
	Average of all Alternatives	**265**	**287**	**58**	**611**

Table 3.7. Average License Termination Costs (Percent of Total)

Alternative	Reactor Type	Direct Costs	Management Costs	Other Costs	Total
DECON	BWR	49%	43%	8%	100%
	PWR	44%	49%	7%	100%
	DECON Average	**46%**	**47%**	**7%**	**100%**
Delayed DECON	BWR	48%	40%	11%	100%
	PWR	42%	46%	12%	100%
	Delayed DECON Average	**45%**	**43%**	**12%**	**100%**
SAFSTOR	BWR	42%	47%	11%	100%
	PWR	39%	50%	11%	100%
	SAFSTOR Average	**40%**	**49%**	**11%**	**100%**
	Average of all Alternatives	**43%**	**47%**	**10%**	**100%**

3.4.3 Direct Decommissioning Costs

Direct decommissioning costs for the same 42 cases discussed in Section 4.2 are shown in Figure 3.4 and 3.5. Again, for each decommissioning scenario, cost estimates for each decommissioning case are arranged by decreasing costs. To facilitate graphing, the eight direct cost elements defined in Table 3.2 have been categorized into three major cost elements as follows:

Direct Cost Element from Table 3.2	Major Cost Element Shown in Figure 3.4
Decontamination Removal Packaging Transportation	Decontamination/Removal
Waste Disposal Waste Processing	Waste Disposition
Spent Fuel Pool Isolation Miscellaneous Equipment	Other Direct

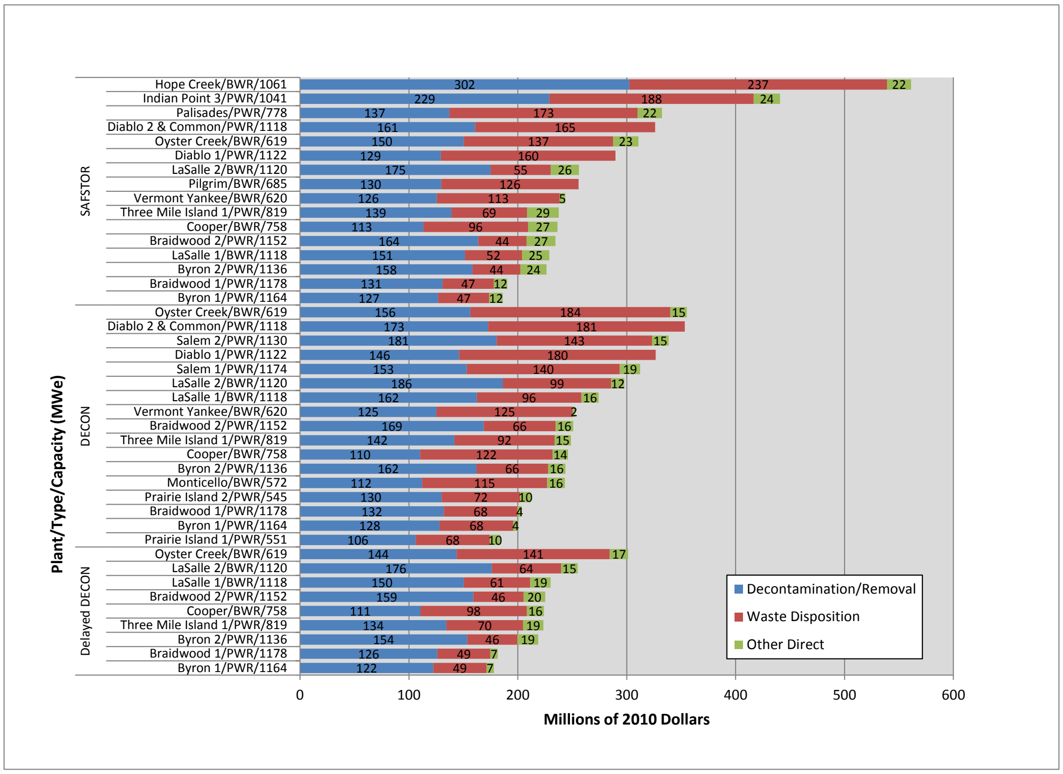

Figure 3.4. Direct Decommissioning Costs Breakdown

These figures continue to show significant variability in the cost estimates for each of these cost elements. Tables 3.8 and 3.9 summarize the direct decommissioning costs for the cases shown in the Figures 3.4 and 3.5.

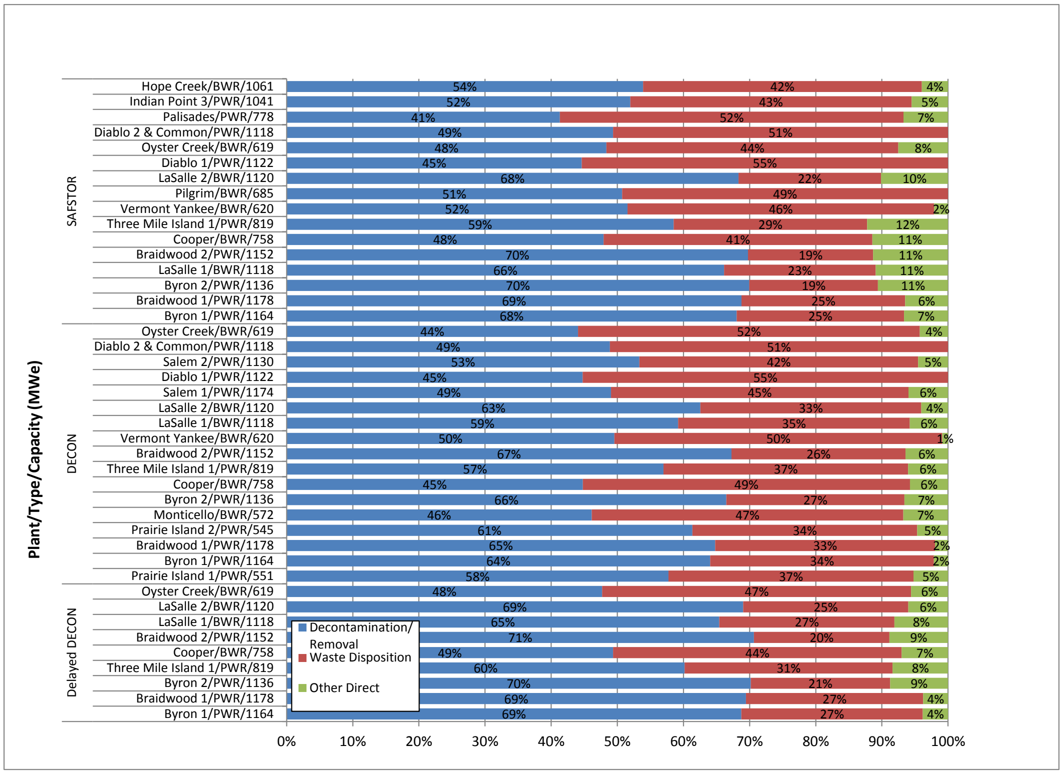

Figure 3.5. Direct Decommissioning Costs Breakdown by Percent of Total

Table 3.8. Average Direct Decommissioning Costs (Millions of 2010 Dollars)

Alternative	Reactor Type	Decon/Remove	Waste Disposition	Other Direct	Total
DECON	BWR	142	123	13	278
	PWR	147	104	10	261
	DECON Average	**146**	**111**	**11**	**267**
Delayed DECON	BWR	145	91	17	253
	PWR	139	52	14	205
	Delayed DECON Average	**142**	**69**	**15**	**226**
SAFSTOR	BWR	164	117	18	299
	PWR	153	104	17	274
	SAFSTOR Average	**158**	**110**	**18**	**285**
	Average of all Alternatives	**149**	**101**	**14**	**265**

Table 3.9. Average Direct Decommissioning Costs (Fraction of Total)

Alternative	Reactor Type	Decon/Remove	Waste Disposition	Other Direct	Total
DECON	BWR	51.1%	44.4%	4.5%	100.0%
	PWR	56.4%	39.8%	3.8%	100.0%
	DECON Average	**54.4%**	**41.5%**	**4.1%**	**100.0%**
Delayed DECON	BWR	57.5%	35.9%	6.6%	100.0%
	PWR	67.7%	25.3%	7.0%	100.0%
	Delayed DECON Average	**62.6%**	**30.6%**	**6.8%**	**100.0%**
SAFSTOR	BWR	54.8%	39.0%	6.2%	100.0%
	PWR	55.8%	38.1%	6.1%	100.0%
	SAFSTOR Average	**55.3%**	**38.5%**	**6.2%**	**100.0%**
	Average of all Alternatives	**56.3%**	**38.3%**	**5.4%**	**100.0%**

3.4.4 Waste Volumes and Waste Disposition Costs

Much of the waste generated during decommissioning consists of material that is likely to be uncontaminated. Such waste may be analyzed onsite or shipped offsite to licensed facilities for further analysis, processing, and conditioning. This waste is referred to as processed waste. It is reasonable to assume that the disposal cost of this waste is an increasing function of its volume. This assumption seems to be borne out, as shown in Table 3.10 and in Figure 3.6. Diablo Canyon sites are not included in Table 3.10 or in the figure since the cost estimates for those plants did not include processed waste volumes (all waste was apparently directly disposed). In general waste processing costs increase with waste volume processed as would be expected. The outliers wherein 600-700 thousand cubic feet is processed for $10–20 million is from the estimates for the LaSalle 1 & 2 DECON and SAFESTOR scenarios. The reason for the much lower apparent unit processing cost for these scenarios is unclear.

Radwaste disposal costs are more difficult to analyze, primarily because disposal charges are very much dependent on which disposal site is chosen. Both TLG and Energy*Solutions* assumed in their cost estimates that two burial sites were available for radwaste disposal: a generic LLW site (generally assumed to be Barnwell) which is assumed to accept Class A, B, and C waste, and Energy*Solutions* at Clive, Utah, which accepts only Class A waste. Since Class A waste volume greatly exceeds Class B and C volume, and since the cost of disposal is significantly less at Energy*Solutions*, the relative amounts of Class A waste sent to each of these sites is an important driver in determining radwaste disposal costs.

Table 3.10. Waste Processing Costs vs. Processed Waste Volume

Alternative	Plant/Type/Capacity (MWe)	Waste Volume ($\times$ 1000 ft^3)	Waste Processing Cost (2010 $Millions)
SAFSTOR	Byron 2/PWR/1136	222	5
	Byron 1/PWR/1164	222	5
	Braidwood 1/PWR/1178	223	5
	Braidwood 2/PWR/1152	223	5
	Hope Creek/BWR/1061	228	68
	Three Mile Island 1/PWR/819	248	14
	Palisades/PWR/778	326	89
	Vermont Yankee/BWR/620	347	41
	Indian Point 3/PWR/1041	380	36
	Cooper/BWR/758	385	47
	Pilgrim/BWR/685	409	56
	Oyster Creek/BWR/619	457	60
	LaSalle 1/BWR/1118	686	16
	LaSalle 2/BWR/1120	686	17
DECON	Salem 1/PWR/1174	73	24
	Salem 2/PWR/1130	74	25
	Prairie Island 1/PWR/551	132	14
	Prairie Island 2/PWR/545	157	17
	Three Mile Island 1/PWR/819	180	10
	Byron 1/PWR/1164	189	4
	Byron 2/PWR/1136	189	4
	Braidwood 1/PWR/1178	192	4
	Braidwood 2/PWR/1152	192	4
	Cooper/BWR/758	320	39
	Vermont Yankee/BWR/620	340	40
	Oyster Creek/BWR/619	386	50
	LaSalle 2/BWR/1120	579	14
	LaSalle 1/BWR/1118	579	13
Delayed DECON	Byron 1/PWR/1164	221	5
	Byron 2/PWR/1136	221	5
	Braidwood 2/PWR/1152	222	5
	Braidwood 1/PWR/1178	222	5
	Three Mile Island 1/PWR/819	248	14
	Cooper/BWR/758	384	47
	Oyster Creek/BWR/619	462	60
	LaSalle 2/BWR/1120	684	17
	LaSalle 1/BWR/1118	684	16

Figure 3.7 shows how Class A waste was split between the LLW site and Energy*Solutions* for 44 decommissioning cases. The first twelve plants listed in the graph submitted early cost estimates (from 2002-2005). For these plants the waste was split between an LLW facility and Energy*Solutions*. The remaining plants (submitting cost estimates from 2006 to 2010)

shipped all Class A waste to Energy*Solutions*. The high volume of waste for Indian Point 3 (2,846,000 ft^3) includes the 2,400,000 ft^3 of potentially contaminated soil discussed in Section 3.

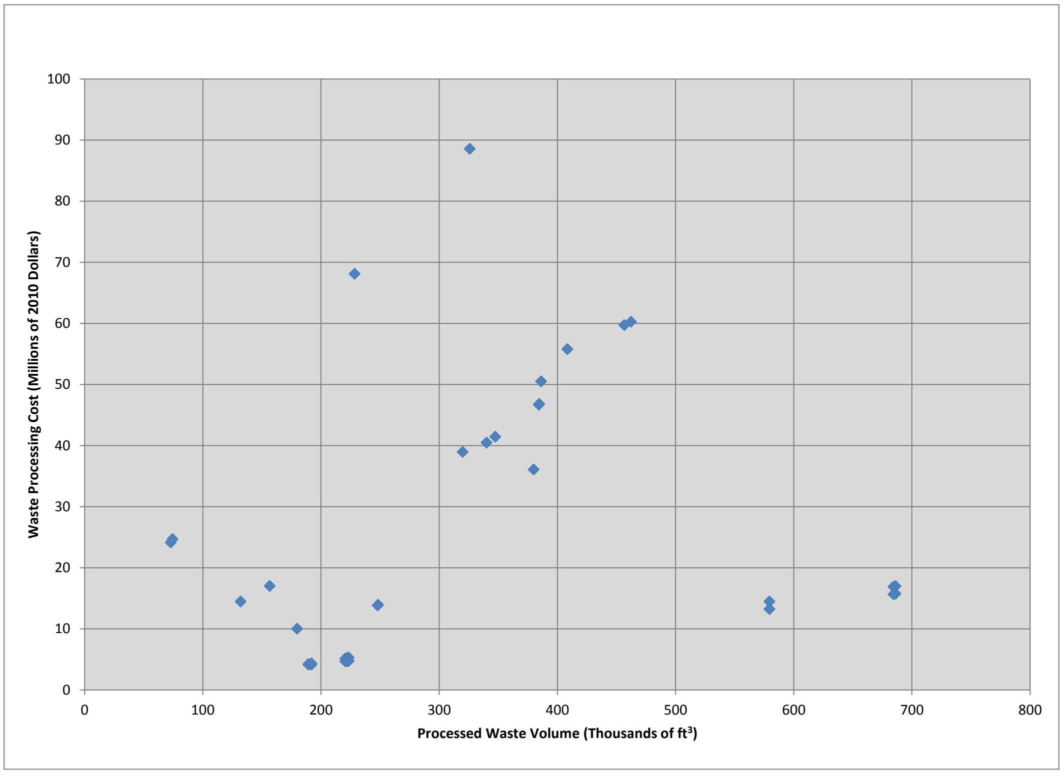

Figure 3.6. Waste Processing Cost vs. Processed Volume

In Figure 3.8 waste disposal cost is shown as a function of total waste volume (Class A, B, and C waste). It is anticipated that for the foreseeable future cost estimates will generally assume that all Class A waste will be sent to Energy*Solutions* or equivalent Class A facility. For this reason, only plants sending all Class A waste to Energy*Solutions* are shown in the figure. To avoid clutter, for those facilities decommissioning two plants at the same time (LaSalle 1 and 2, for example), only the first plant is plotted (i.e., LaSalle 1). The trend lines suggest a correlation between increasing waste volume and waste disposal cost. Clearly SAFSTOR costs are higher than either DECON or DELAYED DECON.

3.4.5 Decommissioning Management Costs

On average, management costs account for almost 50% of the total direct decommissioning costs. In the licensee-provided cost estimates, two cost elements comprise the largest component of the management costs: utility staff and decommissioning operations contractor (DOC) staff. These two cost elements generally contribute more than 70% of the decommissioning management cost.

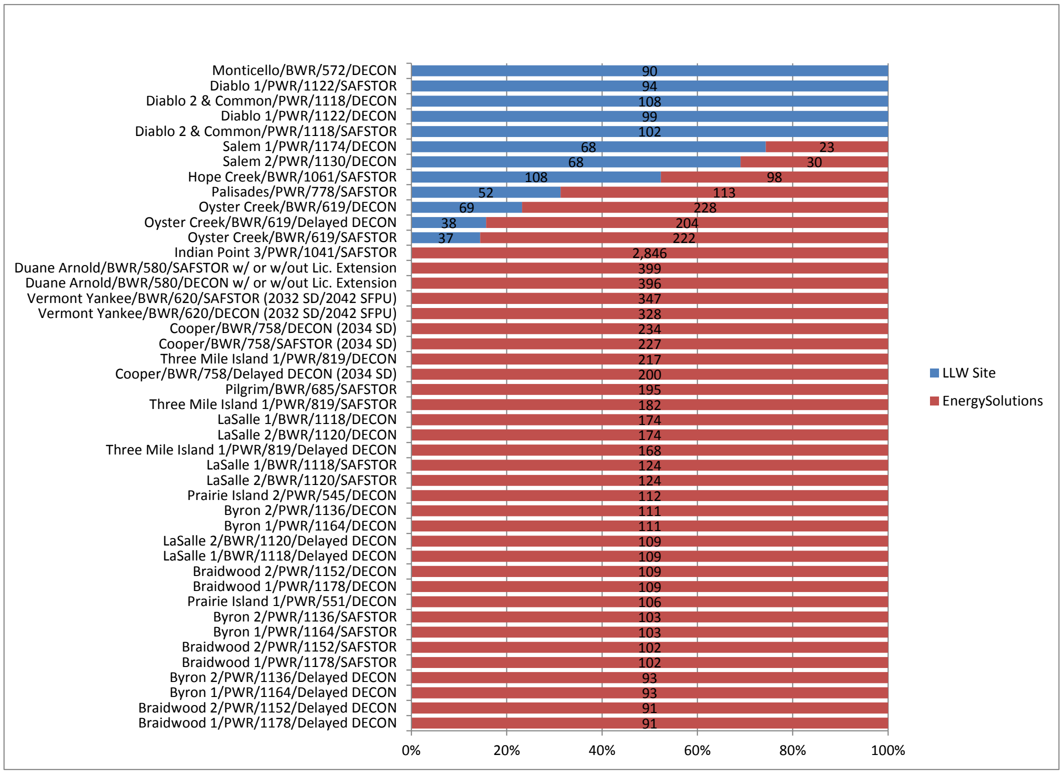

Figure 3.7. Waste Disposal Site Distribution

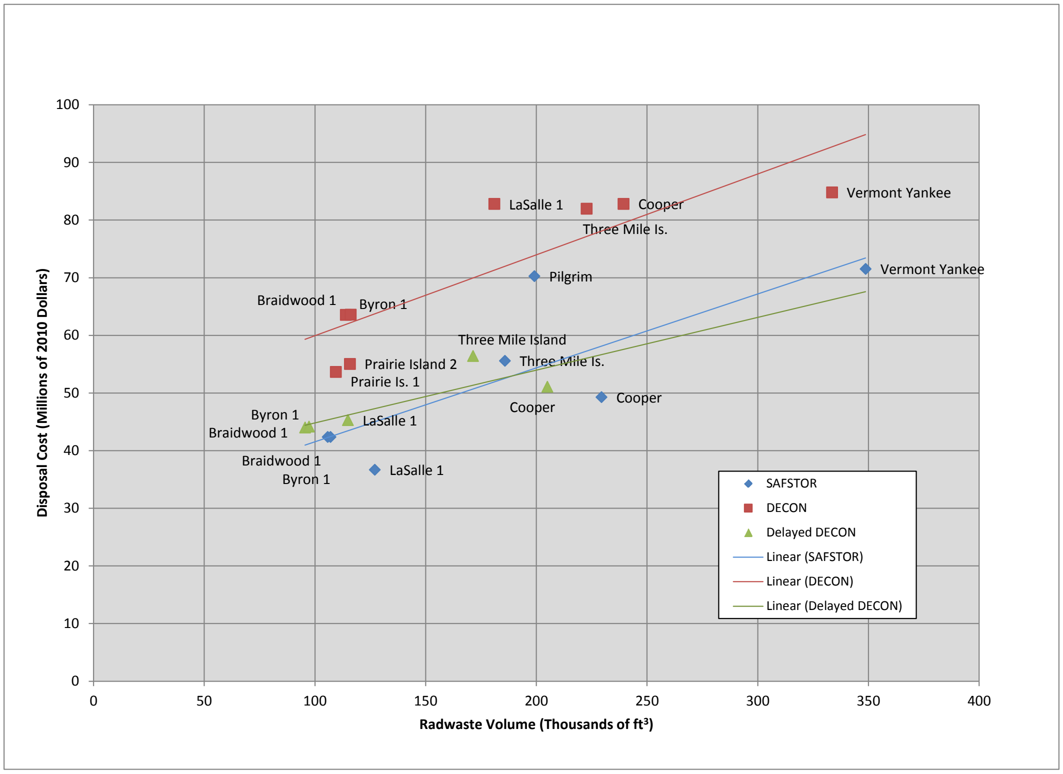

Figure 3.8. Waste Disposal Cost vs. Radwaste Volume

In order to develop a better understanding of the cost drivers for the decommissioning management costs, the utility staff and DOC staff costs were further evaluated. It seems reasonable that a larger plant (as measured by its electrical generating capacity) would require more man-hours to decommission than a smaller one. That is, one would expect greater utility/DOC staffing costs associated with larger plants than with smaller. To determine if this is the case, these costs are compared against plant electrical capacity. The results are shown in Figure 3.9.

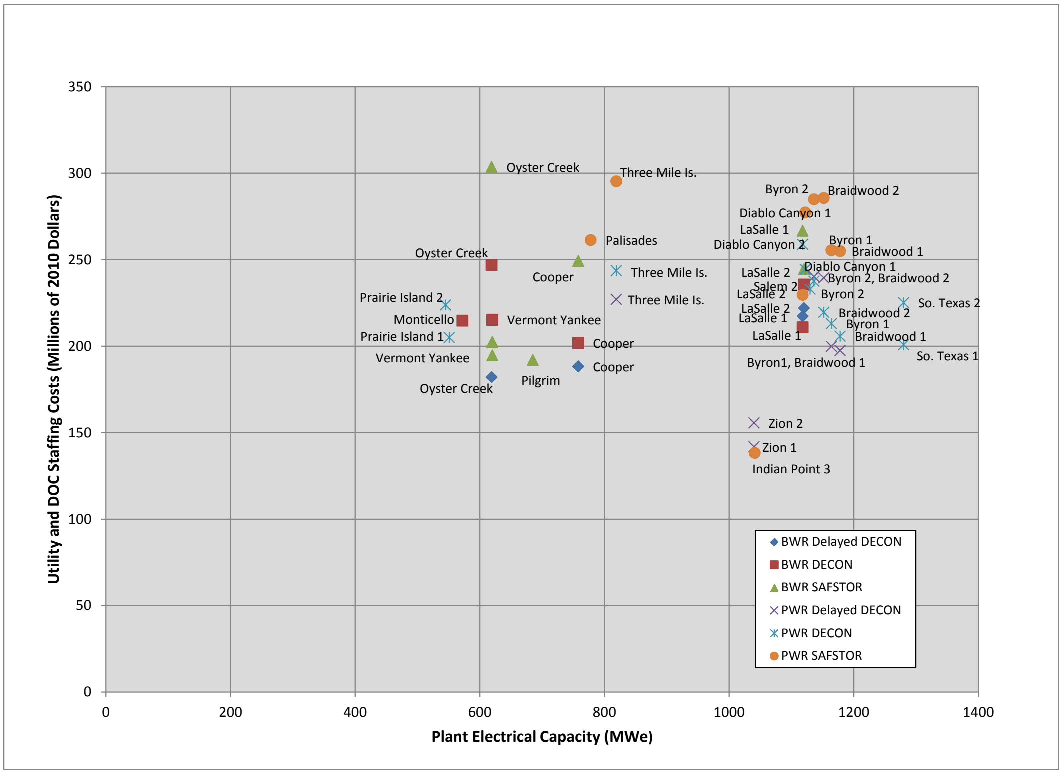

Figure 3.9. Utility and DOC Staffing Cost vs. Plant Capacity

As is expected, utility and DOC staffing costs for the DECON scenario generally reflect an increasing trend from lower to higher plant capacities. Particularly noticeable in the figure, however, is the very large variance in SAFSTOR costs. One potential source of this variance is the disparity in the allocation of utility staffing costs between license termination (10 CFR 50.75) and spent fuel management (10 CFR 50.54(bb)) for the SAFSTOR periods, as indicated in Table 3.11. For some estimates (Pilgrim and all four of Vermont Yankee's SAFSTOR estimates) all utility and DOC staff costs are allocated to spent fuel management and none to license termination. By contrast, for the Diablo Canyon 1 and 2 estimates, all utility costs are allocated to license termination and none to spent fuel management. For the remainder of the estimates, utility costs are divided (to varying degrees) between license termination and spent fuel management. This difference in assumptions accounts for most of the huge disparity in utility and DOC staffing costs between the Oyster Creek SAFSTOR scenario and the Vermont Yankee and Pilgrim SAFSTOR scenarios, as shown in Figure 3.9.

Table 3.11. Allocation of Utility Staffing Costs for Periods of SAFSTOR Dormancy

Plant	License Termination Costs	Spent Fuel Management Costs
Vermont Yankee SAFSTOR 1	0	104
Vermont Yankee SAFSTOR 2	0	88
Vermont Yankee SAFSTOR 3	0	178
Vermont Yankee SAFSTOR 4	0	168
Pilgrim	0	104
Palisades	14	60
Indian Point 3	16	12
LaSalle 2	33	9
Byron 2	51	23
Braidwood 2	51	24
Braidwood 1	57	15
Byron 1	57	15
Cooper 2034	62	43
Cooper 2014	62	49
LaSalle 1	67	19
Three Mile Island	74	31
Diablo Canyon 2 & Common	79	0
Oyster Creek	120	70
Diablo Canyon 1	132	0

It is interesting to note that when the costs for the SAFSTOR and DECON scenarios are compared for the same reactor, SAFSTOR costs are higher for Three Mile Island and Oyster Creek, as is expected, but are lower for Vermont Yankee. This discrepancy again appears to be due to the assumption in the Vermont Yankee case that the SAFSTOR dormancy costs are all allocated to Spent Fuel Management and none to License Termination.

Unfortunately, the number of available licensee-provided decommissioning cost estimates for BWR-type reactors is limited. For this reason, it is not feasible to draw any solid conclusions about the relative differences in utility and DOC staffing costs between PWR and BWR reactors.

A second source of scatter is in the utility and DOC staff costs is seen for those cases where twin units are decommissioned as a single combined operation (i.e., Braidwood 1&2, Byron 1&2, LaSalle 1&2, and Diablo Canyon 1&2). Note that for these cases, TLG assigned the first unit (Braidwood 1, Byron 1, etc.) a larger portion of the utility and DOC staff costs; the costs that are common to both units were assigned to unit 1 for accounting purposes. If one compares the cost of the single unit plants then with just the cost of the first unit of the two unit plants, there is clearly an increasing trend in utility and DOC staffing cost from lower to higher electrical capacity.

If these costs and the plant capacity for the twin units are averaged, there is no clear relationship between utility and DOC staffing costs and plant capacity, as shown in Figure 3.10.

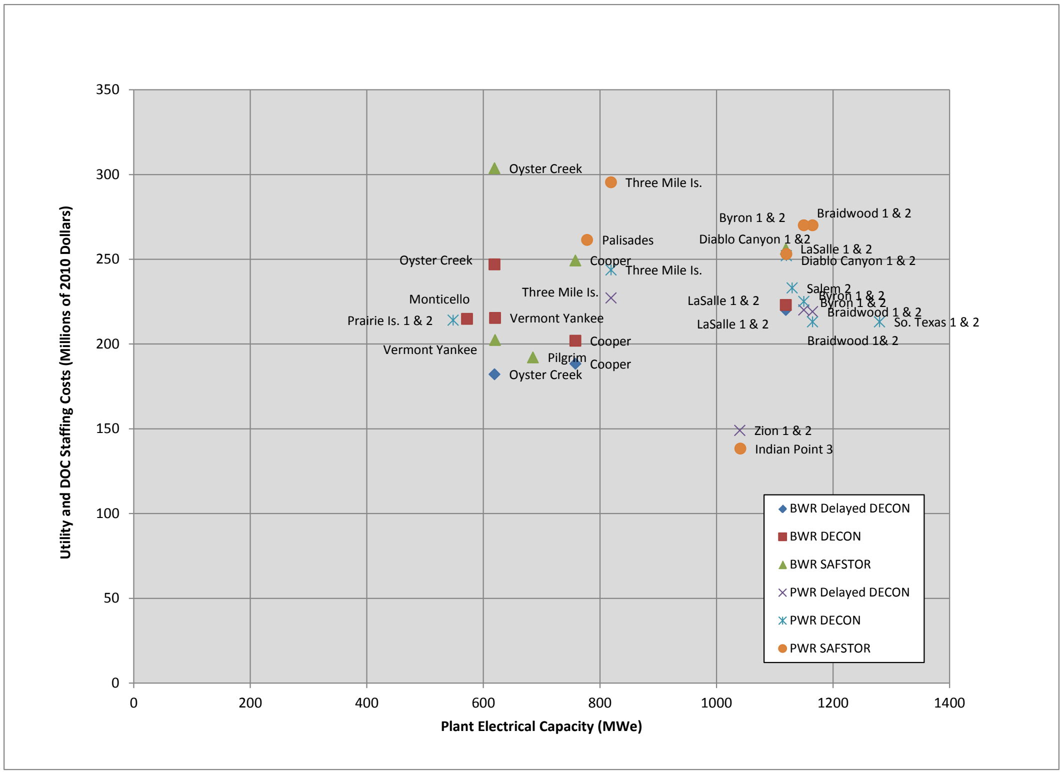

Figure 3.10. Utility and DOC Staffing Cost vs. Plant Capacity for 2-Unit Plants

It is interesting that utility and DOC staffing costs for the Zion Delayed DECON scenario are very low relative to the other estimates, yet Table 3.5 reports Zion 2 as having one of the highest license termination cost of all decommissioning scenarios evaluated. The licensee-provided documentation is insufficient to fully understand these disparities. It appears that spent fuel management and site restoration costs are included, whereas these costs are differentiated and separated out in the other scenarios. Furthermore, the Zion decommissioning cost estimate is the oldest (1996) of all of the scenarios evaluated and the cost estimating methodology and cost element categories appear to have changed in the later estimates. The result is that the cost escalation to 2010 dollars assumed in this report may not be accurate.

3.4.6 Other License Termination Costs

Certain costs, referred to as other license termination costs, are categorized as neither decommissioning management nor direct decommissioning. However, as shown in Figure 3.2, these costs can vary significantly, especially for the SAFSTOR decommissioning scenario, between the licensee decommissioning cost estimates considered in this study. Three of the more significant cost elements that contribute to these other costs property taxes, nuclear liability insurance, and regulatory fees. These costs depend on local, state, and Federal statutes and are thus virtually independent of plant size or type. It should be noted that property taxes, at the discretion of the licensee, may or may not be included in decommissioning cost estimates submitted to the NRC. The estimates from Pilgrim, Vermont Yankee, and Diablo Canyon specifically excluded property taxes.

These costs, listed in ascending order, are shown in Table 3.12, Property Taxes, and Table 3.13, Nuclear Liability Insurance and Regulatory Fees. Since property taxes, nuclear liability insurance, and regulatory fees are imposed annually, these costs tend to be higher for SAFSTOR scenarios than for DECON scenarios. As shown in Tables 3.12 and 3.13, this is especially the case for property taxes.

Table 3.12. Property Taxes (Millions of 2010 Dollars)

Plant/Type/Capacity (MWe)/Alternative	Cost
Three Mile Island 1/PWR/819/DECON	6.6
LaSalle 2/BWR/1120/DECON	8.8
LaSalle 1/BWR/1118/DECON	9.5
Three Mile Island 1/PWR/819/Delayed DECON	11.3
Prairie Island 1/PWR/551/DECON	11.5
Prairie Island 2/PWR/545/DECON	11.6
Braidwood 1/PWR/1178/DECON	12.7
Oyster Creek/BWR/619/DECON	13.0
Braidwood 2/PWR/1152/DECON	13.5
LaSalle 2/BWR/1120/Delayed DECON	14.8
Monticello/BWR/572/DECOM	15.3
Oyster Creek/BWR/619/Delayed DECON	15.5
LaSalle 1/BWR/1118/Delayed DECON	16.1
Byron 2/PWR/1136/DECON	16.6
Braidwood 1/PWR/1178/Delayed DECON	16.8
Byron 1/PWR/1164/DECON	17.0
Braidwood 2/PWR/1152/Delayed DECON	18.1
Byron 1/PWR/1164/Delayed DECON	20.4
Byron 2/PWR/1136/Delayed DECON	21.8
LaSalle 2/BWR/1120/SAFSTOR	29.9
Palisades/PWR/778/SAFSTOR	31.0
LaSalle 1/BWR/1118/SAFSTOR	31.4
Braidwood 2/PWR/1152/SAFSTOR	34.0
Braidwood 1/PWR/1178/SAFSTOR	34.4
Three Mile Island 1/PWR/819/SAFSTOR	36.8
Byron 2/PWR/1136/SAFSTOR	37.1
Byron 1/PWR/1164/SAFSTOR	39.1
Oyster Creek/BWR/619/SAFSTOR	51.5
Average	**11.7**

Table 3.13. Insurance and Regulatory Fees (Millions of 2010 Dollars)

Plant/Type/Capacity (MWe)/Alternative	Cost
Diablo 1/PWR/1122/SAFSTOR	5.4
Diablo 2 & Common/PWR/1118/SAFSTOR	5.5
LaSalle 2/BWR/1120/DECON	6.5
Byron 2/PWR/1136/DECON	7.4
Braidwood 2/PWR/1152/DECON	7.8
Braidwood 1/PWR/1178/DECON	8.1
LaSalle 1/BWR/1118/DECON	8.4
Three Mile Island 1/PWR/819/DECON	8.5
Byron 1/PWR/1164/DECON	8.6
Hope Creek/BWR/1061/SAFSTOR	9.0
LaSalle 2/BWR/1120/Delayed DECON	10.0
Byron 2/PWR/1136/Delayed DECON	11.9
Vermont Yankee/BWR/620/DECON (2012 SD/2017 SFPU)	12.0
Byron 1/PWR/1164/Delayed DECON	12.3
LaSalle 1/BWR/1118/Delayed DECON	12.4
Braidwood 2/PWR/1152/Delayed DECON	12.5
Monticello/BWR/572/DECOM	12.5
Braidwood 1/PWR/1178/Delayed DECON	12.6
Oyster Creek/BWR/619/DECON	12.9
Salem 2/PWR/1130/DECOM	13.0
Prairie Island 2/PWR/545/DECON	13.3
Three Mile Island 1/PWR/819/Delayed DECON	13.5
Prairie Island 1/PWR/551/DECON	13.8
Diablo 2 & Common/PWR/1118/DECON	14.0
Vermont Yankee/BWR/620/DECON (2032 SD/2042 SFPU)	14.1
Vermont Yankee/BWR/620/SAFSTOR (2012 SD/2017 SFPU)	14.3
Vermont Yankee/BWR/620/DECON (2032 SD/2017 SFPU)	15.3
Vermont Yankee/BWR/620/DECON (2012 SD/2057 SFPU)	15.8
Diablo 1/PWR/1122/DECON	16.0
Vermont Yankee/BWR/620/SAFSTOR (2012 SD/2057 SFPU)	16.1
Salem 1/PWR/1174/DECOM	16.1
Palisades/PWR/778/SAFSTOR	17.5
Vermont Yankee/BWR/620/SAFSTOR (2032 SD/2042 SFPU)	17.5
Pilgrim/BWR/685/SAFSTOR	17.7
Vermont Yankee/BWR/620/SAFSTOR (2032 SD/2017 SFPU)	18.0
Oyster Creek/BWR/619/Delayed DECON	20.7
Byron 2/PWR/1136/SAFSTOR	25.8
Braidwood 2/PWR/1152/SAFSTOR	26.9
Braidwood 1/PWR/1178/SAFSTOR	28.7
Byron 1/PWR/1164/SAFSTOR	28.8
Cooper/BWR/758/DECON (2014 SD)	28.9

Table 3.13. (contd)

Plant/Type/Capacity (MWe)/Alternative	Cost
Cooper/BWR/758/Delayed DECON (2014 SD)	29.3
Cooper/BWR/758/DECON (2034 SD)	29.4
LaSalle 2/BWR/1120/SAFSTOR	29.5
Cooper/BWR/758/Delayed DECON (2034 SD)	29.6
LaSalle 1/BWR/1118/SAFSTOR	32.6
Three Mile Island 1/PWR/819/SAFSTOR	36.0
Indian Point 3/PWR/1041/SAFSTOR	48.7
Cooper/BWR/758/SAFSTOR (2014 SD)	57.6
Cooper/BWR/758/SAFSTOR (2034 SD)	58.1
Oyster Creek/BWR/619/SAFSTOR	58.7
Average	**19.6**

3.5 Summary of Available Decommissioning Cost Estimates

Based on the estimated decommissioning cost data provided to the NRC by licensees and evaluated in this section of the report, the average license termination costs by decommissioning scenario are as follows:

Alternative	Direct Costs	Management Costs	Other Costs	Total
DECON (17 Cases)	267	272	41	580
Delayed DECON (9 Cases)	226	218	58	502
SAFSTOR (16 Cases)	285	343	76	704
Average	**265**	**287**	**58**	**611**

The average direct decommissioning costs are likewise summarized as follows:

Alternative	Decontamination/ Removal	Waste Disposition	Other Direct	Total
DECON (17 Cases)	146	111	11	267
Delayed DECON (9 Cases)	142	69	15	226
SAFSTOR (16 Cases)	158	110	17	285
Average	**149**	**101**	**14**	**265**

As expected, SAFSTOR costs are higher than DECON costs, principally due to annual costs incurred during the SAFSTOR dormancy period.

The average license termination cost by reactor type is as follows:

Reactor Type	Direct Costs	Management Costs	Other Costs	Total
BWR (17 Cases)	281	271	60	613
PWR (25 Cases)	255	298	55	609
Average	**265**	**287**	**58**	**611**

The average direct decommissioning costs are likewise summarized as follows:

Reactor Type	Decontamination/ Removal	Waste Disposition	Other Direct	Total
BWR (17 Cases)	152	113	16	281
PWR (25 Cases)	148	94	13	255
Average	**149**	**101**	**14**	**265**

Regarding cost drivers, the following observations may be made:

- As is expected, the licensee-provided decommissioning cost estimates show that waste processing costs and radwaste burial costs are increasing functions of processed volume and radwaste volume. Relative to radwaste burial costs, these costs are also a function of the assumed cost of disposal of Class A wastes.

- While there is significant disparity in the utility and DOC staff cost data due to how the cost data are categorized and key variations in assumptions used to develop the estimates, there does appear to be a relationship between plant capacity and these costs; that is, utility and DOC staff costs increase with plant capacity. In addition, as expected, and after accounting for differences in estimating assumptions, utility and DOC staff costs are higher for the SAFSTOR scenario than for the DECON scenario. There is insufficient data to ascertain cost differences between PWR and BWR reactors.

- Other license termination costs such as property taxes, insurance, and regulatory fees, while site specific, also show a clear correlation to the decommissioning scenario. These costs for the SAFSTOR scenario are generally higher than for the DECON scenario.

3.6 References

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4 REVIEW OF FOUR DECOMMISSIONED NUCLEAR POWER PLANTS

The actual decommissioning experience from four nuclear plants (see below) that have completed radiological decommissioning is reviewed in this section. Each review includes a summary of the decommissioning strategy implemented, a description of the decommissioning approach and significant issues addressed, an assessment of the low-level waste (LLW) volumes and activities generated during decommissioning, and an evaluation of the actual cost of decommissioning incurred based on the level-of-detail available.

4.1 Background

While Section 3 compared the radiological decommissioning cost estimates for operating plants, this section compares the actual radiological decommissioning costs for four nuclear plants that have completed radiological decommissioning. The four plants chosen for this evaluation are: Haddam Neck Plant (HNP), Maine Yankee Plant (MY), Trojan Nuclear Plant (TNP), and Rancho Seco Generating Plant (Rancho Seco). These plants were chosen for this study for the following reasons:

1. They are fairly large electrical generating plants, ranging in electrical generating capacity from 590 MWe to 1130 MWe, representative of today's U.S. nuclear power plant operating fleet that continues to collect decommissioning funds for future decommissioning.

2. Each plant had essentially completed radiological decommissioning and received either a termination of the 10 CFR Part 50 license or received approval of the release of all but a small portion of the land from the 10 CFR Part 50 license. In those cases in which a small portion of land is being retained in the 10 CFR Part 50 license, the land is being used for the ISFSI (HNP and MY) or for a facility for storing containerized Class B/C LLW (Rancho Seco).

An extensive review and evaluation of each of the four decommissioning projects was performed based on publicly available information and information provided by representatives for each of the four projects. For each decommissioning project, a section discussing the following topic areas is provided:

- Section 1 – Historical Background
- Section 2 – Decommissioning Schedule (Timeline)
- Section 3 – License Termination Strategy
- Section 4 – Project Management
- Section 5 – Decommissioning Issues/Approaches
- Section 6 – Non-Decommissioning Fund Activities

- Section 7 – Soil and Groundwater Remediation
- Section 8 – Radioactive Waste Volumes and Activity
- Section 9 – Cost of Decommissioning and License Termination
- Section 10 – References

4.2 Haddam Neck Plant

The Haddam Neck Plant (HNP), owned by Connecticut Yankee Atomic Power Company (CYAPCO), was located in Haddam, Connecticut, on the east bank of the Connecticut River. The majority of the area surrounding the plant site is rural and wooded. The independent spent fuel storage installation (ISFSI) is located approximately 3/4 mile from the former reactor plant area.

4.2.1 Historical Background

HNP achieved initial criticality on July 24, 1967, and began commercial operation on January 1, 1968 [Docket No. 50-213; License No. DPR-61]. The Westinghouse pressurized water reactor (PWR) was a 4-loop closed-cycle nuclear steam supply system (NSSS), with a large, dry containment; a turbine generator and electrical systems; engineered safety features; radioactive waste systems; fuel handling systems; instrumentation and control systems; the necessary auxiliaries; and structures to house plant systems and other onsite facilities. The reactor was designed by Westinghouse and built by Combustion Engineering, while the balance of the plant was built by Stone & Webster. HNP was designed to produce 1,825 MW of thermal power and 590 MW of gross electrical power.

In 1996, CYAPCO permanently ceased power operations at the Haddam Neck Plant. As of March 30, 2005, all spent fuel and greater-than-Class C (GTCC) waste have been transferred to the ISFSI. All plant related structures have been removed down to at least 3 feet belowgrade. This leaves concrete structures in only a few areas of the site, such as the reactor building basement, the discharge canal tunnel and part of the spent fuel building. Portions of the original site boundary, remote from the plant, have been removed from the license under phased release. When decommissioning activities and the phased releases are completed, the ISFSI will remain as a part 50 license.

On December 4, 1996, HNP permanently shut down after approximately 28 years of operation. On December 5, 1996, CYAPCO notified the NRC of the permanent cessation of operations at the HNP and the permanent removal of all fuel assemblies from the reactor pressure vessel (RPV) and their placement in the spent fuel pool. The Post Shutdown Decommissioning Activities Report (PSDAR) was submitted to the NRC, in accordance with 10 CFR 50.82 (a)(4), on August 22, 1997 (Reference 1). On January 26, 1998, CYAPCO transmitted an Updated Final Safety Analysis Report to reflect the plant's permanent shutdown status, and on June 30, 1998, the NRC amended the HNP Facility Operating License to reflect this plant condition. On October 19, 1999, the Operating License was amended to reflect the decommissioning status of the plant and long-term storage of the spent fuel in the spent fuel pool. Additional licensing basis documents were also revised and submitted to reflect long-term fuel storage in the spent fuel pool (Defueled Emergency Plan, Quality Assurance (QA) program, and Operator Training Program).

4.2.2 Decommissioning Schedule (Timeline)

All activities required by the HNP License Termination Plan (LTP) (References 2 through 9) except for the ISFSI areas have been completed and all non-ISFSI related areas have been released from the HNP license. Major milestones and timeline elements are represented below based primarily on information provided in the HNP LTP (References 2 through 9) and the EPRI Experience Report (Reference 10).

- On December 5, 1996, CYAPCO notified the NRC of the permanent shutdown, including removal of all fuel assemblies from the reactor and their placement in the spent fuel pool. Certification of permanent cessation of operation and removal of fuel, in accordance with 10 CFR 50.82(a)(1)(i) and (ii), was submitted to the NRC.

- From January 1997 to July 1998, initial decommissioning planning and site scoping survey was completed.

- On August 22, 1997, the HNP PSDAR was submitted to the NRC in accordance with 10 CFR 50.82 (a)(4)(i).

- On January 26, 1998, CYAPCO transmitted an Updated Final Safety Analysis Report to reflect the plant's permanent shutdown status.

- On June 30, 1998, the NRC amended the HNP Facility Operating License to reflect this shutdown plant condition.

- From 1998–1999, bulk removal of asbestos insulation was completed.

- From July to August 1998, chemical decontamination of the reactor coolant system (RCS) and many auxiliary systems was completed.

- In 1998, installation of modifications to establish a spent fuel pool island was completed.

- On April 5, 1999, a contract was awarded to a DOC. In July 2003, CYAPCO decided to self-manage the remainder of the HNP decommissioning work and ended the contract with the DOC.

- In the fall of 1999, the steam generators (SGs) were removed from the Containment Building, and shipped offsite from 1999–2001.

- The reactor coolant pumps (RCPs) and pressurizer were removed and shipped for disposal in 2001.

- From March 2000 to August 2002, segmentation of the RPV internals was completed.

- On July 7, 2000, as revised in August 2002 and October 2002, CYAPCO submitted the LTP to the NRC.

- On November 25, 2002, the NRC approved the License Termination Plan via License Amendment No. 197.

- From July 2003 to January 2004, the RPV was removed, packaged, and shipped to Barnwell, South Carolina, for disposal.

- From April 2004 to March 30, 2005, removal of all used fuel and GTCC waste from the spent fuel pool was completed and stored in an ISFSI at the HNP site.

- On December 2005, remediation of the subsurface soil was completed.

- From December 2005 to June 2007, the 18-month groundwater monitoring period for the NRC was completed.

- From September 2004 to July 2006, major building demolition was completed.

- October of 2007, CYAPCO had completed all activities required to remove all areas of the site other than those related to the ISFSI from the Haddam Neck Plant NRC license, Docket No. 50-213 (License NO. DPR-6 1).

- On October 11, 2007, the final status survey (FSS) was completed and submitted to the NRC.

- On November 6, 2007, the NRC terminated the HNP 10 CFR Part 50 license for all non-ISFSI areas.

Table 4.1 compares the HNP decommissioning schedule originally estimated in the PSDAR with the actual decommissioning schedule discussed above. As can be seen from the table, the FSS was completed about 3 years later than originally projected in the PSDAR. Based on available information, the following appear to have been the major reasons for the delayed completion of the HNP decommissioning project:

- The PSDAR plan was for the used fuel to continue to be stored in the spent fuel pool until the year 2022, at which point it would be decontaminated and removed from the site. Based on the results of an economic evaluation, CYAPCO decided to construct an ISFSI and to decontaminate and demolish the Fuel Building on the same schedule as the remainder of the HNP decommissioning project. As discussed below, construction of the ISFSI was significantly delayed during the permitting process, which resulted in a significant delay in completing decommissioning of HNP.

- As discussed below, CYAPCO contracted with a DOC on April 5, 1999, to complete the HNP decommissioning project and, in July 2003, ended the contract with the DOC and self-managed the remainder of the decommissioning activities. The transition of project staff and subcontracts from the DOC to CYAPCO likely contributed to the delay in completing the project.

- As discussed below, regulation of HNP decommissioning by multiple government agencies complicated the process for obtaining approval of site release criteria. This process required significantly more resources and time to complete than originally estimated.

- As discussed below, CYAPCO was required to conduct groundwater monitoring for 18 months after completion of site remediation activities to demonstrate compliance with the derived concentration guideline levels (DCGLs). The PSDAR did not include this activity in the schedule.

- As discussed below, the segmentation of the internals of the HNP reactor proved to be a very challenging project and took significantly longer to complete than originally estimated.

Table 4.1. Comparison of PSDAR and Actual HNP Decommissioning Schedule

Activity	PSDAR Schedule	Actual Schedule
Decommissioning Planning	Jan 1997–July 1998	Jan 1997–July 1998
PSDAR to NRC	Aug 22, 1997	Aug 22, 1997
Updated FSAR	Early 1998	Jan 26, 1998
RCS Decontamination	1st half 1998	July–Aug. 1998
Asbestos Abatement	2nd half 1997–2nd half 1999	1998-1999
Large Component Removal (RPV, internals segmentation, SGs, and Pressurizer)	July 1998–June 1999	Fall 1999 SGs; 2001 RCPs and Pressurizer; Mar 2000–Aug 2002 RPV Internals Segmentation; July 2003–Jan 2004 RPV
Removal of used fuel and GTCC waste from Spent Fuel Pool to ISFSI	Not in Schedule	April 2004 to March 30, 2005
Soil Remediation	2nd half 2002–June 2003	Completed Dec. 2005
System/Building Decontamination and Removal	July 1998–2nd half 2002 (Excluding Fuel Building)	1998–July 2006
Groundwater Monitoring Period for Site Closure	Not in Schedule	Dec 2005–June 2007
Final Status Survey	July 2003–2nd half 2004	Completed Oct 11, 2007

4.2.3 License Termination Strategy

CYAPCO submitted, in July 2000, Revision 0 of the LTP to the NRC as a supplement to the Updated Final Safety Analysis Report [Reference 2]. The NRC subsequently approved the LTP via a license amendment. The LTP was subsequently revised several times prior to completion of HNP decommissioning activities (References 3 through 9).

CYAPCO's decommissioning approach generally included the removal of above-grade portions of site buildings and structures (an exception being structures supporting the ISFSI) and demolition of structures, systems, and components (SSCs) to 4 feet belowgrade. In structures where portions of the foundations remain within the 4-foot belowgrade elevation, the remaining concrete was included as part of the final status survey of the land area after the area was backfilled with clean material. The remaining below-grade structures (including embedded piping that was built into concrete walls and runs through structures) are:

- Turbine Building foundation and footings,
- Reactor Building concrete base and exterior walls,
- Radwaste Reduction Facility,
- Fuel Building footings and below-grade portion of the spent fuel pool,
- Several support buildings, including Service Building, Administration Building, Shutdown Auxiliary Feed Pump House, Steam Generator Mockup Building, North and South Warehouses, Training Stores Office Building, Warehouses #1 and #2, Information Center, Screenwell Building, and
- Buried piping.

A "basement fill model" was developed to better assist in the decontamination efforts of belowgrade concrete and steel. For those structures to remain onsite, the basements were considered inaccessible. The radioactivity that remained in the concrete was assumed to leach from the concrete and contribute to the site dose due to the groundwater pathway. CYAPCO generally used the same approach as was used in the decommissioning of the Maine Yankee nuclear power plant. The general scenario of the basement fill model is as follows:

- The radioactive inventory in the concrete is assumed to defuse from concrete surfaces at conservative rates based on diffusion studies.
- The total amount released from the remaining concrete in the walls of the containment and fuel pool is conservatively assumed to migrate to the containment basement.
- This radioactive inventory in the containment basement will mix with the groundwater and backfill soil resulting in contributing to the groundwater concentrations.

- The calculated groundwater concentrations were compared to the LTP groundwater DCGLs. A projected groundwater dose was calculated.

- The basement contamination included any other subsurface concrete structures in the radiologically controlled area (RCA) to remain at site closure.

- Structures outside the RCA such as the discharge tunnels will be included in a separate calculation assuming all the radioactivity travels into the discharge tunnels. As the discharge tunnels will not be backfilled, the calculation assumes only water is present.

As described in the LTP, CYAPCO choose to implement a phased approach to release of the 525-acre (212.5-hectare) HNP site from the 10 CFR Part 50 license. The phased release of land from the NRC license proceeded as follows:

- Phase I. Phase I was comprised of the east side grounds area of the HNP site and was unaffected by site operations. This area, encompassing approximately 93 acres (37.56 hectares), was released from the 10 CFR Part 50 license in September 2004 (Reference 11).

- Phase II. Phase II was comprised of areas having various contamination classifications, but did not include areas with potential future groundwater contamination. This area, encompassing approximately 224 acres (90.76 hectares), was released from the 10 CFR Part 50 license on February 27, 2006 (Reference 12).

- Phases III through VII. These phases were comprised of areas having the potential for or were known to have radioactive contamination, or had known or a potential for future groundwater contamination. As of October 2007, CYAPCO had completed all activities required to remove all areas of the HNP site, other than those related to the ISFSI, from the HNP NRC license, Docket No. 50-213 (License NO. DPR-61). The NRC approved the removal of the remaining non-ISFSI areas from the license via a partial site release on November 26, 2007 (Reference 13).

The area remaining in the 10 CFR Part 50 license is an approximately 4.6-acre area associated with the ISFSI. CYAPCO subsequently revised the description of the licensed area of the site in the HNP UFSAR and Quality Assurance Plan (QAP).

The ISFSI-related areas of the site will remain in the HNP license until:

- the spent nuclear fuel has been shipped from the site for storage or disposal,

- the facilities on the ISFSI site have been decommissioned,

- a FSS has been conducted and the results submitted to the NRC, and

- the NRC approves the partial site release of remaining areas covered by the HNP license.

4.2.4 Project Management

CYAPCO's initial plan was to self-manage the decommissioning of HNP and so developed an in-house organization to self-implement decommissioning. In April 1999, based on the successful use of a DOC at another decommissioning project, CYAPCO issued a fixed price, turnkey scope contract to a DOC to complete the decommissioning and dismantlement tasks through final grading and performance of the final status survey, including implementation of the ISFSI. During this period, CYAPCO continued to perform Spent Fuel Pool Island Operations and to provide oversight of the DOC activities. However, due to the significant effort associated with managing contract changes concerning the scope of the DOC, CYAPCO decided in July 2003 to self-manage the remainder of the decommissioning work.

Some of the key subcontracts that were in place were assigned (i.e., continued directly under CYAPCO Management) to CYAPCO. CYAPCO chose to seek bids for a demolition contractor and awarded a contract to a local construction firm in June 2004. This contract was fixed price for much of the remaining work to be performed onsite. This firm performed the majority of the decommissioning work at HNP.

4.2.5 Decommissioning Issues/Approaches

The technology used for decontamination, dismantlement, and disposal is as follows:

Spent Fuel Pool Island

Modifications were designed and installed to develop a spent fuel pool island. These modifications provided physical isolation between decommissioning activities and the spent fuel pool. In addition, they provided systems, independent from normal plant systems, for cooling, ventilation, and independent power supplies for the spent fuel pool and its associated equipment and structure. A backup diesel generator was also installed to maintain electrical capabilities during a loss of normal power supply. More details of these modifications are presented in the EPRI Experience Report (Reference 10). The modifications were completed in 1998.

Large Component Removal (LCR)

- Steam Generator Removal and Disposal

  Since the HNP steam generators could not be removed in one piece without structural modification of the Containment Building, the SGs were cut at the feedwater ring. The steam dome (upper portion of the SG) was separated from the steam generator lower assembly (SGLA), with a horizontal cut, and shipped by truck/rail to a licensed radioactive material processor in Tennessee in 1999 (Reference 2). The SGLA, containing the channel head and tube bundle, was originally planned to be shipped primarily by barge to the Barnwell Disposal Site in South Carolina. However, because of low water conditions in the Savannah River, barge transportation was not immediately available and a temporary laydown area was established. A route using barges to the

South Carolina coast and rail lines from the South Carolina coast was developed and the shipment was accomplished without incident in 2000/2001.

- Shipment and Disposal of Primary System Parts including Reactor Coolant Pumps and Pressurizer

  The reactor coolant system and any other large bore piping was decontaminated and removed in accordance with the general decommissioning activities.

  The removal and shipment of the reactor coolant pumps and the pressurizer was also fairly straightforward and accomplished without incident. Due to the relatively low activity levels of these components, shipment was by rail to the Clive, Utah, disposal facility.

- Reactor Vessel Internals Segmentation/Reactor Vessel Removal and Disposal

  Because the Barnwell disposal facility has a limit of 50,000 curies (Ci) for a package and the activity of the RPV was estimated to be greater than 800,000 Ci, the RPV internals (the core barrel, baffles, and lower core support plate) were segmented, removed, and stored onsite as GTCC LLW at the ISFSI (resulting in the removal of about 750,000 Ci).

  The majority of the segmentation for the RPV core internals was performed using an abrasive water jet. Garnet was used as the abrasive media. Metal discharge machining was used to remove the lower core support plate bolts and to remove the bolts from the upper internals. Cutting was done on a specially designed cutting table to segregate the cutting operations from the rest of the refueling cavity. The separation of the upper portion of the core support barrel was conducted in place. The position of the upper core support barrel presented serious personnel exposure and airborne contamination concerns. A specially designed stand was constructed so that core barrel (with the core shroud still in place) could be supported from the reactor vessel flange. This kept the core barrel underwater. While in the stand, the core barrel was cut horizontally above the shroud and this segmented piece moved to the segmentation table for cutting. After the upper portion of the core barrel had been segmented, the remainder of the core barrel and core shroud was moved to the segmentation table for cutting. A debris collections and filtration system was used to capture the cutting debris and maintain water clarity. The cutting was done on a specially designed cutting table to segregate the cutting operations from the rest of the cavity. The underwater filtration system consisted of a cyclone separator, back flushable filters, and ion exchanger vessel and a debris collection vessel. The pre-deployment testing of the equipment used for the CYAPCO internals segmentation was a limited integrated test. As only a relatively small shallow pool was used, all of the segmentation equipment could not be tested together. As will be discussed later, experience has shown that integrated, full-scale testing is extremely important to successful internal segmentation project.

  The segmentation of the internals of the HNP reactor proved to be a very challenging project. The project took approximately 29 months to accomplish with a total radiation exposure of approximately 205 person-rem (2.05 person-Sv). Both were well in excess of that originally estimated for the project.

The EPRI Experience Report provides a detailed discussion of the internals segmentation project (Reference 10).

The RPV was removed in one piece, filled with grout, and transported by barge to Barnwell, South Carolina, for disposal.

- Low Pressure Turbine Rotors

The low pressure turbine rotors were removed from HNP and transported to the Palisades Nuclear Plant. These were the first large components removed from the site.

Decontamination and System Dismantlement Activities

- RCS Chemical Decontamination

A chemical decontamination of the primary coolant systems was performed prior to conducting major decommissioning activities. The chemical decontamination was a significant as low as reasonably achievable (ALARA) initiative being performed to reduce personnel exposure during decommissioning work activities, with a projected dose savings to the HNP decommissioning project of 1035 person-rem (10.35 person-Sv). The decontamination effort included the entire reactor coolant system (RCS), including the pressurizer but excluding the reactor vessel surface and 80% surface area of the steam generators. This also included portions of the letdown and charging, residual heat removal (RHR), loop fill and drains, seal injection and return, and selected dead leg piping. The RHR pumps were used to provide the necessary decontamination flow. Jumper piping modifications were made to establish the required flow paths. The decontamination operation will be controlled by approved plant procedures.

The radioactivity content of the reactor vessel is almost exclusive activation and therefore dose rates would not be significantly reduced by a chemical decontamination.

The total surface area of the steam generator tubes is very large. The decontamination of this tubing would generate a large quantity of ion exchange waste. Due to the presence of tubes that had been plugged during plant operation, any decontamination would not be complete. As the costs of the disposal of the steam generator would not be greatly reduced by decontamination, the expense of the additional ion exchange resin generated by decontaminating the steam generators tubes was not justified.

The chemical decontamination process removed about 129 Ci of ^{60}Co and generated about 465 ft^3 (13.2 m^3), which was less than the 200 Ci and 600 ft^3 (17 m^3), respectively, estimated in the PSDAR.

The EPRI Experience Report provides a detailed discussion of the chemical decontamination project (Reference 10).

- Decontamination Methods

  Contaminated systems and components were typically removed and sent to an offsite processing facility, sent to a low-level radioactive waste disposal facility, or decontaminated onsite and released. Other decontamination methods typically included wiping, washing, vacuuming, scabbling, spalling, and abrasive blasting. Selection of the preferred method was based on the specific situation. Other decontamination technologies were considered and used as appropriate.

  Concrete that has surface or near-surface contamination was cleaned, if necessary, to meet applicable DCGLs and ALARA. Activated concrete was removed as necessary to meet DCGLs (and ALARA considerations) or was sent to an LLW disposal facility, or handled by other methods in accordance with applicable regulations. The removal of concrete was performed using methods that control the removal depth to minimize the waste volume produced.

- Dismantlement Methods

  Disassembly and cutting were the dismantlement methods used for contaminated systems. Disassembly generally means removing fasteners and components in an orderly non-destructive manner (i.e., the reverse of the original assembly). Cutting methods include flame cutting, abrasive cutting, and cold cutting. Abrasive water-jet cutting was used to segment the RPV internals.

Decontamination and Disposition of Site Buildings

- Decontamination and Disposition Methods

  Review of the site indicated that many horizontal surface areas within the RCA had elevated surface contamination levels. Therefore, to reduce worker exposure and to avoid generation of new LLW through cross-contamination of the clean base materials from the contaminated surfaces, structural concrete surfaces were decontaminated before a structure was dismantled.

  Exposed faces of buildings and foundations were surveyed and decontaminated until the surface met or was below the release criteria. The subsurface foundations (i.e., those more than four feet below ground level) were decontaminated, as necessary, to meet the release criteria, and left in place as discussed previously.

- Containment Building Demolition

  The containment surfaces and structure was decontaminated and dismantled in accordance with the general decommissioning activities. The demolition of the HNP containment was carried out exclusively using excavators fitted with hoe rams and shears, using a process which had never been used before. The demolition of the HNP containment took approximately 3 months to complete, working 2–10 ten-hour work shifts (4 days per week). This time span was shorter than originally planned and prevented the containment building from being the decommissioning project critical path. Project costs were reduced due to the avoidance of the cost of controlled explosive demolition. More detailed information regarding the process of demolition can be found in the EPRI Experience Report (Reference 10).

4.2.6 Non-Decommissioning Fund Activities

ISFSI

CYAPCO chose the NAC International Multi-Purpose Canister (MPC) system for the interim storage of the HNP used fuel until the DOE takes possession of the fuel. The system includes 40 concrete casks that provide dry storage for 1,019 used fuel assemblies and three concrete casks that provide storage of the segmented reactor internals or GTCC waste described previously. Construction of the ISFSI was completed in spring 2004. The first casks moved to the ISFSI were those containing the GTCC waste, followed by casks containing used fuel (Reference 3).

A significant delay in the decommissioning process occurred while attempting to obtain a permit from the town of Haddam related for the construction of the ISFSI facility. There was considerable discussion regarding the proposed location of the facility. Eventually an agreement was reached and the construction permit for the site was received, allowing facility construction to begin. Movement of the used fuel and GTCC waste to the ISFSI was completed in March 2005.

Offsite Material Recovery

Although not strictly part of the decommissioning of the HNP site, the preparation of the historical site assessment and subsequent characterization efforts identified periods in the past where surveys conducted to radiologically free release materials from the site were not as sensitive as current technology. There were also cases where surveys were not conducted thoroughly. These periods in the 1970s resulted in material such as soil, concrete block and other construction materials being released from the site with very low levels of detectable plant related radioactivity. An extensive project called the Offsite Material Recovery Project (OMRP) was needed to survey for and retrieve these materials from identified offsite properties. The OMRP was completed in 2003, diverted personnel resources from the decommissioning, and cost approximately $10 million.

4.2.7 Soil and Groundwater Remediation

The information developed during the initial HNP characterization program represents a radiological and hazardous material assessment based on the knowledge and information available at the end of 1999. One objective of this initial characterization program was to identify the potential and known sources of radioactive contamination in systems, on structures, in surface or subsurface soils, and in groundwater.

Soil Remediation

During 1998 and 1999, greater than 100 subsurface soil samples, in some cases down to 6 feet in depth, were collected outside of the RCA. None of the samples had plant related radioactivity levels greater than the corresponding base-case soil DCGLs. During the same time period, over 200 subsurface soil samples, in some cases down to 4 feet in depth, were collected inside the RCA. Some isolated spots showed ^{60}Co and ^{137}Cs activity levels up to several hundred pCi/g each. Most of the sampling was performed in support of the spent fuel pool project. Continued characterization of site soils resulted in identification of contaminated areas and depth of the contamination.

Remediation of soil was conducted so as to also meet the state of Connecticut Remediation Standard Regulations (RSRs), 19 mrem/yr, and the U.S. Environmental Protection Agency (EPA)/NRC Memorandum of Understanding (MOU) residential soil levels (4 mrem/yr groundwater dose), as well as the NRC's 25 mrem/yr license termination requirement. Table 4.2 provides a comparison of the DCGLs for a few radionuclides for each of the different regulatory requirements. CYAPCO committed to meet the state of Connecticut RSR levels and determined that the more restrictive RSR levels for soil, compared to the NRC levels, would not greatly affect the quantity of soil remediated.

Table 4.2. Comparison of DCGLs for Different Site Release Limits

Media: Radionuclide	NRC 25 mrem/yr (0.25 mSv/yr)	State of Connecticut RSRs 19 mrem/yr (0.19 MSv/yr)	EPA/NRC MOU Residential Soil Levels	Soil Remediation Concentrations to Achieve MCL
Soil: ^{60}Co	3.81 pCi/g (0.14 Bq/g)	2.9 pCi/g (0.11 Bq/g)	4 pCi/g (0.15 Bq/g)	3.5 pCi/g (0.13 Bq/g)
Soil: ^{137}Cs	7.91 pCi/g (0.29 Bq/g)	6 pCi/g (0.22 Bq/g)	6 pCi/g (0.22 Bq/g)	3.3 pCi/g (0.12 Bq/g)
Soil: ^{90}Sr	1.55 pCi/g (0.06 Bq/g)	1.18 pCi/g (0.04 Bq/g)	23 pCi/g (0.85 Bq/g)	0.065 pCi/g (0.0024 Bq/g)
Soil: ^{3}H	412 pCi/g (15.2 Bq/g)	313 pCi/g (11.6 Bq/g)	228 pCi/g (8.4 Bq/g)	3.3 pCi/g (0.12 Bq/g)
Water: ^{60}Co	1,140 pCi/L (42.8 Bq/L)	100 pCi/L (3.7 Bq/L)	100 pCi/L (3.7 Bq/L)	Not Applicable
Water: ^{137}Cs	431 pCi/L (15.9 Bq/L)	200 pCi/L (7.4 Bq/L)	200 pCi/L (7.4 Bq/L)	Not Applicable
Water: ^{90}Sr	251 pCi/L (9.3 Bq/L)	8 pCi/L (0.3 Bq/L)	8 pCi/L (0.3 Bq/L)	Not Applicable
Water: ^{3}H	652,000 pCi/L (24,124 Bq/L)	20,000 pCi/L (740 Bq/L)	20,000 pCi/L (740 Bq/L)	Not Applicable

However, the DCGLs for groundwater are much lower for the RSRs and EPA/NRC MOU than for the NRC license termination criteria. Since the groundwater beneath the HNP site was classified for residential use, CYAPCO agreed to meet the EPA maximum contaminant levels (MCLs) for the drinking water standards, with a goal of “no measurable concentrations over background." For the two primary radionuclides present in groundwater at HNP, tritium (^{3}H) and strontium 90 (^{90}Sr), this resulted in soil DCGLs substantially lower than the LTP DCGLs, with the resulting dose from the MCL calculation being approximately 1 mrem/yr (0.01 mSv/yr). As discussed below, this required the removal of substantially more soil than would have been required to meet the LTP DCGLs only.

The required soil removal was fairly centrally located to the industrial area. In order to maintain overall schedule, the buildings in this area needed to be removed first to allow remediation of the soil below and permitting the groundwater monitoring period to begin.

The structures in the tank farm area and the Primary Auxiliary Building were removed in their entirety due to:

- the presence of soil requiring removal under portions of these structures and
- the concrete in these structures was contaminated to the point that decontamination to meet the DCGLs was determined to be more expensive than simply removing all of the concrete.

Soils not meeting the applicable DCGLs were removed and disposed of as radioactive waste. Offsite fill was used to replace the excavated materials. In cases where offsite fill was used to replace the excavated materials, a direct radiation survey was conducted of either each load of fill or of the site from which the material was obtained.

Site Landfill

HNP had a permitted landfill onsite in which demolition debris could be disposed. Because of the low-level activity in small quantities in the debris, it had to be demonstrated that the landfill met the site release criteria. An extensive survey was performed. This survey had the following major steps:

1. The soil contained in the facility that was known to exceed the release criteria was remediated and disposed of as radwaste. Post-remediation samples were taken to confirm that the remediation was complete.
2. The large-scale screening process using excavators and industrial-sized screens were used to expose items so they could be sampled and scanned for radioactivity. Items such as asbestos insulation, and piping, which could not be used as fill were removed at this time and disposed of appropriately.
3. In order to ensure meeting the RCRA requirements for petroleum related constituents, the soil was screened to remove asphalt.
4. After completion of the above process and the landfill graded, a surface and subsurface final site survey was conducted along with samples to confirm that the area met RCRA program release limits.

Groundwater Monitoring

The site characterization at HNP identified areas where groundwater contamination was suspected. As a result, a Phase I Groundwater Monitoring Program was initiated in 1997. After initial characterization information had been collected, a more refined groundwater monitoring program was developed. This program was called the Phase 2 Hydrogeologic Work Plan and was approved in May of 2001. In parallel with the development of the Phase 2 work, CYAPCO was in the process of developing the LTP. In the process of preparing the LTP a list of 20 radionuclides was developed which would potentially be evaluated as part of the closure of the HNP site.

As part of this program, CYAPCO installed 40 groundwater monitoring wells in various areas of the site and began monitoring those wells in late 1997.

The wells were located in three areas of the plant:

1. The industrial area of the plant where the reactor containment and the building housing the auxiliary equipment (Primary Auxiliary Building) were located.

2. The Peninsula Area located between the discharge canal and the Connecticut River.

3. The landfill area where trace levels of radionuclides had been found.

In order to demonstrate that residual contamination following remediation of the HNP site was below the DCGLs, an 18-month groundwater monitoring period was required following completion of the removal of all contaminated structures and soil. The prerequisites for the start of the 18-month groundwater monitoring period necessary to determine the dose due to "existing groundwater" was as follows:

- Fate and transport modeling has determined the well network needed to adequately monitor the movement of contamination from the source areas.

- Any new wells identified by the fate and transport modeling were installed.

- Remediation completed, areas backfilled, and dewatering terminated.

- Groundwater has recharged to normal levels for the season when the monitoring was initiated.

All of these prerequisites were satisfied in December 2005 when subsurface soil remediation was completed. A groundwater monitoring plan was prepared and sent to the NRC for review. The first round of LTP compliance sampling was conducted during the month of December 2005. The final sample round needed to support release of the HNP site (excluding the ISFSI) from the NRC license was completed in June 2007. However, groundwater monitoring for the state of Connecticut continued.

4.2.8 Radioactive Waste Volumes and Activity

This section provides the total volume of LLW generated from the decommissioning of HNP that was shipped offsite, to either direct disposal or to waste processors, and the total volume of LLW that was shipped directly to disposal. The volume shipped for disposal is compared to the LLW volume assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

LLW Volume and Activity Shipped Offsite

The volume and activity of radwaste generated and shipped offsite during the HNP decommissioning project is provided in Table 4.3 (References 14 through 22). The total quantity of waste reported to have been shipped offsite, excluding years 1997 and 1998, is 2.4E+05 m^3, or 8.5E+06 ft^3, and a total activity of 3.58E+04 Ci. While information on the volume and activity for 1997 and 1998 were not available, these years are expected to be small contributors to the total (i.e., similar to, or less than, the values reported for 1999) since 1997 and 1998 were prior to significant decommissioning activity at HNP. Furthermore, while the 1999 data did not provide a breakdown by waste classification, most of the volume would be expected to be Class A waste. The activity level increases substantially, starting in 2000, due to the start of the segmentation of the RPV internals.

Because of the very large quantity of waste generated during the decommissioning project, the packing, transport, and disposal of the generated waste was a major undertaking and was a large fraction of the overall decommissioning cost. In order to minimize these costs, CYAPCO used the following LLW management methods, as described in the EPRI Experience Report (Reference 10):

- Intermodal packages were used for most demolition debris, except for very LLW shipped via trans-loading, as described below.

- Since HNP did not have rail access onsite, and rail shipment was less costly than truck shipments, waste bound for the Clive, Utah, disposal facility was initially shipped by truck in intermodal packages to a waste processor facility in Pennsylvania, repackaged into gondola cars, and then shipped to the Clive, Utah, disposal facility.

- Because of disposal cost efficiencies associated with the physical form of the waste, concrete debris was reduced in size and made free of rebar at the HNP site prior to shipment offsite.

- Since the waste from building demolitions was being generated much faster than it could be packaged, shipped, and repackaged at the Pennsylvania facility, as described above, an alternate approach was implemented in which separated concrete demolition debris was loaded into covered dump trucks or trailer dumps and taken to a trans-loading facility in Worcester, Massachusetts. At this facility, the waste was dumped into gondola cars and shipped via rail to the Clive, Utah, disposal facility.

- Similarly, the separated rebar was trans-loaded using a similar operation through a New Haven, Connecticut, rail yard.

- Because of the large quantities and very low activity of much of the demolition debris, much of this waste qualified for and was disposed of at controlled landfills near Memphis and Oak Ridge, Tennessee, at lower cost than shipment to and disposal at the Clive, Utah, disposal facility.

Table 4.3. Radwaste Volume and Activity Generated During HNP Decommissioning[(a)]

	Class A		Class B		Class C		Total[(b)]	
Year Received	Volume (m^3/ft^3)	Activity (Ci)	Volume (m^3/ft^3)	Activity (Ci)	Volume (m^3/ft^3)	Activity (Ci)	Volume (m^3/ft^3)	Activity (Ci)
1999	NA[(c)]	NA	NA	NA	NA	NA	4,328 152,835	541
2000	4,876 172,194	23	7 240	343	7 240	2,340	4,890 172,675	2,706
2001	8,450 298,426	143	17 601	1,323	235 8,284	4,050	8,702 307,311	5,516
2002	9,999 353,094	152	28 982	1,780	13 452	1,090	10,039 354,527	3,022
2003	4,515 159,459	22	0 0	0	263 9,305	23,176	4,779 168,765	23,197
2004	34,595 1,221,715	310	14 490	15	12 412	49	34,621 1,222,618	374
2005	81,823 2,889,552	92	42 1,494	36	33 1,156	215	81,988 2,892,202	344
2006	90,760 3,205,167	60	36 1,278	1	19 663	20	90,815 3,207,108	81
2007	12 440	0	0 0	0	0 0	0	12 440	0
Total[(c)]	**235,031** **8,300,048**	**802**	**144** **5,085**	**3,498**	**581** **20,513**	**30,941**	**240,084** **8,478,480**	**35,782**

(a) Information is from HNP Annual Radioactive Effluent Reports (References 14 through 22). Similar information is not available for 1997 and 1998.
(b) Totals may not add due to rounding.
(c) NA - information not available.

Table 4.4 provides the number of shipments required to transport the radwaste reported in Table 4.3 (References 14 through 22). As described above, much of the waste was shipped to commercial waste vendors for further processing and disposal.

Table 4.4. Number of Radwaste Shipments[(a)]

Year Received	Barnwell Waste Management Facility	Clive, Utah (Energy*Solutions* Facility)	Radwaste Vendor	**Total**
1999	7	0	79	**86**
2000	4	2	109	**115**
2001	28	11	184	**223**
2002	27	7	207	**241**
2003	11	35	140	**186**
2004	13	325	996	**1,334**
2005	5	287	2,458	**2,750**
2006	4	1,077	1,848	**2,929**
2007	0	0	1	**1**
Total	**99**	**1,744**	**6,022**	**7,865**

(a) Information is from HNP Annual Radioactive Effluent Reports (References 14 through 22). Similar information is not available for 1997 and 1998.

LLW Volume and Activity Directly Shipped to a Disposal Facility

Table 4.5 reports the volume and activity of LLW generated from the decommissioning of HNP and shipped directly to commercial LLW disposal sites for disposal. This information was obtained from the DOE Manifest Information Management System (MIMS), which is a database of LLW information derived from the manifests for waste shipments as reported to the DOE by each of the commercial LLW disposal sites (Reference 23). The information provided in Table 4.5 is only that LLW shipped directly from the HNP site to the LLW disposal facility, including that which was trans-loaded for rail shipment to the Clive, Utah, disposal facility. It does not include LLW shipped from radwaste vendors after processing.

Based on the information in Tables 4.3 and 4.5, the following observations are made:

- The total activity disposed of at LLW disposal facilities is 35,600 Ci, which corresponds well to the total activity of 35,800 Ci reported by CYAPCO as having been shipped from the HNP site during decommissioning.

- The total volume of LLW disposed of at both the Clive, Utah, and Barnwell disposal facilities is reported to be 1.1E+06 ft^3 (3.2E+04 m^3), implying about 7.3E+06 ft^3 (2.1E+05 m^3) was shipped to radwaste vendors for further processing and disposal. This represents about 86.5% of the total volume of 8.5E+06 ft^3 (2.4E+05 m^3) reported by CYAPCO as having been shipped from the HNP site during decommissioning.

- The total volume of LLW disposed of at the Clive, Utah, disposal facility is reported to be 1.1E+06 ft^3 (3.1E+04 m^3). This represents about 13% of the total volume of 8.5E+06 ft^3 (2.4E+05 m^3) reported by CYAPCO as having been shipped from the HNP site during decommissioning.

Table 4.5. LLW Volume and Activity Received at LLW Disposal Sites(a)

Disposal Site	Year Received	Class A Volume (m³/ft³)	Class A Activity (Ci)	Class B Volume (m³/ft³)	Class B Activity (Ci)	Class C Volume (m³/ft³)	Class C Activity (Ci)	Total Volume (m³/ft³)	Total Activity (Ci)
Clive, Utah	2001	254 8,966	16	0 0	0	0 0	0	254 8,966	16
	2002	162 5,720	0	0 0	0	0 0	0	162 5,720	0
	2003	423 14,940	0	0 0	0	0 0	0	423 14,940	0
	2004	2,302 81,312	4	0 0	0	0 0	0	2,302 81,312	4
	2005	8,417 297,243	20	0 0	0	0 0	0	8,417 297,243	20
	2006	19,679 694,952	28	0 0	0	0 0	0	19,679 694,952	28
	2007	173 6,110	0	0 0	0	0 0	0	173 6,110	68
	Total	**31,410** **1,109,243**	**68**	**0** **0**	**0**	**0** **0**	**0**	**31,410** **1,109,243**	**0**
Barnwell, SC	1997	16 554	2	0 0	0	0 0	0	16 554	2
	1998	16 566	1	0 0	0	0 0	0	16 566	1
	1999	1 32	1	0 0	0	24 842	541	25 874	542
	2000	1 31	0	7 241	343	7 241	2,340	14 512	2,683
	2001	47 1,673	101	23 816	1,345	227 8,032	4,028	298 10,521	5,473
	2002	36 1,264	52	26 908	1,758	43 1,516	1,227	104 3,688	3,036
	2003	37 1,307	7	0 0	0	16 565	84	53 1,872	91
	2004	54 1,922	53	0 0	0	242 8,541	23,233	296 10,463	23,286
	2005	4 131	4	5 187	22	38 1,324	269	46 1,642	295
	2006	3 103	0	0 0	0	37 1,320	84	40 1,423	84
	2007	0 0	0	0 0	0	2 73	5	2 73	5
	Total	**215** **7,581**	**221**	**61** **2,151**	**3,468**	**636** **22,454**	**31,811**	**911** **32,186**	**35,499**

Table 4.5. (contd)

Disposal Site	Year Received	Class A Volume (m^3/ft^3)	Class A Activity (Ci)	Class B Volume (m^3/ft^3)	Class B Activity (Ci)	Class C Volume (m^3/ft^3)	Class C Activity (Ci)	Total Volume (m^3/ft^3)	Total Activity (Ci)
Total	1997	16	2	0	0	0	0	16	2
		554		0		0		554	
	1998	16	1	0	0	0	0	16	1
		566		0		0		566	
	1999	1	1	0	0	24	541	25	542
		32		0		842		874	
	2000	1	0	7	343	7	2,340	14	2,683
		31		241		241		512	
	2001	301	116	23	1,345	227	4,028	552	5,489
		10,639		816		8,032		19,486	
	2002	198	52	26	1,758	43	1,227	266	3,036
		6,984		908		1,516		9,408	
	2003	460	7	0	0	16	84	476	91
		16,247		0		565		16,812	
	2004	2,357	57	0	0	242	23,233	2,599	23,290
		83,234		0		8,541		91,775	
	2005	8,421	24	5	22	38	269	8,463	315
		297,373		187		1,324		298,884	
	2006	19,682	29	0	0	37	84	19,719	113
		695,054		0		1,320		696,375	
	2007	173	0	0	0	2	5	175	5
		6,110		0		73		6,183	
TOTAL		**31,625**	**289**	**61**	**3,468**	**636**	**31,811**	**32,322**	**35,567**
		1,116,824		**2,151**		**22,454**		**1,141,429**	

(a) Information is from the DOE Manifest Information Management System (Reference 23).

- The total volume of LLW disposed of at the Barnwell disposal facility is reported to be 3.2E+04 ft^3 (9.1E+02 m^3). This represents about 0.4% of the total volume of 8.5E+06 ft^3 (2.4E+05 m^3) reported by CYAPCO as having been shipped from the HNP site during decommissioning.

- The total volume of Class B and C LLW disposed of at the Barnwell disposal facility is reported to be 2.2E+03 ft^3 (61 m^3) and 2.2E+04 ft^3 (6.4E+02 m^3), respectively. The volume of Class B waste is about 10% of the volume of Class C waste disposed.

The total volume of LLW generated from the decommissioning of HNP and shipped for disposal as LLW was estimated in the PSDAR to be 283,117 ft^3 (8,017 m^3), which is substantially less than the LLW volume actually shipped directly to disposal. This difference is at least partially due to the significant volume of contaminated soil that was removed to meet the DCGLs. The EPRI Experience Report (Reference 10) reports that approximately 1.17E+06 ft^3 (3.3E+05 m^3) of soil required removal and disposal as radioactive waste, of which approximately 4.12E+05 ft^3 (1.17E+04 m^3) was required to meet the groundwater MCLs. It is unknown how much of this contaminated soil was shipped directly to disposal as LLW and how much was shipped to waste processors for further processing and disposal.

A comparison of Tables 4.3 and 4.5 shows that the annual and total activity shipped offsite and received at LLW disposal facilities are in very good agreement. This is to be expected since most of the activity would be expected to be shipped for disposal, while LLW having very low levels of activity would be expected to be shipped to a waste vendor for further processing or to alternate disposal. On the other hand, the total volumes shipped and the total volumes disposed of at LLW facilities are vastly different. This is to be expected since large volumes of waste were shipped to waste processors for treatment and/or alternate disposal. This is discussed further below.

Decommissioning LLW Volume Comparison to Minimum Decommissioning Fund Requirements

The cost basis for the 10 CFR 50(c) minimum decommissioning fund formula includes assumptions with regard to the volume of LLW generated during decommissioning. The cost bases and assumptions for the formula are provided in NUREG/CR-0130 (Reference 27) and subsequent Addendums 3 and 4 to that report (References 28 and 29). The volume of LLW assumed in the formula is shown in Table 4.6, which provides a breakdown of the total LLW volume generated/shipped and the LLW volumes assumed to be shipped to the Barnwell disposal facility, to the Clive, Utah, disposal facility, and to waste processors. Table 4.6 also provides a comparison of the formula LLW volume assumptions to the actual LLW volumes generated during decommissioning of HNP, as summarized from Tables 4.3 and 4.5. The following observations are made:

- The total volume shipped from the HNP site is a factor of 13 greater than that assumed in the formula. As was discussed previously, the majority of this waste was demolition debris having very low activity, much of which was shipped to waste processors for treatment and/or disposal at controlled landfills near Memphis and Oak Ridge, Tennessee, at lower cost than shipment to and disposal at the Clive, Utah, disposal facility. The cost basis for the formula assumes that demolition debris and soil having very low activity levels remains onsite and is not a decommissioning waste.

- The total volume of LLW disposed of at the Barnwell facility is about 40% higher for the formula than the actual volume disposed. However, the actual volume of Class B and C waste disposed of at Barnwell is a factor of 2.6 greater than that assumed in the formula (Class B, Class C, and GTCC waste).

- The cost basis for the formula assumed that the GTCC waste is disposed of at the Barnwell facility as LLW. GTCC waste is actually being stored at the ISFSI for later disposal. Disposition of GTCC waste is no longer considered a decommissioning cost.

- The actual volume of LLW disposed of at the Clive, Utah, facility is about 80% higher than assumed in the formula. The formula also assumes a small volume of Class B waste goes to the Clive, Utah, facility for processing and disposal, while no Class B wastes were actually sent to this facility from the HNP decommissioning project. It is recognized that the Clive, Utah, disposal facility cannot dispose of Class B LLW; however, it is assumed that this small volume can be processed/treated and appropriately dispositioned.

- The current cost basis for the formula does not assume any of the LLW is shipped to waste processors for treatment and/or to alternate disposal. The actual volume of LLW shipped to waste processors represents about 87% of the total volume shipped from the Haddam Neck site.

Table 4.6. Comparison of Formula and Actual LLW Volumes

LLW Shipped/Received	Formula Volumes m^3	Formula Volumes ft^3	Actual Volumes m^3	Actual Volumes ft^3
Total Volume Shipped[(a)]				
Class A	17,964	634,392	239,359[(b)]	8,452,883[(b)]
Class B	214	7,564	144	5,085
Class C	17	600	581	20,513
GTCC	133	4,700	0	0
Total	**18,328**	**647,256**	**240,084**	**8,478,480**
Volume to Barnwell Disposal Facility				
Class A	982	34,675	215	7,581
Class B	116	4,100	61	2,151
Class C	17	600	636	22,454
GTCC	133	4,700	0	0
Total	**1,248**	**44,075**	**911**	**32,186**
Percentage		6.8%		0.4%
Volume to Clive, Utah, Disposal Facility				
Class A	16,982	599,717	31,410	1,109,243
Class B	98	3,464	0	0
Class C	0	0	0	0
GTCC	0	0	0	0
Total	**17,080**	**603,181**	**31,410**	**1,109,243**
Percentage		93.2%		13.1%
Volume to Waste Processors				
Class A	0	0	207,734	7,336,059
Class B	0	0	83	2,934
Class C	0	0	0	0
GTCC	0	0	0	0
Total	**0**	**0**	**207,817**	**7,338,993**
Percentage		0.0%		86.6%

(a) The total actual volume shipped is somewhat low because volumes for 1997 and 1998 were not available. The volumes for these years would be expected to be less than the volumes shipped in 1999 since significant decommissioning activity had not yet started, which is small relative to the total volume. This missing data are expected to have a minimal impact on the comparisons in this table.
(b) The total volume from Table 4.3 for 1999 is assumed to be Class A LLW for the purposes of this comparison. The Class B and C volumes for 1999 are expected to be very small relative to the Class A volume and to have a minimal impact on the comparisons in this table.

4.2.9 Cost of Decommissioning and License Termination

This section provides the decommissioning cost estimated by the licensee prior to the start of significant decommissioning activity and the actual decommissioning cost incurred by the licensee to decommission the HNP. The actual decommissioning cost incurred is also compared to the decommissioning cost assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

Estimated Decommissioning Cost

Table 4.7 provides a breakdown of the estimated cost to decommission HNP as provided in the PSDAR (Reference 1). Excluding spent fuel storage, the estimated cost to complete radiological decommissioning was $344 million (1996).

Table 4.7. Decommissioning Cost Estimate in PSDAR

Decommissioning Activity	Cost ($)[a]
Planning/Preparation[b]	76,248,000
Large Component Removal	46,550,000
Dismantlement Activities[c]	142,612,000
Low-Level Waste Shipping/Burial	71,928,000
Spent Fuel Storage[d]	82,345,000
Site Restoration[c]	7,043,000
Total Cost to Remove/Dismantle	**426,726,000**

(a) Costs are in 1996 dollars.
(b) Includes asbestos abatement, RCS decontamination, and development of the Spent Fuel Pool Island.
(c) The cost of Site Restoration is provided in the Site-Specific Decommissioning Cost Estimate (Reference 26) and the corresponding adjusted cost of Dismantlement Activities.
(d) Storage of used fuel was assumed to be in the Spent Fuel Storage Pool (i.e., no ISFSI was assumed to be available).

The PSDAR estimated decommissioning costs were subsequently updated in LTP, Rev. 0 (Reference 2) and LTP, Rev. 2 (Reference 3). These revised estimates, including actual costs incurred up until the LTP revision, are provided in Table 4.8. As can be seen, the total cost of decommissioning HNP (i.e., radiological decommissioning, spent fuel management, and site restoration) increased from $427 million in 1996 to $523 million in 2000 and to $930 million in 2003. A breakdown of the actual expenditures into major cost categories is not provided for the LTP revisions and so a direct comparison between the PSDAR and LTP revisions is not possible. However, it is clear that the increase in total decommissioning cost (i.e., radiological decommissioning, spent fuel management, and site restoration) is principally due to the following factors:

- A cost increase of over $200 million due to the decision to construct an ISFSI and decommission the spent fuel pool.

- The cost of site restoration and license termination and final status survey increased by about $100 million.

- Some cost increase in going to 2003 dollars (LTP, Rev. 2) from 2000 dollars (LTP, Rev. 0) and 1996 dollars (PSDAR).

- About $100 million increase in cost in other areas for which insufficient information is available to determine the specific reasons for the increase. However, it is presumed that the reasons for the increase are due to the previously stated reasons for the delays in completing the project, including reactor internals segmentation complexity, inclusion of a groundwater monitoring period, change from DOC to self-management, more stringent license termination cleanup criteria, etc.

Table 4.8. LTP Actual and Projected Decommissioning Costs

Decommissioning Activity	LTP, Rev. 0 Cost ($M)[(a)]	LTP, Rev. 2 Cost ($M)[(b)]
Actual Expenditures		
1997 Dismantlement and Decontamination	6.7	6.7
1998 Dismantlement and Decontamination	74.0	74.0
1999 Dismantlement and Decontamination	88.3	88.3
2000-2002 Dismantlement and Decontamination	Not Applicable	157.9
Subtotal Actual Expenditures	169.0	326.9
Projected Remaining Costs[(c)]		
Dismantlement and Decontamination	153.7	106.2
Radioactive Waste Disposition	78.6	64.5
Long Term Spent Fuel Storage[(d)]	102.4	317.9
Site Restoration and License Termination	19.3	99.8
Final Status Survey	Not Available[(e)]	14.9
Subtotal Projected Remaining Costs	354.0	603.3
Total Decommissioning Cost	523.0	930.2

(a) Actual costs are in nominal year dollars. Projected costs are in 2000 dollars. Costs for 1998 and 1999 include spent fuel storage costs.
(b) Actual costs are in nominal year dollars. Projected costs are in 2003 dollars. Costs for 1998 through 2002 include spent fuel storage costs.
(c) Projected costs for LTP, Rev. 0 do not include contingency.
(d) Cost includes construction of an ISFSI, interim storage of used fuel and GTCC waste in the ISFSI and spent fuel pool island, and decommissioning of the ISFSI.
(e) Included in cost of Site Restoration and License Termination.

Actual Decommissioning Cost

The actual costs to decommission HNP are shown in Table 4.9 (Reference 25). The same costs adjusted to 2010 dollars are shown in Table 4.10.

During the transitional period (1997 and 1998), the costs reflect initial decommissioning planning, chemical decontamination of the RCS, and removal of much of the asbestos insulation. The abrupt rise in program management cost in 1999 is due to augmentation of the

DOC staff and CYAPCO oversight staff as the DOC begins its D&D responsibilities. Program management costs increase again in 2004. This reflects the termination of the DOC contract and the assumption of D&D activities by CYAPCO.

Detailed decommissioning costs at the project or task level are not available for the period during which the DOC was performing D&D (April 1999 through June 2003); only a single total DOC cost is available for each year, hence, the DOC costs are all categorized under the category "Decontamination." During this period, CYAPCO was overseeing the DOC, and cost breakdowns were structured in financial terms ("CY oversight staffing", "employee expenses", "indirect overheads", etc.) rather than in terms of actual decommissioning events (steam generator removal, segmentation of the reactor pressure vessel internals, etc.). Because of this, the number of cost categories is necessarily limited to those shown in Tables 4.9 and 4.10. It should also be noted (again because of the lack of project-related information during the DOC period) that some costs, which would normally be assigned to the "Waste Disposal" and "Spent Fuel Management" categories, could not be explicitly identified and had to remain in the broader "Decontamination" category. Similarly, any final status survey costs which may have occurred during the DOC period are not explicitly known and would have been rolled up into "Program Management" or "Decontamination" costs during this period. Thus, total final status survey costs are at least as high as those shown in Tables 4.9 and 4.10, but may be higher.

Regarding the "Spent Fuel Management" cost category, procurement and construction of the ISFSI was not included in the DOC scope and so this cost is accurately accounted for in Tables 4.9 and 4.10. However, the cost to manage procurement of the ISFSI was included in the DOC scope and so these costs during the DOC period are included in the "Decontamination" category rather than the "Spent Fuel Management" category. The authors estimate that these costs are on the order of $5–$10 million and are therefore a minimal contributor to the license termination cost. Also, the information provided by CYAPCO (Reference 25) included a cost category called "Dry Storage." However, based on other detailed information supplied by CYAPCO, this category was renamed "Spent Fuel Management" and all costs associated with the ISFSI, and with the management of used fuel returned from the G.E. Morris storage facility, were moved into this category, which is reflected in the costs reported in Tables 4.9 and 4.10.

Insurance costs for most of the years shown in Tables 4.9 and 4.10 are negative. This is due to refund distributions that CYAPCO received from its insurance companies, particularly Nuclear Electric Insurance Limited (NEIL).

From time to time during the course of decommissioning, CYAPCO was involved in litigation with some of its subcontractors, the Federal Energy Regulatory Commission (FERC), and DOE. These legal costs have been retained in Tables 4.9 and 4.10. In total, these costs amount to $30M (2011 dollars) or about 3% of the total cost to decommission.

Table 4.9. Decommissioning Costs by Year (Millions of Dollars)

	Cost Category	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**Total**
Decommissioning Costs	Decontamination	0.0	54.8	41.1	52.3	20.5	35.3	21.9	24.5	23.4	13.1	3.0	**289.9**
	Waste (Packaging, Transport & Disposal)	0.0	0.0	0.0	0.0	0.0	0.0	5.0	25.3	39.5	28.0	4.3	**102.1**
	Program Management	6.7	19.3	43.9	17.7	17.3	18.1	41.9	58.8	40.8	23.2	8.3	**295.9**
	Insurance	0.0	0.0	-1.1	-2.8	-2.7	-1.5	0.2	-0.3	-0.7	-1.0	-0.7	**-10.8**
	Property Taxes	0.0	0.0	4.6	1.7	1.7	2.3	0.5	1.4	1.5	1.3	1.1	**16.1**
	Regulatory	0.0	0.0	0.8	0.6	1.2	1.1	0.7	3.5	1.8	2.1	0.0	**11.8**
	Final Status Survey	0.0	0.0	0.0	0.0	0.0	0.0	0.7	4.6	4.8	3.9	1.6	**15.5**
	Decommissioning Costs Total	**6.7**	**74.1**	**89.3**	**69.5**	**37.9**	**55.2**	**70.8**	**117.8**	**111.1**	**70.5**	**17.5**	**720.5**
Other Costs	Spent Fuel Management	0.0	0.0	0.7	0.4	27.5	29.2	11.1	33.2	11.9	0.7	0.3	**115.2**
	Site Remediation/ Restoration	0.0	0.0	0.0	0.0	0.0	0.0	2.3	13.7	13.7	12.3	1.3	**43.4**
	Other Costs Total	**0.0**	**0.0**	**0.7**	**0.4**	**27.5**	**29.2**	**13.5**	**47.0**	**25.6**	**13.0**	**1.6**	**158.6**
Grand Total		**6.7**	**74.1**	**90.1**	**69.9**	**65.4**	**84.4**	**84.3**	**164.8**	**136.8**	**83.5**	**19.1**	**879.1**

Table 4.10. Decommissioning Costs by Year (Millions of 2010 Dollars)

	Cost Category	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	**Total**
Decommissioning Costs	Decontamination	0.0	78.1	56.9	70.3	26.8	44.7	27.9	30.1	27.8	15.1	3.3	**381.0**
	Waste (Packaging, Transport & Disposal)	0.0	0.0	0.0	0.0	0.0	0.0	6.3	31.1	47.0	32.1	4.8	**121.3**
	Program Management	9.8	27.5	60.7	23.7	22.5	22.9	53.3	72.1	48.4	26.5	9.2	**376.7**
	Insurance	0.0	0.0	-1.6	-3.8	-3.5	-1.9	0.2	-0.4	-0.9	-1.2	-0.8	**-13.8**
	Property Taxes	0.0	0.0	6.4	2.2	2.2	2.9	0.6	1.7	1.8	1.4	1.2	**20.4**
	Regulatory	0.0	0.0	1.1	0.9	1.6	1.4	0.9	4.3	2.2	2.4	0.0	**14.7**
	Final Status Survey	0.0	0.0	0.0	0.0	0.0	0.0	0.8	5.6	5.7	4.5	1.8	**18.4**
	Decommissioning Costs Total	**9.8**	**105.6**	**123.7**	**93.4**	**49.5**	**69.9**	**90.0**	**144.4**	**131.9**	**80.9**	**19.4**	**918.5**
Other Costs	Spent Fuel Management	0.0	0.0	1.0	0.6	35.9	37.0	14.1	40.7	14.1	0.8	0.4	**144.6**
	Site Remediation/ Restoration	0.0	0.0	0.0	0.0	0.0	0.0	3.0	16.9	16.3	14.1	1.4	**51.8**
	Other Costs Total	**0.0**	**0.0**	**1.0**	**0.6**	**35.9**	**37.0**	**17.1**	**57.6**	**30.4**	**15.0**	**1.8**	**196.4**
Grand Total		**9.8**	**105.6**	**124.7**	**93.9**	**85.4**	**106.9**	**107.1**	**202.1**	**162.3**	**95.9**	**21.2**	**1,114.9**

The program management costs include a net credit of $732 thousand from the sale of surplus equipment generated by the asset recovery program, all of which was generated after 2004. The LTP reports that the salvage value credit of plant equipment was about $5 million to date in 2000 (Reference 2). This credit does not appear to be included in the costs reported in Tables 4.9 and 4.10.

It is unclear if the reported costs include the costs associated with remediating contaminated materials that were improperly released early in the plant's life, referred to as the Offsite Material Recover Project discussed above. The LTP reports that this cost was $10 million to date at the time of the LTP (Reference 2).

Decommissioning Fund Status

While the decommissioning of the HNP is completed and the 10 CFR Part 50 license has been amended to reflect the removal of all land areas from the NRC license except that associated with the ISFSI, the HNP ISFSI continues to be licensed under the HNP 10 CFR Part 50 license. Consequently, CYAPCO is maintaining a decommissioning fund of $152.9 million (2008 dollars), $145.4 million for ISFSI operations and $7.5 million for ISFSI decommissioning (Reference 24).

Decommissioning Cost Comparison to Minimum Decommissioning Fund Requirements

The actual cost to complete the radiological decommissioning of HNP, as reported in Table 4.9, was $720.5 million. However, as discussed previously, $20–$30 million of spent fuel management costs are estimated to be included in the radiological decommissioning cost. After subtracting these costs, the total radiological decommissioning cost is estimated to be $690.5–$700.5 million.

The minimum decommissioning fund requirement for a nuclear power plant is specified by the formula in 10 CFR 50.75(c). For HNP and using the latest revision of NUREG-1307 (Reference 30), the inputs to the formula are as follows:

- thermal power – 1825 MW
- labor factor (L) – 2.41 (for northeastern U.S.)
- energy factor (E) – 2.139 (for PWR)
- burial factor (B) – 12.28 (for direct disposal of Class B and C waste at the Barnwell facility with vendor disposal of Class A waste)

Using these inputs, the calculated minimum decommissioning fund requirement in 2010 dollars is $414 million ($246 million for LLW disposal costs and $168 million for other costs). The total radiological decommissioning cost for HNP is almost $300 million greater than this minimum decommissioning fund. Because the detailed DOC cost for the years 1999 through 2003 were not available, a detailed comparison of the HNP actual decommissioning cost to the minimum decommissioning fund is not possible. However, high level comparisons do provide some insight into the differences. A comparison of the actual costs and the minimum decommissioning fund is provided in Table 4.11. A discussion of the differences and potential reasons for the differences follows:

- The actual program management costs, which do not include program management costs associated with the DOC, are higher by at least $327 million than the minimum decommissioning fund. Key factors contributing to this difference are:
  - o The total CYAPCO labor requirement to complete HNP decommissioning was 3600 person-years. While a breakdown of this total into program management and other cost categories was not available, this total is substantially greater than the 520 person-years assumed in the 10 CFR 50.75(c) formula.
  - o The HNP decommissioning cost includes about $30 million for litigation activities. The cost basis for the formula did not include any assumptions for litigation.

Table 4.11. Comparison of Actual Costs with the Minimum Decommissioning Fund Requirement (Adjusted to Millions of 2010 Dollars)

Cost Category	Actual Cost	Formula Cost[(a)]
Radiological decontamination and dismantlement	381.0	81.0
LLW packaging, transportation, and disposal	121.3	278.6[(b)]
Program Management	376.7	50.0
Insurance	-13.8	4.1
Taxes	20.4	0.0[(c)]
Regulatory (NRC) fees	14.7	0.3
Final status survey	18.4	0.0[(c)]
Total	**918.5**	**414.0**

(a) Costs may not sum to total due to rounding.
(b) Formula cost for LLW packaging, transportation, and disposal assumes direct disposal of Class B and C waste at the Barnwell disposal facility with vendor processing/disposal of Class A waste.
(c) Formula does not provide for taxes or for a final status survey.

- The actual cost for radiological decontamination and dismantlement, which includes program management costs associated with the DOC, are higher by at least $300 million than the minimum decommissioning fund. A key factor, as discussed previously, is the differences in the total CYAPCO labor requirement and the labor assumptions for the formula.

- The actual cost of LLW disposition (i.e., packaging, transportation, and disposal), which do not include LLW disposition costs associated with the DOC, are lower by up to $157 million than the minimum decommissioning fund. Key factors contributing to this difference are:
  - o This result is counterintuitive since, as discussed previously, the total actual volume of LLW shipped and disposed of at an LLW disposal facility is significantly greater

than assumed in the formula. The EPRI Experience Report (Reference 10) states that the approximate rate for disposal, applying volume discounts available, of the very large volumes of contaminated soil as radioactive waste was $0.40 per pound. The cost basis for the formula assumes an average rate of $2.50 per pound for debris, which does not account for volume discounts. This rate difference adds about $50 million to the formula disposal cost.

- o The cost basis for the formula assumes that GTCC waste is disposed of as LLW, while CYAPCO is storing this waste with the spent fuel at the ISFSI for later disposition as HLW. Disposal of GTCC waste adds approximately $20–$30 million to the formula disposal cost.

- o The cost basis for the formula assumes the volume of Class A waste disposed of at the Barnwell facility is about a factor of 4.6 higher than what was actually disposed while the volume of Class B and C waste actually disposed was about a factor of 5.2 higher than assumed in the formula. Since the cost of disposal of Class B and C was is substantially higher than the cost of disposal of Class A waste, the resulting cost differences are expected to be small.

- o The EPRI Experience Report (Reference 10) estimates the cost of remediation and packaging of contaminated soil, including the cost of engineered soil needed to backfill the excavation, to be more than $20 million and the cost for transportation and disposal of the contaminated soil to be an additional $35 million, for a total cost of about $55 million. However, about $5 million of the remediation and packaging cost and $12.4 million of the transportation and disposal cost, for a total of about $17.4 million, was estimated to be the cost of remediating contaminated soil to meet the MCLs, which is included in the “Site Remediation/Restoration” cost category. Based on this, the radiological decommissioning cost includes about $38 million to remediate contaminated soil. The cost basis for the formula does not include any costs for remediating and disposing of contaminated soil.

- The actual HNP decommissioning costs include a small credit of less than $1 million resulting from the sale of surplus assets. The formula includes no such credits.

- The actual HNP decommissioning costs include a credit of about $14 million for a refund of insurance previously paid. The formula assumes the cost of insurance premiums is $4.1 million.

- No allowances for property taxes and final status surveys are provided for in the formula. Thus these two additional HNP decommissioning costs would not be included in the formula calculations.

4.2.10 References

1. Connecticut Yankee Atomic Power Company (CYAPCO). 1997. "Haddam Neck Plant Post Shutdown Decommissioning Activities Report (PSDAR)," dated August 22, 1997. ADAMS Legacy Library Accession No. 9710160015.

2. Connecticut Yankee Atomic Power Company (CYAPCO). 2000. "Haddam Neck Plant Submittal of License Termination Plan and Proposed Revision To Operating License," dated July 7, 2000. ADAMS Accession No. ML003735143.

3. Connecticut Yankee Atomic Power Company (CYAPCO). 2004. "Haddam Neck Plant Update of License Termination Plan – Revision 2," dated August 30, 2004. ADAMS Accession No. ML042740450.

4. Connecticut Yankee Atomic Power Company (CYAPCO). 2005. "Revision 2A of the Haddam Neck Plant (HNP) License Termination Plan (LTP), dated January 2005, according to the directions provided," dated February 10, 2005. ADAMS Accession No. ML050530267.

5. Connecticut Yankee Atomic Power Company (CYAPCO). 2005. "Haddam Neck Plant License Termination Plan Through Revision 3, August 2005," dated September 6, 2005. ADAMS Accession No. ML052560278.

6. Connecticut Yankee Atomic Power Company (CYAPCO). 2006. "Haddam Neck Plant License Termination Plan," Revision 4, dated November 16, 2006. ADAMS Accession No. ML063310075.

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4.3 Maine Yankee Plant

The Maine Yankee Plant (MY) was owned by a consortium of 10 New England electric utilities, Maine Yankee Atomic Power Company (MYAPC), representing consumers in Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island. The plant was located on an 820-acre site located at 321 Old Ferry Road, Wiscasset Maine, 04578 in Lincoln County, Maine. The majority of the area surrounding the plant site is rural and wooded. This location is approximately 0.43 miles from the nearest residence and is within 5 miles of the nearest population center, Town of Wiscasset.

4.3.1 Historical Background

MY began commercial operation on December 28, 1972 under Atomic Energy Commission Docket No. 50-309, License No. DPR-36, and last operated on December 6, 1996 (Certification of cessation of operation under 10 CFR 50.82(a)(1) submitted August 7, 1997). The Combustion Engineering pressurized water reactor (PWR) was a 3-loop closed-cycle nuclear steam supply system (NSSS), with a large, dry containment; three Asea Brown Boveri turbines; a Westinghouse 950-MVA turbine generator and electrical systems; engineered safety features;

radioactive waste systems; fuel handling systems; instrumentation and control systems; the necessary auxiliaries; and structures to house plant systems and other onsite facilities. These onsite facilities included ancillary facilities such as warehouses, administrative office buildings, security structures, an environmental sampling complex, a substation and a fire protection system. The reactor was designed by Combustion Engineering and built by Stone & Webster. MY was designed to produce 2,700 MW of thermal power. In June 1973, the facility received a full power license for up to 2440 megawatts thermal (MWt), corresponding to approximately 774 megawatts electrical (MWe). Operating license amendments were later issued allowing power operation up to 2,700 MWt with a gross electrical output of approximately 931 MWe. The plant operated for a total of approximately 16 effective full power years based on its rated thermal power (Reference 4).

The MY board of directors voted to permanently cease further operation and decommission the plant in August 1997. On August 27, 1997, MY submitted the Post Shutdown Decommissioning Activities Report (PSDAR) and discussion on environmental impact (Reference 1). On November 6, 1997, a public meeting was held in Wiscasset to hear public comments on the PSDAR. On November 3, 1998, MY submitted the Site-Specific Decommissioning Cost Estimate along with a PSDAR Update (Reference 8).

All spent fuel and GTCC waste have been transferred to the ISFSI. All plant related structures have been removed down to at least 3 feet belowgrade. This leaves concrete structures in only a few areas of the site, such as the reactor building basement, the discharge canal tunnel and part of the spent fuel building. Portions of the original site boundary, remote from the plant, have been removed from the license under phased release. When decommissioning activities and the phased releases were completed, the ISFSI will remain under the MY 10 CFR Part 50 license.

The Final Safety Analysis Report (FSAR) was revised to reflect the permanently defueled plant condition and was re-titled “Defueled Safety Analysis Report” (DSAR). The DSAR was submitted to the NRC on February 6, 1998 and has since been revised in accordance with 10 CFR 50.71(e). Additional licensing basis documents were also revised and submitted to reflect the plant’s defueled condition (Defueled Security Plan, Fire Protection Plan, QA Plan, Training Plan and Emergency Plan).

4.3.2 Decommissioning Schedule (Timeline)

All activities required by the MY License Termination Plan (LTP) (References 2 through 6) except for the final release of the ISFSI areas have been completed and have been released from the MY license. Major milestones and timeline elements are represented below based primarily on information provided in the MY LTP (References 2 through 6) and the EPRI Experience Report (Reference 8).

- On December 6, 1996, MY shut down the plant as a result of design basis implementation concerns associated with cable separation and control logic issues.

- On August 7, 1997, the NRC was notified of permanent cessation of plant operations in accordance with 10 CFR 50.82(a)(1).

- On August 27, 1997, the first publication of the Post Shutdown Decommissioning Activities Report (PSDAR) was issued in accordance with 10 CFR 50.82(a)(4).

- In October 1997, the initial characterization surveys (ICS) begin.

- On February 5, 1998, MY submitted defueled safety analysis report to NRC in accordance with 10 CFR 50.82 (a)(4)(i).

- On August 4, 1998, the decommissioning operations contractor (DOC) was selected.

- On December 1998, asbestos abatement project was completed.

- On May 27, 1999, the source term reduction program was completed.

- In May 1999, MY submitted the permit application to the state of Maine Board of Environmental Protection for ISFSI construction.

- In October 1999, all three reactor coolant pumps were shipped by rail to the Barnwell low-level waste site. Reactor coolant pump motors were shipped to Envirocare of Utah. Site main power transformers were shipped offsite by barge to Midwest utility.

- January 13, 2000, Revision 0 to License Termination Plan (LTP) submitted to NRC.

- On April 26, 2000, the state of Maine signed into law (LD 2688-SP1084) unrestricted release criteria of 10 mrem/yr for all pathways and 4 mrem/yr for groundwater.

- On May 17, 2000, the NRC published notice of the license amendment application proposing to authorize the LTP in the Federal Register (65 FR 31357-31358).

- In June 2000, the steam generators and pressurizer removal was completed. These components were shipped by barge to Tennessee for processing by a waste vendor.

- In July 2000, MY received the construction permits for building the ISFSI. The facility is constructed to be in accordance with 10 CFR 72.

- In November 2000, reactor pressure vessel internals segmentation began.

- In July 2000, MY determined to self-perform decommissioning after DOC declared Chapter 11 bankruptcy.

- In July 2001, Revision 1 of the LTP was submitted to the NRC without the rubblization plan.

- On August 13, 2001, Revision 2 of the LTP submitted to the NRC.

- On October 1, 2001, the Historical Site Assessment was submitted to the NRC.
- In August 2002, the reactor pressure vessel was removed from containment and stored onsite until final burial shipment in May 2003. In addition, the spent fuel began movement from the spent fuel pool to the ISFSI.
- In May 6, 2003, the reactor pressure vessel was transferred to the Barnwell disposal facility.
- On February 27, 2004, all spent fuel had been moved to the ISFSI pad.
- On September 17, 2004, the containment shell was explosively demolished.
- In September 2005, radiological decommissioning was completed.
- On September 30, 2005, the MY 10 CFR Part 50 license was amended to include the unrestricted release of land remaining under License No. DPR-36 with the exception of land where the ISFSI is located and a 3.17-acre parcel of land adjacent to the ISFSI.
- October 2005, remaining contaminated soil stored on the parcel of land adjacent to the ISFSI removed for disposal.

Table 4.12 compares the MY decommissioning schedule originally estimated in the PSDAR with the actual decommissioning schedule discussed above. As can be seen from the table, decommissioning activities and the final status survey were completed essentially on the original PSDAR schedule. The only activity that was significantly delayed from the original planned schedule was the removal of spent fuel to the ISFSI, which is discussed further below.

4.3.3 License Termination Strategy

The MY PSDAR was submitted to the NRC on August 27, 1997. The PSDAR as submitted identified that license termination and site remediation should be completed approximately seven years following cessation of operations. With the cessation of operations occurring in August of 1997, the PSDAR suggested that decommissioning would be complete by August 2004. MYAPC submitted, on January 13, 2000, the original License Termination Plan (LTP) to the NRC (Reference 2). On May 17, 2000, the NRC published a notice in the Federal Register (65 FR 31357-31358) regarding the MYAPC submittal of the License Termination Plan and the request for license amendment mandating implementation of the LTP. The NRC subsequently approved the LTP via a license amendment. The revised LTP (Revision 2) was submitted to provide further refinement and clarifications to the decommissioning activities required to be described. The LTP was subsequently revised several times prior to completion of MY decommissioning activities (References 2 through 6).

The MY LTP was written with very broad and general methods for demonstrating compliance with NRC requirements and guidance. “Although licensees generally believe that a less specific LTP allows for greater decommissioning flexibility, the potential for differing interpretations of the LTP commitments by NRC and licensee staffs is increased. The different interpretations during the LTP review lead to numerous meetings and teleconferences to resolve NRC questions, which required 37 months for LTP approval" (Reference 20).

Table 4.12. Comparison of PSDAR and Actual MY Decommissioning Schedule

Activity	PSDAR Schedule (completion date)	Actual Schedule (completion date)
NRC Notified of Permanent Cessation of Operations	Aug 1997	Aug 1997
PSDAR to NRC	Aug 27, 1997	Aug 27, 1997
Updated DSAR to NRC	not in schedule	Feb 5, 1998
RCS Decontamination	Feb 2001	Mar 1998
Asbestos Abatement	not in schedule	Mar–Dec 1998
Large Component Removal (RPV, internals segmentation, SGs, and Pressurizer)	+3.5 years after cessation Feb 2001	June–Nov 1999 RCPs; May 1999–June 2000 SGs; Aug 1999–June 2000 Pressurizer; Summer 2002 RPV; Aug 2000–Apr 2002 RPV internals segmentation; May 6, 2003 RPV shipped for disposal
Removal of used fuel and GTCC waste from Spent Fuel Pool to ISFSI	+ 5 years after cessation Aug 2002	Jan 2002–Feb 2004
Soil Remediation	not in schedule	Sept 2002–Nov 2004
System/Building Decontamination and Removal	Jan 26, 2005	Mar 1999– Feb 2005
Final Status Survey	+ 7 years after cessation Mar 10, 2005	Sept 1999–Feb 2005
Site Restoration Complete	+8 years after cessation Aug 2005	October 2005 (Reference 20)

As permitted by the NRC in 10 CFR Part 50, licensees can revise the LTP using the 10 CFR 50.59 process. During the course of the decommissioning, the LTP was revised by Maine Yankee three times. Most of the changes were updates to the LTP citing the physical progress in the decommissioning the site. However, there were changes to the technical methods and survey requirements that impacted the staff review of Final Site Survey Reports (Reference 20).

The goal of the MYAPC decommissioning project was to release the site for unrestricted use in compliance with the NRC's annual dose limit of 25 mrem/y plus ALARA and the enhanced State of Maine clean-up criteria of 10 mrem/yr or less for all pathways and 4 mrem/y or less for groundwater sources. Both the State and NRC dose limits apply to residual radioactivity that is distinguishable from background. Dose assessment methods were used to determine DCGLs for nine different potentially contaminated materials.

MYAPC accomplished this as a phased release by submitting LTP changes to the site boundary footprints to allow unrestricted release and license termination of parcels of property. Following the completion of LTP activities in a given area, MYAPC provided to the NRC a license amendment request covering the area which it sought to release from the 10 CFR Part 50 license. This process has been informed by NRC Regulatory Issue Summary 2000-19 (Reference 7).

The overall project schedule identified the site dismantlement activities. These activities included 1) the removal of structures to increase the free area needed for large vehicles and equipment; 2) commodity removal; 3) decontamination and remediation; 4) movement of spent fuel to dry storage; and 5) demolition of structures to 3 feet belowgrade. These activities (were) conducted under 10 CFR 50.59 as described in the LTP. The final state of the site, including any underground remnants, was also described.

The ISFSI-related areas of the site remain in the MY license until:

- the spent nuclear fuel has been shipped from the site for storage or disposal,
- the facilities on the ISFSI site have been decommissioned,
- a Final Status Survey has been conducted and the results submitted to the NRC, and
- the NRC approves the partial site release of remaining areas covered by the MY license.

4.3.4 Project Management

MYAPC's initial plan was to self-manage a prompt dismantlement of the plant based on economic models presented to and accepted by the Board of Directors. Selection of the DOC was made during the transition period from August 1997 to July 1998. The DOC differs from the general contractor approach in that the DOC accepts some portion of the risk on a fixed price basis for the project from the licensee, in addition to providing all necessary labor and skills for the job. MY selected the DOC approach and a contract with the DOC was placed on August 4, 1998.

On May 4, 2000, MY terminated the DOC contract based on performance issues with the contract including contractor insolvency provisions. Less than a week later, the DOC announced that it would file for corporate reorganization under Chapter 11 of the U.S. bankruptcy code. In order to continue project activities, a separate interim contract was issued to the DOC for the period from May 4, 2000 through June 30, 2000. MYAPC took over direct management of the project. MYAPC began serving as the DOC (so called "self-performing) effective July 1, 2000. During this period, MY curtailed work on some non-critical path tasks that could be easily done once the contract issues were sorted out and focused on keeping the critical path work moving forward. The primary focus was on the dry cask storage system implementation and reactor vessel internals segmentation. These two major tasks were the primary drivers of the overall project critical path. In January 2001, the Board of Directors directed MYAPC to continue the management of the overall project through its completion, which it did.

As described in the LTP, MYAPC carried out dismantlement activities in four phases:

- Phase 1: Prepare Site and Release Non-Impacted Areas
- Phase 2: Dismantle Commodities and Decontaminate Structures
- Phase 3: Demolish Buildings and Restore Site
- Phase 4: Establish Independent Spent Fuel Storage Installation (ISFSI)

The Phase 1 period began with permanent plant closure on August 7, 1997. This phase involved the demolition of miscellaneous tanks, buildings, fences and vehicle barriers, etc. to allow ease of access to the site. During this phase, no radiological contaminants were found north of Old Ferry Road, or west of Bailey Cove, and these areas were released on an early basis in accordance with 10 CFR Part 20 Subpart E (Radiological Criteria for Unrestricted Use), the enhanced state cleanup standards, and 10 CFR 50.82 (a)(11)(i) and (ii) (Reference 4). The NRC granted this request for the release of these lands on July 30, 2002 (Reference 5). This phase also included site characterization activity, license basis document revision, spent fuel pool island construction and system evaluation, reclassification and deactivation.

Commodities were dismantled and removed during Phase 2. Following commodity removal, applicable portions of structures were decontaminated as necessary. MYAPC demolished structures, with few exceptions, down to 3 feet belowgrade. For structures on the secondary side of the plant, sufficient surveys were conducted prior to demolition to ensure that any applicable portions of the structure were decontaminated. Structures on the primary (radiologically controlled) side of the plant above 3 feet belowgrade generally were demolished, packaged and either transported to an LLW disposal facility or an alternate disposal facility. Some metals, such as rebar, were recycled, as appropriate, if the metals could be released using a “no detectable” radioactivity standard. Basement surfaces below 3 feet belowgrade were decontaminated and remediated (paint removal, chemical stain removal, etc.) as necessary and a final status survey was performed before the basement was filled with soil.

During Phase 3, structures were demolished to an elevation corresponding to 3 feet belowgrade. These demolition activities were reviewed during planning to ensure no adverse effect on the spent fuel pool installation (i.e. walls of adjacent buildings that have a support function of the SFP remained intact). Concrete buildings were demolished to 3 feet belowgrade. Basement foundations below this level remain in place and were backfilled with soil fill following remediation. Some or all of the intervening walls and floors in the basements were removed. The steel liner in the basement of the Containment Building remained in place. Many of the basement concrete and steel liner surfaces were covered with paint known to contain trace amounts of lead and/or PCB’s. This paint was removed prior to final status survey. The spent fuel pool liner was removed due to known contamination levels. Other buildings were designated for industrial reuse, recycling, or offsite disposal; and dispositioned accordingly. Activated portions of remaining foundations above the activated concrete DCGLs were removed. Some limited amounts of embedded pipe which penetrate basement walls remained. These embedded pipes are easily accessible from either side for final status survey. Sub-mat “popcorn” concrete and its embedded drain lines around the sub-base of the containment remained. These lines lead to the containment foundation sump pump which was regularly sampled for contaminants. The containment drain sump was demolished to 3 feet belowgrade.

The ISFSI was designed, constructed, and loaded with fuel stored in casks during Phase 4. MYAPC storage of spent fuel in the ISFSI was originally anticipated to be regulated under a general license pursuant to 10 CFR Part 72, Subpart K. Therefore, MYAPC made the decision to store fuel only in fuel casks approved by the NRC as listed in 10 CFR 72.214. New boundaries were also required in the development of the ISFSI. The boundary required per 10 CFR 72 is at least 100 meters. The ISFSI itself covers about 8.5 acres, but an NRC security design basis threat evaluation led to the establishment of a perimeter extending 300 meters from the ISFSI (about 100 acres) as the controlled area. Following complete transfer of the spent fuel from the SFP to the ISFSI, MYAPC dismantled and demolished the SFP.

4.3.5 Decommissioning Issues/Approaches

The State of Maine required that MYAPC comply with a 4-mrem (0.04-mSv) per year drinking water limit and a 10-mrem (0.1-mSv) per year limit from all sources, lower than NRC's 25-mrem (0.25-mSv) per year radiological release criteria. The State of Maine also required additional long term monitoring, and the out-of-state disposal of decommissioning concrete waste. In order to fulfill the state requirements, the MY LTP called for the removal of all site structures to 3 feet belowgrade and the removal of all debris from the state (Reference 20).

The technology used for decontamination, dismantlement, and disposal is as follows:

Spent Fuel Pool Island

Systems and functions required to support the safe storage of spent fuel were redesigned, as necessary and consolidated into the Spent Fuel Pool Island (SFPI). Electrical power was provided from the 115KV incoming line with a backup diesel generator specifically for security, but available for the SFPI. An industrial water-to-air cooling system replaced the primary component cooling /service water systems that serviced the spent fuel pool cooling and clean up system. Makeup water is supplied from the primary water system tank with back up from the Wiscasset water supply and the fire protection service system. A portable mix tank and pump batches borated water when required in the make up for the spent fuel pool.

Large Component Removal (LCR)

- Steam Generator and Pressurizer Removal and Disposal

  Removal of the steam generators and the pressurizer was completed in 2000. The external surfaces were decontaminated as required, and all openings sealed-welded. These components served as their own transport containers and were shipped by barge to a waste vendor in Tennessee for processing.

- Shipment and Disposal of Primary System Parts Including Reactor Coolant Pumps

  The reactor coolant system and any other large bore piping was decontaminated and removed in accordance with the general decommissioning activities.

  The removal and shipment of the reactor coolant pumps was also fairly straightforward and accomplished without incident. All three RCPs were shipped by rail to the Barnwell, South Carolina, disposal facility in October 1999. The reactor coolant pump motors were shipped to the Clive, Utah, disposal facility at the same time (Reference 8).

- Reactor Vessel Internals Segmentation/Reactor Vessel Removal and Disposal

The segmentation of the reactor vessel internals was performed by abrasive water jet and mechanical cutting. The initial cutting activities began in November 2000. The initial estimate of weight was 363,000 pounds with 70% shipped with the reactor vessel, 20% shipped in casks and 10% (GTCC) stored in the ISFSI. The entire project was estimated to require 57 person-rem (0.57 person-Sv). The project ultimately required only 29 person-rem (0.29 person-Sv) to complete (Reference 8).

Full mockup testing was performed for the segmentation system at Framatome. MYAPC kept a consistent focus on maintaining water clarity. The segmentation approach was to cut the internals into larger sections. A special cask container was fabricated for fragments and larger pieces. This substantially reduced the number of required cuts, and thereby reduced debris and filings. A detailed CAD/CAM based plan was developed allowing for optimization of cask loading as well as requiring the fewest cuts, tool movements, and placement of pieces into cask. Approximately 2/3 of the cut internals were able to be put back into the reactor pressure vessel for subsequent disposal using the custom rigging equipment.

The RPV internals segmentation was performed in the flooded refueling cavity. Cavity penetrations were sealed to confine the cutting debris to the reactor cavity. Reactor cavity housekeeping and contamination controls were strictly maintained to prevent buildup of high radiation sources. In order to minimize cross contamination, the cutting was performed first on the least activated components and progressed to cutting the most highly activated materials. The RPV was removed in one piece, filled with grout, and transported by barge to Barnwell, SC for disposal (Reference 8).

The EPRI Decommissioning Report on Reactor Pressure Vessel Internals Segmentation provides a detailed discussion of the internals segmentation project (Reference 12).

Decontamination and System Dismantlement Activities

- Initial Characterization Surveys

Initial characterization surveys were used to group affected structures for method of continued processing. The operational history and the range of contamination determined during site characterization are summarized for the survey groups in Table 4.13.

- RCS Chemical Decontamination (Reference 10 through 11)

MYAPC decided to perform a chemical decontamination of the RCS prior to conducting major decommissioning activities. The chemical decontamination was a significant ALARA initiative being performed to reduce personnel exposure during decommissioning work activities. The Radiation Protection Manager estimated that RCS decontamination likely reduced the total project exposure by ~150 person-rem (1.5 person-Sv).

Table 4.13. Contamination Survey Results for Survey Groups

Group	Structures	Typical Activities
A	Affected Structures and Surfaces: Reactor Containment, Fuel, and Primary Auxiliary Buildings, as well as tanks containing radioactive liquids, electrical/mechanical penetration areas and concrete surface samples.	Surface activities range from 1000 to 100,000 dpm/100 cm^2. Exposure rates of 1 mrem/hr to over 1000 mrem/hr.
B	Unaffected Structures and Surfaces: Turbine Hall, sections of the Service Building, the Control Room, office spaces and various out buildings such as the Fire Pond Pump House, the warehouse, and the Bailey House/Barn.	Surface activities range from 1000 to 8600 dpm/100 cm^2. Exposure rates of 2 to 26 μR/hr.
C	Affected Systems: Radioactive systems such as the RCS, CVCS, ECCS, liquid and solid waste, containment ventilation and primary vents and drains.	Surface activities range from 35 to 500,000 dpm/100 cm^2. Exposure rates of 13 to 16 R/hr.
D	Unaffected Systems: Main steam, Feedwater, Compressed Air and Potable Water. [Note: Several of the systems crossed over to other groups where elevated readings were detected.]	Generally the lowest in activity of all those surveyed.
R	Radiologically Affected or Unaffected Environs: The group was broken down into 7 affected and 18 unaffected areas. Environs sampling covered all areas of the 820 acre site. Fifteen of the sample areas showed no detectable plant derived radioactivity. Ten of the areas had elevated readings requiring further evaluation and sampling. These surveys determined which land areas were non-impacted and which were impacted. This group also provided the information necessary to project waste volumes from contaminated soils.	Plant-derived radionuclides had been detected in estuary sediments as a result of permitted liquid releases by environmental samples taken at various times during plant operation. Minor contamination was located near storm drains adjacent to the RA. Contamination levels ranged from 1 to 11 pCi/g for ^{60}Co and 1 to 156 pCi/g for ^{137}Cs in the areas of known soil contamination from old leaks/spills.
E	Hazardous Materials on Structures, Systems, or Surfaces: Plant surfaces, structures, and systems such as protected area paint, transformer oils, pump oils, plant batteries, and asbestos-containing components.	Resolved in RCRA closure process Section 8.6.2 of the LTP (Reference 5).
H	Hazardous Material in Environs: Plant areas such as diesel oil tank loading area, transformers, yard drains, solid waste storage areas, drumming accumulation areas, parking lots, and roof drains.	Resolved in RCRA closure process Section 8.6.2 of the LTP (Reference 5).

The reactor vessel was bypassed by the installation of a flow-through nozzle dam assembly, called a spider, at the interface of the reactor coolant loops and the reactor pressure vessel. The steam generator tubes were bypassed by jumper and reduced flow rates (400–650 gpm) were used. Recirculation was provided by an external 600 gpm pump. External heating, ion exchange vessels, chemical addition, sampling, pump, and filtration were provided by the contractor (Reference 10).

The process included two separate applications or phases. Phase 1 included portions of RCS Loop 2 and 3, the letdown system, charging system, fill and drain system and pressurizer. Phase 2 included all three loops and the residual heat removal system. The process was begun on February 10, 1998 and was completed by March 7. This included two days to change over systems and two days for system clean-up at the end of the decontamination. A total of 11 cycles were applied in Phase 1 requiring 191 hours. Phase 2 completed a total of 13 cycles in 182 hours. The results of the project included:

- 102 curies of gamma-emitting activity were removed (98% ^{60}Co);
- 673 pounds of dissolved metals were removed (278 pounds of iron, 262 pounds of nickel, and 133 pounds of chromium);
- The decontamination factor (DF) over all points was 31, while the DF for points greater than 100 mR/h was 89; and,
- 535 ft^3 of ion exchange resin waste was generated from the decontamination with an additional 90 ft^3 of resin generated from the system deboration.

The subject of the RCS decontamination and RPV removal is addressed in detail in EPRI Reports (References 10 through 12).

- Hot Spot Reduction (Reference 8)

MYAPC viewed the reduction of radiation exposure for decommissioning as a significant objective for the overall project. Two early projects were initiated for the purpose of reducing the source term, or amount of radioactive material, in the plant to which decommissioning workers would be exposed. These two projects were Reactor Coolant System Decontamination (discussed above) and Hot Spot Reduction.

The hot spot reduction program intended to specifically identify the hot spots to allow them to be “surgically” removed, by cutting out the specific valve or piping section versus removal of entire lines or components in an area.

In order to accomplish this program, the systems were drained and taken out of service. Radiation surveys were conducted during plant operation noting general hot spots in plant cubicles, pipe chases and other areas. These hot spots were often at piping elbows, valve connection points, locations in piping with flow changes, and other locations. In order to avoid unnecessary exposure to technicians, these areas were only generally located. The primary purpose of these surveys was to identify the general area of elevated exposure rates to notify workers to avoid the area.

MY obtained a gamma camera (Gamma Cam) consisting of computer based video camera and radiation detection equipment. In use, the Gamma Cam would provide a black and white image of a monitored area with superimposed color areas. The color variations represent variations in radiation exposure rate. The images produced would allow clear identification of the highest activity sources in an area, which could then be removed. The site Radiation Protection Manager estimated that the hot spot reduction program likely reduced the total project exposure by ~150 person-rem (1.5 person-Sv).

- Decontamination Methods

Structure decontamination methods typically include wiping, washing, vacuuming, spalling, and abrasive blasting. Selection of the preferred method was based on the specific situation. If structural surfaces were washed to remove contamination, controls were implemented in accordance with approved plant procedures to ensure that wastewater was collected for processing by liquid waste processing systems. Airborne contamination control and waste processing systems were used as necessary to control and monitor releases.

Concrete that was activated was removed using diamond sire saw cutting down to the activated concrete DCGL and sent to a low-level radioactive waste disposal facility. Removal of contaminated (non-activated) concrete was performed using methods that control the removal depth to minimize the waste volume produced. Appropriate engineering controls for control of dust and debris were used to minimize the spread of contamination and reliance on respiratory protection measures using methods that control the removal depth to minimize the waste volume produced.

- Dismantlement Methods

Disassembly and cutting were the dismantlement methods used for contaminated systems. Disassembly generally means removing fasteners and components in an orderly non-destructive manner (i.e., the reverse of the original assembly). Abrasive water-jet cutting was used to segment the RPV internals.

Systems and components removed and released from the secondary side of the plant for commercial disposal were surveyed in accordance with plant procedures based upon a no detectable radioactivity standard. Generally, systems and components removed from the primary (radiologically controlled) side of the plant were packaged and either transported to an offsite processing facility, LLW disposal facility, or an appropriate disposal facility. Application of coatings and hand wiping may be used to stabilize or remove loose surface contamination. Potentially or slightly contaminated components (i.e., lighting ballast, mercury switches, etc.) were decontaminated onsite for release in accordance with plant radiological monitoring procedures for release.

Tanks and vessels were evaluated and, if required, flushed or cleaned to reduce contamination levels and remove sludge prior to sectioning and/or removal.

There are two categories of pipe: buried pipe and embedded pipe. Buried pipe was run underground, buried in a trench and surrounded by soil, whereas embedded pipe was encased in concrete. Treatment of buried pipe depended on results from the surveys associated with the RCRA closure process as to whether it was left in place, filled with inert material and left in place, or removed. If buried pipe was to remain, it was surveyed using the "pipe crawlers" to compare residual activity to the DCGLs or if the buried pipe was not expected to contain any residual activity, survey was only conducted at accessible portions of the pipe, intakes or outfalls. The majority of embedded pipe (~1000 feet) was removed when concrete was demolished to 3 feet belowgrade.

Explosive demolition was a viable alternative and was used in concert with mechanical demolition for the fuel building, spray building, containment structure, polar crane, and the turbine building. Explosives were used to reduce the demolition time by a factor of 3 to 5. This, however. was balanced against the increased costs for explosives use. It was essential to maintain strict security oversight of the transfer and accounting of all explosives onsite and necessary to include an explosives handler in the initial post-blast inspection entry team to identify and recover unexploded ordinance.

Table 4.14 summarizes the approach applied to the disposition of materials generated during the demolition of structures.

Table 4.14. Approach to Handling of Building Materials for Regulatory Release (Reference 5)

No.	Type of Building Material	Approach
1	Areas with low contamination potential	Free-release in accordance with procedures.
2	Concrete with medium to high surface contamination potential (at elevations above - 3 feet belowgrade)	Ship offsite for disposal at Utah or South Carolina or an appropriate disposal facility.
	Concrete with medium to high surface contamination potential (at elevations below - 3 feet belowgrade)	Remediate to acceptance criteria levels and leave in place, with removed material disposal at Utah or South Carolina.
3	Contaminated metals removed	Ship to processor or for disposal at Utah or South Carolina.
	Non-contaminated metals removed	Ship to processor for scrap or disposal.
4	Built-up tar roofing, inner layer of siding (with actual or potential contamination)	Process at LLW treatment facility or directly dispose at Utah.
	"Clean" tar roofing, siding	Ship to a processor or disposal.
5	Outer layer of siding (Galbestos)	Surface release survey; send to asbestos landfill.
6	Refueling cavity and spent fuel pool liners	Process at LLW treatment facility.

Decontamination and Disposition of Site Buildings

- Decontamination and Disposition Methods

  Review of the site indicated that many horizontal surface areas within the RCA had elevated surface contamination levels. Therefore, to reduce worker exposure and to avoid generation of new LLW through cross-contamination of the clean base materials from the contaminated surfaces, structural concrete surfaces were decontaminated before a structure was dismantled.

  Exposed faces of buildings and foundations were surveyed and decontaminated until the surface met or was below the release criteria. The subsurface foundations (i.e., those more than three feet below ground level) were decontaminated, as necessary, to meet the release criteria, and left in place as discussed previously.

  Characterization of concrete within the Restricted Area (RA) of the site showed the following (Reference 5):

  1. Painted concrete had surface contamination up to 1 million dpm/100 cm^2 (worst case) which was amenable to surface remediation techniques such as wiping, washing, power washing or abrasive surface removal.

  2. Bare concrete had surface contamination, absorbed contamination and activation products within the concrete matrix. Surface contamination levels were similar to those for painted concrete. Absorbed activity was found to penetrate to a depth of approximately 1 mm.

  3. Concrete structures adjacent to the reactor vessel also showed activation products at levels of a few pCi/g except for the In Core Instrumentation (ICI) sump where levels were as high as 600–800 pCi/g to depths of several inches. These types of radioactivity were amenable to remediation by surface removal techniques except for the deeply deposited activation products.

  4. Because surface abrasive or surface removal remediation techniques may generate airborne radioactivity, airborne activity was controlled within the requirements of 10 CFR Part 20 and measured using standard processes and procedures existing within the radiation protection program. These processes and procedures were successful for controlling decontamination and demolition activities in the past while protecting the health and safety of the workers and the public.

- Containment Building Demolition

  The demolition of the MY containment was carried out using standard dismantlement techniques and explosive charges. The focus was on safety for workers, public and nearby structures, especially the spent fuel pool. Demolition was completed in September 2004.

Blast loads considered included the explosive demolition of the arches and the development of a high pressure air pocket under the containment dome as it collapsed after the arch demolition. The demolition sequence was therefore designed to progress circumferentially to allow the dome to tilt and land on edge. The dome and remaining portion of the containment were estimated to weigh 10,450 tons. On September 17, 2004 the containment building was safely demolished with explosives. This demolition resulted in approximately 20 million pounds of rubble (Reference 8).

Source Disposal

MY had a plutonium-beryllium (Pu-Be) neutron source which posed a special disposition challenge. In the case of MY, they received a legal opinion that this source was not “associated with the fuel.” As such, it could not be disposed of in a dry cask system canister. The source activity was such that it could also not be disposed of in available low-level waste burial sites. MYAPC then applied to the DOE orphan source program. Ultimately, this was successful, but the source disposal required four years of interaction with DOE to accomplish (Reference 8).

Asset Recovery

MYAPC sold the emergency diesel generators to a mid-west utility on June 7, 1999. The site main power transformers were shipped offsite by barge to a Midwest utility in October 1999 (Reference 8).

4.3.6 Non-Decommissioning Fund Activities

ISFSI

The PSDAR assumed dry cask storage of the spent fuel. However, MYAPC solicited public input on the spent fuel storage selection decision (i.e., continued storage in the spent fuel pool or dry storage). The selection process took longer than anticipated and resulted in delays to the spent fuel transfer project. In addition, the DOC was originally contracted to construct the ISFSI pad. When the DOC contract was cancelled, MYAPC subcontracted separately for the construction of the ISFSI pad. At this time, MYAPC also took over the DOC subcontract with the fuel cask provider in May 2000 and in late 2000 extended the scope to include fuel transfer activities. The selected dry cask system was the NAC-UMS Transportable Storage Canister system, a multi-purpose canister system designed to contain 24 spent fuel assemblies. At the time of selection, the vendor had not yet received certification by the NRC. In January 2003, MYAPC terminated the contract with the cask provider and a new contract with the cask provider was issued in April 2003, resulting in further delays in the fuel transfer project (Reference 8).

The loading and transfer of GTCC materials to the ISFSI pad began in January 2002. On August 24, 2002, with assistance from the cask contractor, MYAPC transferred the first of 60 spent fuel canisters for storage at their ISFSI. After loading the canister with spent fuel, a shield lid was welded on and the canister was pressure-tested, dewatered, and vacuum dried. The canister was then backfilled with helium, the vent and drain ports were sealed, the canister was leak-tested, and a structural lid was welded onto the canister. The canister was then placed into a vertical concrete cask for shielding and transferred to the ISFSI concrete storage pad. In January 2003, MYAPC terminated the contract with the cask provider and a new contract with the cask provider was issued in April 2003, resulting in further delays in the fuel transfer project. Fuel transfer activities concluded in late February 2004. A total of 60 spent fuel canisters and four GTCC canisters were stored on the ISFSI pad. The average cask loading rate for the MY team was just under eight calendar days per canister with those toward the end of the project being loaded and transferred in approximately five days (Reference 8).

Failed Fuel Assemblies

Because MY had fuel failure issues early in plant operation, the plant needed a contingency program to deal with any fuel fragments/pellets found. This contingency program dealt with both radiological and safeguards issues. This inspection and verification program was conducted prior to any fuel canister loading could be performed. Of the total 1436 fuel assemblies that were transferred to the ISFSI, nearly 300 of them were considered “non-standard” fuel by virtue of actual or potential fuel failures. Specific reviews were essential with the dry cask system provider to assure the canister/cask system was correctly licensed for all the materials to be stored within, including GTCC and non-standard fuel (Reference 8).

4.3.7 Soil and Groundwater Remediation

The initial site characterization process focused on providing both shutdown and current data for structures, systems, radiological environs, and hazardous materials environs. The extent and range of contamination were reported for structures, systems, drains, vents, embedded piping, paved areas, water, and soils. In addition, activation analyses were performed on key components within the restricted area to estimate radioactive waste volumes and classes.

Soil Remediation

Soil received scan surveys at the pre-defined coverage levels and volumetric samples at designated locations as described in Reference 5. Surface soil samples were taken at a depth of 0 to 15 cm. The possibility of sub-surface contamination was considered during the survey design process and the survey design package. Samples were collected and prepared in accordance with approved procedures.

Open land areas were scanned for gamma-emitting nuclides. Sodium iodide detectors were used for scanning. The detector was held within a few centimeters of the ground surface and was moved at a speed of 0.25 m/sec, traversing each square meter five times. The area covered by scan measurements was based on the survey unit classification.

Soil materials were analyzed by gamma spectroscopy. Soil samples of approximately 1500 grams were collected from the surface layer (top 15 cm). If contamination below 15 cm was suspected, split spoon sampling or other methods, were used for the final survey unless the area had already been excavated and remediated to the deep soil DCGL. If an area containing subsurface contamination had been remediated, the excavated area was treated as a surface soil.

Major areas of soil remediation included the primary water storage tank (PWST), refueling water storage tank (RWST), shielded radioactive waste storage area, forebay area (intake and discharge of water for MY) and yard west area (areas south and west of the former reactor building). Soil was remediated to meet the DCGLs. The total volume of remediated contaminated soil was estimated to be 25,000 ft^3 in the LTP.

Groundwater Monitoring

The groundwater regime at the MY facility is comprised of two aquifers: 1) a discontinuous surficial aquifer in the unconsolidated glaciomarine soils and fill material; and 2) a bedrock aquifer. The surficial aquifer is not present continuously across the site, as the overburden soils are thin to nonexistent in some portions of the site. This is especially true in the southern portion of Bailey Point. The bedrock aquifer is present below the entire site and vicinity.

During plant operation, impacts to the groundwater flow regime were limited to draw-down of the groundwater surface caused by foundation drains around the containment structure and, to a lesser extent, draw-down caused by active water supply wells.

A separate calculation was developed for existing groundwater. Potential additional groundwater contributions from other contaminated materials were included in the applicable dose calculation. The groundwater dose was calculated from the highest individual groundwater sample result from site monitoring wells. The only nuclide identified in site groundwater is ^{3}H with a maximum concentration of 6812 pCi/l. The dose was calculated using the 478 l/y intake and the FGR-11 dose conversion factors.

No groundwater remediation of the MY site was required. While not required by the NRC, MYAPC agreed with the State of Maine to provide groundwater monitoring of the former MY site for five years following completion of site remediation activities to demonstrate that the decommissioning radiological cleanup criteria were met (Reference 22).

Surface Water Monitoring

The only sources of site surface water were the fire pond and the reflecting pond. No plant derived nuclides were identified in the fire pond, so only the reflecting pond was evaluated in the dose assessment. Tritium was identified in the reflecting pond at a maximum value of 960 pCi/l. Although this likely is a background level, the doses were likewise calculated for this input. In addition to direct water intake, a potential pathway is fish ingestion. The dose was calculated by combining the water intake result (obtained as in the groundwater calculation above), and using the fish consumption rate and a water-to-fish contamination transfer rate of 1.

In the forebay sediment the initial characterization noted positive results for ^{60}Co from 0.04–11.2 pCi/g and for ^{137}Cs from less than the minimum detectable activity to 0.53 pCi/g. The minimal sediment that exists is found between rocks on the canal dikes and at low tide. The small sediment volume is reasonable considering the high water flow through the canal during plant operations. Additional characterization noted the following:

- ^{60}Co – 31.7 pCi/g
- ^{55}Fe – 13.6 pCi/g

- ^{63}Ni – 8.9 pCi/g
- ^{137}Cs – 1.2 pCi/g
- ^{125}Sb – 0.4 pCi/g.

The dose assessment assumed an inch layer of sediment at the base of 2-foot diameter rocks with an individual standing on or walking over the rocks. The pathways to consider were direct exposure and ingestion. Inhalation was deemed not reasonable as the sediment is either submerged or wet at all times. Resultant doses were approximately eight times lower than the soil exposure contributions.

4.3.8 Radioactive Waste Volumes and Activity

This section provides the total volume of LLW generated from the decommissioning of MY that was shipped offsite, to either direct disposal or to waste processors, and the total volume of LLW that was shipped directly to disposal. The volume shipped for disposal is compared to the LLW volume assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

LLW Volume and Activity Shipped Offsite

The volume and activity of radwaste generated and shipped offsite during the MY decommissioning project is provided in Table 4.15. This data were principally derived from the Annual Radioactive Effluent Release Reports for MY (References 15 through 18). These reports provide the volume and activity of Class A, B, and C LLW shipped annually from the MY site. However, these annual reports were not available for the years 1998, 2000, 2001, and 2003. For these years, the total volume of LLW shipped was estimated using the weight of radioactive waste shipped annually reported in Table E-1 of the EPRI Experience Report (Reference 8). The total quantity of waste reported and estimated to have been shipped offsite is 1.4E+05 m^3, or 4.8E+06 ft^3. The total activity of the shipped radioactive waste was reported to be 1.0E+03 Ci, which does not include the activity of waste shipped in years 1998, 2000, 2001, and 2003. Since significant activity was shipped offsite during these missing years, including the RPV in 2003, this total activity is extremely low compared to what was actually shipped. This is shown below in the discussion of the volume of activity disposed of at low-level waste disposal sites.

Table 4.16 provides the number of shipments required to transport the radwaste reported in Table 4.15. This data was taken principally from the Annual Radioactive Effluent Release Reports for MY (Reference 15 through 18), with data gaps for years 1998, 2000, 2001, and 2003 filled in with data provided in Table E-1 of the EPRI Experience Report (Reference 8). As can be seen in the table, shipments were generally by truck to the Barnwell disposal facility and to LLW processors, whereas shipments to the Clive, Utah, disposal facility were generally by train.

Table 4.15. Radwaste Volume and Activity Generated During MY Decommissioning[(a)]

	Class A		Class B		Class C		Total[(b)]	
Year Received	Volume (m^3/ft^3)	Activity (Ci)	Volume (m^3/ft^3)	Activity (Ci)	Volume (m^3/ft^3)	Activity (Ci)	Volume (m^3/ft^3)	Activity (Ci)
1998[3]	NA[(c)]	NA	NA	NA	NA	NA	476	NA
							16,815	
1999	2,772	61	4	24	5	119	2,782	204
	97,890		154		186		98,232	
2000[(d)]	NA	NA	NA	NA	NA	NA	7,091	NA
							250,433	
2001[(d)]	NA	NA	NA	NA	NA	NA	4,357	NA
							153,874	
2002	8,307	199	9	478	4	12	8,320	689
	293,359		322		126		293,807	
2003[(e)]	NA	NA	NA	NA	NA	NA	19,852	NA
							701,076	
2004	52,900	32	7	76	0	0	52,907	108
	1,868,164		245		0		1,868,391	
2005	39,500	6	0	0	0	0	39,500	6
	1,394,929		0		0		1,394,929	
Total[(f)]	**103,479**	**298**	**20**	**578**	**9**	**131**	**135,285**	**1,007**
	3,654,326		**722**		**312**		**4,777,558**	

(a) Information is from MY Annual Radioactive Effluent Release Reports (References 15 through 18). Similar information is not available for 1998, 2000, 2001, and 2003.

(b) The total volume was estimated using weight information from the EPRI Experience Report (Reference 8) and an average waste density estimated for 1999. The year 1999 density was used since no contaminated concrete or soil was shipped in either 1998 or 1999.

(c) NA = information not available.

(d) The total volume was estimated using weight information from the EPRI Experience Report (Reference 8) and average waste densities estimated for 1999 and 2002. The year 2002 density was used to estimate the volume of contaminated concrete while the year 1999 density was used to estimate the volume of other radwaste. The year 1999 density was used for other radwaste since no contaminated concrete or soil was shipped in 1999 and the year 2002 density was used for contaminated concrete since the volume of contaminated concrete represented a large portion (about 85%) of the total radioactive waste shipped.

(e) The total volume was estimated using weight information from the EPRI Experience Report (Reference 8) and an average waste density estimated for 2002. The year 2002 density was used since the volume of contaminated concrete and soil for both 2002 and 2003 represented a similar portion (about 86% for 2002 and 88% for 2003) of the total radioactive waste shipped.

(f) Totals may not add due to rounding.

Table 4.16. Number of Radwaste Shipments and Mode of Transport[a]

Year Received	Barnwell Waste Management Facility	Clive, Utah (Energy*Solutions* Facility)		LLW Processor	Total	
	Truck	Truck	Train	Truck	Truck	Train
1998[b]	NA	NA	NA	NA	21	0
1999	18	1	2	55	74	2
2000[b]	NA	NA	NA	NA	96	5
2001[b]	NA	NA	NA	NA	102	11
2002	5	8	35	2	15	35
2003[b]	NA	NA	NA	NA	10	40
2004	2	7	670	0	9	670
2005	0	2	502	1	3	502
Total	**99**	**18**	**1,209**	**58**	**309**	**1,265**

(a) Information is generally from MY Annual Radioactive Effluent Release Reports (References 15 through 18). Similar information is not available for 1998, 2000, 2001, and 2003.
(b) Information is from the EPRI Experience Report (Reference 8).

LLW Volume and Activity Directly Shipped to a Disposal Facility

Table 4.17 reports the volume and activity of LLW generated from the decommissioning of MY and shipped directly to commercial LLW disposal sites for disposal. This information was obtained from the DOE MIMS, which is a database of LLW information derived from the manifests for waste shipments as reported to the DOE by each of the commercial LLW disposal sites (Reference 19). The information provided in Table 4.17 is only that LLW shipped directly from the MY site to the LLW disposal facility. It does not include LLW shipped from radwaste vendors after processing. Note that the data in Table 4.17 shows a small volume of LLW arriving at the LLW disposal facilities in 2006 even though the MY decommissioning project ended in 2005. It is unclear the reason for this discrepancy with the waste shipment data in Tables 4.15 and 4.16; however, one potential explanation is that while the shipments was made in 2005 they were not actually processed until 2006.

Based on the information in Tables 4.15 and 4.17, the following observations are made:

- The 36,000 Ci of Class C LLW shown to have been shipped to the Barnwell facility in 2003 corresponds to the RPV shipment that was made that same year. This is in good agreement with the EPRI RPV segmentation experience report (Reference 12) which estimated that 2% of the activity, or about 39,000 Ci, associated with the RPV segmented internals would be disposed of with the RPV. Table 4.17 also reports that 111,000 Ci of Class C LLW was disposed of at the Barnwell facility in 2001. This is believed to be RPV segmented internals that were packaged and shipped separately in casks. The 111,000 Ci is less than half that reported in the EPRI RPV segmentation experience report (Reference 12) which estimated that 15% of the activity, or about 295,000 Ci, associated with the RPV segmented internals would be disposed of as LLW separately from the RPV.

Table 4.17. LLW Volume and Activity Received at LLW Disposal Sites[(a)]

Disposal Site	Year Received	Class A Volume (m^3/ft^3)	Class A Activity (Ci)	Class B Volume (m^3/ft^3)	Class B Activity (Ci)	Class C Volume (m^3/ft^3)	Class C Activity (Ci)	Total Volume (m^3/ft^3)	Total Activity (Ci)
Clive, Utah	1998	0 0	0	0 0	0	0 0	0	0 0	0
	1999	124 4,385	0	0 0	0	0 0	0	124 4,385	0
	2000	1,377 48,615	0	0 0	0	0 0	0	1,377 48,615	0
	2001	2,358 83,289	7	0 0	0	0 0	0	2,358 83,289	7
	2002	8,621 304,461	316	0 0	0	0 0	0	8,621 304,461	316
	2003	10,809 381,710	96	0 0	0	0 0	0	10,809 381,710	96
	2004	41,049 1,449,634	48	0 0	0	0 0	0	41,049 1,449,634	48
	2005	32,349 1,142,410	48	0 0	0	0 0	0	32,349 1,142,410	48
	2006	96 3,400	0	0 0	0	0 0	0	96 3,400	0
	Total	**96,784** **3,417,904**	**517**	**0** **0**	**0**	**0** **0**	**0**	**96,784** **3,417,904**	**517**
Barnwell, SC	1998	38 1,351	157	40 1,403	892	0 2	0	78 2,756	1,049
	1999	84 2,983	45	3 103	19	5 183	119	93 3,269	183
	2000	17 588	20	2 70	13	14 494	2,640	33 1,152	2,674
	2001	28 995	507	11 372	83	30 1,062	110,694	69 2,430	111,284
	2002	9 322	173	13 450	486	7 252	37	29 1,024	696
	2003	0 0	0	4 132	53	274 9,662	35,937	277 9,794	35,990
	2004	0 0	0	3 120	39	4 148	56	8 269	95
	2005	0 0	0	0 0	0	0 0	0	0 0	0
	2006	0 0	0	0 0	0	0 1	0	0 1	0
	Total	**177** **6,239**	**902**	**75** **2,652**	**1,586**	**334** **11,804**	**149,483**	**586** **20,695**	**151,971**

Table 4.17. (contd)

Disposal Site	Year Received	Class A Volume (m³/ft³)	Class A Activity (Ci)	Class B Volume (m³/ft³)	Class B Activity (Ci)	Class C Volume (m³/ft³)	Class C Activity (Ci)	Total Volume (m³/ft³)	Total Activity (Ci)
Total	1998	38	157	40	892	0	0	78	1,049
		1,351		1,403		2		2,756	
	1999	209	45	3	19	5	119	217	183
		7,368		103		183		7,654	
	2000	1,393	21	2	13	14	2,640	1,409	2,674
		49,203		70		494		49,767	
	2001	2,387	515	11	83	30	110,694	2,427	111,291
		84,284		372		1,062		85,718	
	2002	8,630	489	13	486	7	37	8,650	1,012
		304,783		450		252		305,485	
	2003	10,809	96	4	53	274	35,937	11,086	36,087
		381,710		132		9,662		391,504	
	2004	41,049	48	3	39	4	56	41,057	144
		1,449,634		120		148		1,449,903	
	2005	32,349	48	0	0	0	0	32,349	48
		1,142,410		0		0		1,142,410	
	2006	96	0	0	0	0	0	96	0
		3,400		0		1		3,401	
TOTAL		**96,961**	**1,420**	**75**	**1,586**	**334**	**149,483**	**97,370**	**152,489**
		3,424,143		**2,652**		**11,804**		**3,438,598**	

(a) Information is from the DOE Manifest Information Management System (Reference 19).

- The total activity disposed of at LLW disposal facilities is 152,000 Ci. Since complete information was not available on the activity of waste shipped from the MY site, no comparison of the two quantities is possible.

- The total volume of LLW disposed of at both the Clive, Utah, and Barnwell disposal facilities is reported to be 3.4E+06 ft^3 (9.7E+04 m^3), implying about 1.4E+06 ft^3 (3.8E+04 m^3) was shipped to radwaste vendors for further processing and disposal. This represents about 72% of the total volume of 4.8E+06 ft^3 (1.4E+05 m^3) reported/ estimated as having been shipped from the MY site during decommissioning.

- The total volume of LLW disposed of at the Clive, Utah, disposal facility is reported to be 3.4E+06 ft^3 (9.7E+04 m^3). This represents about 71.5% of the total volume of 4.8E+06 ft^3 (1.4E+05 m^3) reported/estimated as having been shipped from the MY site during decommissioning.

- The total volume of LLW disposed of at the Barnwell disposal facility is reported to be 2.1E+04 ft^3 (5.9E+02 m^3). This represents about 0.4% of the total volume of 4.8E+06 ft^3 (1.4E+05 m^3) reported/estimated as having been shipped from the MY site during decommissioning.

- The total volume of Class B and C LLW disposed of at the Barnwell disposal facility is reported to be 2.7E+03 ft^3 (75 m^3) and 1.2E+04 ft^3 (3.3E+02 m^3), respectively. The volume of Class B waste is about 22% of the volume of Class C waste disposed.

The total volume of LLW generated from the decommissioning of MY and shipped for disposal as LLW was estimated in the PSDAR to be 209,000 ft^3 (5,920 m^3), which is substantially less than the LLW volume actually shipped directly to disposal. The reason the volume actually shipped is significantly higher is principally a result of the decision to demolish all buildings to an elevation equivalent to 3 feet belowgrade and dispose of the demolition debris from the RCA at a LLW disposal facility or other appropriate disposal facility. Another reason for the increase is the enhanced state cleanup standards that established more restrictive cleanup levels than the NRC regulations (References 5 and 6).

A comparison of Tables 4.15 and 4.17 shows that the annual and total activity, for those years in which complete data are available, is generally lower for that LLW shipped offsite than for that reported as being received at the LLW disposal facilities. There is insufficient information to determine the reasons for this discrepancy. On the other hand, the annual and total volumes shipped are higher than the total volumes disposed to LLW facilities. This is to be expected since some wastes were shipped to waste processors for treatment prior to disposal. This is discussed further below.

Decommissioning LLW Volume Comparison to Minimum Decommissioning Fund Requirements

The cost basis for the 10 CFR 50(c) minimum decommissioning fund formula includes assumptions with regard to the volume of LLW generated during decommissioning. The cost bases and assumptions for the formula are provided in NUREG/CR-0130 (Reference 25) and subsequent Addendums 3 and 4 to that report (References 26 and 27). The volume of LLW assumed in the formula is provided in Table 4.18, which provides a breakdown of the total LLW volume generated/shipped and the LLW volumes assumed to be shipped to the Barnwell disposal facility, to the Clive, Utah, disposal facility, and to waste processors. Table 4.18 also provides a comparison of the formula LLW volume assumptions to the actual LLW volumes generated during decommissioning of MY, as summarized from Tables 4.15 and 4.17. The following observations are made:

- The total volume reported/estimated shipped from the MY site is a factor of 7.4 greater than that assumed in the formula. As was discussed previously, much of the higher volume is a result of the decision to demolish all buildings to an elevation equivalent to 3 feet belowgrade and dispose of the demolition debris from the RCA at an LLW disposal facility or other appropriate disposal facility. Another reason for the increase is the enhanced state cleanup standards that established more restrictive cleanup levels than the NRC regulations (References 5 and 6). The cost basis for the formula assumes that contaminated surfaces are decontaminated and that demolition of the remaining uncontaminated structures is not a decommissioning activity, but rather a post-decommissioning site restoration activity.

Table 4.18. Comparison of Formula and Actual LLW Volumes

LLW Shipped/Received	Formula Volumes m^3	Formula Volumes ft^3	Actual Volumes m^3	Actual Volumes ft^3
Total Volume Shipped[(a)]				
Class A	17,964	634,392	134,979	4,766,726
Class B	214	7,564	76	2,700
Class C	17	600	327	11,533
GTCC	133	4,700	0	0
Total	**18,328**	**647,256**	**135,382**	**4,780,959**
Volume to Barnwell Disposal Facility				
Class A	982	34,675	177	6,239
Class B	116	4,100	75	2,652
Class C	17	600	334	11,804
GTCC	133	4,700	0	0
Total	**1,248**	**44,075**	**586**	**20,695**
Percentage		6.8%		0.4%
Volume to Clive, Utah, Disposal Facility				
Class A	16,982	599,717	96,784	3,417,904
Class B	98	3,464	0	0
Class C	0	0	0	0
GTCC	0	0	0	0
Total	**17,080**	**603,181**	**96,784**	**3,417,904**
Percentage		93.2%		71.5%
Volume to Waste Processors				
Class A	0	0	38,018	1,342,583
Class B	0	0	0	0
Class C	0	0	0	0
GTCC	0	0	0	0
Total	**0**	**0**	**38,018**	**1,342,583**
Percentage		0.0%		28.1%

(a) The total actual volume shipped has been adjusted using data in Table 4.15 to compensate for missing data. Specifically, data from Table 4.17 for years 1998, 2000, 2001, and 2003 was assumed to be the volume and activity shipped values for Class B and Class C waste and the activity shipped values for Class A waste for these same years. The Class A volumes for years 1998, 2000, 2001, 2003 were calculated as the difference between the total values provided in Table 4.15 and the sum of the surrogate values for Class B and Class C waste. The year 2006 data from Table 4.17 was also assumed to be the shipped data for 2006.

- The total volume of LLW disposed of at the Barnwell facility is a factor of 2.1 higher for the formula than the actual volume disposed. However, the actual volume of Class B and C waste disposed of at Barnwell is about 50% greater than that assumed in the formula (Class B, Class C, and GTCC waste).

- The cost basis for the formula assumed that the GTCC waste is disposed of at the Barnwell facility as LLW. GTCC waste is actually being stored at the ISFSI for later disposal. Disposition of GTCC waste is no longer considered a decommissioning cost.

- The actual volume of LLW disposed of at the Clive, Utah, facility is a factor of 5.7 higher than assumed in the formula. The formula also assumes a small volume of Class B waste goes to the Clive, Utah, facility for processing and disposal, while no Class B wastes were actually sent to this facility from the MY decommissioning project. It is recognized that the Clive, Utah, disposal facility cannot dispose of Class B LLW; however, it is assumed that this small volume can be processed/treated and appropriately dispositioned.

- The current cost basis for the formula does not assume any of the LLW is shipped to waste processors for treatment and/or alternate disposal. The actual volume of LLW shipped to waste processors represents about 28% of the total volume shipped from the MY site.

4.3.9 Cost of Decommissioning and License Termination

This section provides the decommissioning cost estimated by the licensee prior to the start of significant decommissioning activity and the actual decommissioning cost incurred by the licensee to decommission MY. The actual decommissioning cost incurred is also compared to the decommissioning cost assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

Estimated Decommissioning Cost

Table 4.19 provides a breakdown of the estimated cost to decommission MY as provided in the PSDAR (Reference 1). The total cost to complete radiological decommissioning was estimated to be $275 million (1997). A site-specific decommissioning cost estimate and PSDAR were subsequently updated in Revision 1 of the PSDAR and the updated costs summarized in LTP, Rev. 0 (Reference 2), which is also provided in Table 4.19 for comparison. As can be seen, the cost of radiological decommissioning increased from $275 million to $343 million. Spent fuel management costs also increased, from $53 million to $129 million. Insufficient information was available to ascertain the reasons for these estimated cost increases. Potential reasons include the award of a fixed price contract for a DOC to perform the decommissioning and the determination that a significant number of non-standard spent fuel assemblies (approximately 20% of the total) needed to be transferred to the ISFSI.

Actual Decommissioning Cost

The actual costs to decommission MY are shown in Table 4.20 (Reference 21). The same costs adjusted to 2010 dollars are shown in Table 4.21. The actual total cost incurred of $509 million (including radiological decommissioning, spent fuel management, and site restoration) would be less than the total cost of $508 million estimated in the LTP if both costs were put into the same year dollars. The cost of radiological decommissioning, or plant dismantlement, is essentially the same after accounting for the costs being in different year dollars, while the actual incurred costs of spent fuel management and site restoration are less than what was estimated in the LTP.

Table 4.19. Decommissioning Cost Estimates

Decommissioning Activity	Cost ($)[a] PSDAR	LTP, Rev. 0
Staffing	119,496,000	91,128,000
Decommissioning Planning Activities	3,555,000	Not Provided
Equipment Removal	43,375,000	44,310,000
Decontamination Activities	6,032,000	6,376,000
LLW Packaging and Shipping	13,683,000	16,663,000
LLW Burial	83,702,000	64,816,000
Other Costs[b]	4,988,000	59,719,000
Contingency	Not Provided	60,265,000
Subtotal – Radiological Decommissioning	274,932,000	343,279,000
Staffing and Security	Not Provided	33,179,000
Property Taxes	Not Provided	25,445,000
Construction Costs	Not Provided	52,249,000
NRC and State Fees	Not Provided	10,093,000
Insurance	Not Provided	3,018,000
Other Costs	Not Provided	4,683,000
Subtotal – Spent Fuel Management[c]	53,395,000	128,677,000
Licensing Termination Survey	Not Provided	10,701,000
Major Component Removal	Not Provided	10,805,000
Close-out Activities	Not Provided	3,222,000
Demolition of Site Buildings	Not Provided	10,973,000
Subtotal – Site Restoration (Greenfielding)	49,251,000	35,701,000
Total Decommissioning Estimate[d]	**377,578,000**	**508,000,000**

(a) Costs are in 1997 dollars.
(b) Includes insurance, property taxes, energy, and NRC and State fees.
(c) Interim storage of used fuel was assumed to be in an independent dry cask storage facility.
(d) Costs may not sum to total due to rounding.

The spike in program management costs in 2000 appears to be a temporary transition of DOC staff to MYAPC following termination of the DOC contract. The negative plant dismantlement program management cost in 2001 and negative dry fuel storage cost in 2004 is due to a credit received from the settlement of DOC contract termination because of non-performance.

The total cost of $509 million to complete decommissioning of MY is actually somewhat higher than this total due to the significant credits associated with settlement of the lawsuit against the DOC. The DOC contractor earned a total of $47.6 million from 1998 to 2001 before the contract was terminated. MYAPC received a performance and payment bond settlement in 2001 for $44 million (Reference 23), which was accounted for as a credit in the program management cost category for plant dismantlement as described above. As a result of litigation against the DOC, MYAPC received a further settlement of $25 million in 2003 through 2005, which was accounted for as a credit in the dry fuel storage cost category also described above. After accounting for a total DOC litigation cost of about $4.5 million from 2000 through 2005, which

Table 4.20. Decommissioning Costs by Year (Millions of Dollars)

PSDAR Description	Cost Category	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total
Plant Dismantlement	Decontamination	0.3	16.6	30.4	10.2	3.4	0.6	0.3	0.0	0.0	61.8
	Component Removal	0.0	0.0	0.0	4.6	5.9	4.8	0.0	0.0	0.0	15.3
	Waste (Packaging, Transport & Disposal)	0.0	0.0	0.0	1.3	20.1	17.4	18.6	21.1	16.7	95.2
	Program Management	0.0	13.6	22.9	42.1	-16.4	26.7	19.4	14.8	2.5	125.6
	Insurance	0.0	0.7	0.9	0.7	0.5	1.5	1.3	0.9	0.1	6.7
	Property Taxes	0.0	0.0	4.2	2.8	1.8	1.2	1.1	1.1	0.0	12.1
	Regulatory	0.0	1.3	1.4	1.9	2.6	1.6	1.4	1.0	0.2	11.3
	Site Remediation/Restoration	1.7	0.7	0.0	0.0	9.2	11.2	11.2	9.9	1.4	45.3
	Final Status Survey	0.0	0.0	0.0	0.4	1.4	2.2	1.9	3.1	2.4	11.3
Plant Dismantlement Total		2.0	32.9	59.8	63.9	28.7	67.1	55.1	51.9	23.3	384.6
Fuel Management	Dry Fuel Storage	0.0	0.2	6.8	25.0	27.1	12.3	8.4	-9.9	0.0	69.9
	Program Management	0.0	7.3	4.5	3.3	4.0	7.2	6.4	1.4	0.2	34.4
	Insurance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Property Taxes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.6	1.6
	Regulatory	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.5
Fuel Management Total		0.0	7.5	11.4	28.4	31.4	19.5	14.8	-7.6	0.9	106.4
Site Restoration	Decontamination	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.7
	Program Management	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
	Insurance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Regulatory	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.5
	Site Remediation/Restoration	0.0	0.0	0.0	0.1	1.2	3.2	7.3	2.8	2.0	16.5
Site Restoration Total		0.0	0.0	0.0	0.7	1.2	3.2	7.3	3.5	2.0	17.9
Grand Total		**2.0**	**40.4**	**71.2**	**93.0**	**61.3**	**89.7**	**77.3**	**47.8**	**26.2**	**508.9**

Table 4.21. Decommissioning Costs by Year (Millions of 2010 Dollars)

PSDAR Description	Cost Category	1997	1998	1999	2000	2001	2002	2003	2004	2005	Total
Plant Dismantlement	Decontamination	0.4	25.2	44.4	14.5	4.7	0.7	0.4	0.1	0.0	90.3
	Component Removal	0.0	0.0	0.0	6.4	8.0	6.3	0.1	0.0	0.0	20.8
	Waste (Packaging, Transport & Disposal)	0.0	0.0	0.0	1.8	27.4	22.9	23.7	26.0	19.9	121.7
	Program Management	0.0	20.5	34.1	59.8	-22.0	35.4	25.0	18.3	3.0	174.0
	Insurance	0.0	1.0	1.3	0.9	0.7	1.9	1.6	1.1	0.1	8.6
	Property Taxes	0.0	0.0	6.2	3.9	2.5	1.5	1.3	1.4	0.0	16.8
	Regulatory	0.0	1.9	2.1	2.7	3.6	2.1	1.8	1.2	0.3	15.5
	Site Remediation/Restoration	2.6	1.1	0.0	0.0	12.6	14.7	14.2	12.1	1.7	59.0
	Final Status Survey	0.0	0.0	0.0	0.5	2.0	2.9	2.4	3.8	2.8	14.3
Plant Dismantlement Total		3.1	49.7	88.1	90.5	39.4	88.5	70.4	63.9	27.7	521.2
Fuel Management	Dry Fuel Storage	0.0	0.3	10.0	35.4	37.0	16.2	10.6	-12.1	0.1	97.3
	Program Management	0.0	12.2	6.6	4.7	5.5	9.4	8.2	1.7	0.2	48.6
	Insurance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Property Taxes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.8	1.9
	Regulatory	0.0	0.0	0.0	0.1	0.4	0.1	0.0	0.0	0.0	0.6
Fuel Management Total		0.0	12.5	16.6	40.1	42.8	25.7	18.9	-9.3	1.1	148.4
Site Restoration	Decontamination	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9
	Program Management	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
	Insurance	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Regulatory	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.7
	Site Remediation/Restoration	0.0	0.0	0.0	0.2	1.6	4.2	9.0	3.4	2.3	20.7
Site Restoration Total		0.0	0.0	0.0	1.0	1.6	4.2	9.0	4.3	2.3	22.4
Grand Total		**3.1**	**62.2**	**104.7**	**131.7**	**83.8**	**118.3**	**98.3**	**58.8**	**31.1**	**692.0**

was included in the cost of plant dismantlement, the net credit is about $17 million ($44 million + $25 million – $47.6 million – $4.5 million). Clearly this credit would be further offset by lost efficiencies from work slowdowns that would have occurred during the period in which MYAPC was taking over performance of the DOC work scope. Nevertheless, just based on these numbers and not accounting for lost efficiencies, the total actual cost of decommissioning MY would appear to be about $573.4 million ($508.9 million + $44 million + $25 million – $4.5 million). Correspondingly, the actual cost of radiological decommissioning is about $424.1 million ($384.6 million + $44 million – $4.5 million). In 2010$ the total cost of decommissioning MY would be about $777.2 million ($692 million + $60.1 million + $31.2 million – $6.1 million), and the cost of radiological decommissioning would be about $575.2 million ($521.2 million + $60.1 million – $6.1 million).

Decommissioning Fund Status

While the decommissioning of MY is completed and the 10 CFR Part 50 license has been amended to reflect the removal of all land areas from the NRC license except that associated with the ISFSI, the MY ISFSI continues to be licensed under the MY 10 CFR Part 50 license. Consequently, MY is maintaining a decommissioning fund of $110.2 million (2010 dollars), $96.2 million for ISFSI operations and $14.0 million for ISFSI decommissioning (Reference 24).

Decommissioning Cost Comparison to Minimum Decommissioning Fund Requirements

The cost to complete the radiological decommissioning of MY in 2010$, as reported in Table 4.21, was $521.2 million. However, as discussed previously, if adjusted for DOC litigation credits, the total radiological decommissioning cost is estimated to be $575.2 million.

The minimum decommissioning fund requirement for a nuclear power plant is specified by the formula in 10 CFR 50.75(c). For MY and using the latest revision of NUREG-1307 (Reference 28), the inputs to the formula are as follows:

- thermal power – 2700 MW
- labor factor (L) – 2.41 (for northeastern U.S.)
- energy factor (E) – 2.139 (for PWR)
- burial factor (B) – 12.28 (for direct disposal of Class B and C waste at the Barnwell facility with vendor disposal of Class A waste).

Using these inputs, the calculated minimum decommissioning fund requirement is $449 million ($267 million for LLW disposal costs and $182 million for other costs) (2010 dollars). The total radiological decommissioning cost for MY, accounting for DOC litigation credits, is about $126 million more than this minimum decommissioning fund. Because of differences in how costs are categorized, a detailed comparison of the MY actual decommissioning cost to the minimum decommissioning fund is not possible. However, high level comparisons do provide some insight into the differences. A comparison of the actual costs and the minimum decommissioning fund is provided in Table 4.22. A discussion of the differences, and potential reasons for the differences, follows:

- The actual program management costs are about $174 million higher than the minimum decommissioning fund. This difference is due at least in part to labor requirements. The total labor requirement to complete MY decommissioning was about 2500 person-years. While a breakdown of this total into program management and other cost categories was not available, this total is substantially greater than the 520 person-years assumed in the 10 CFR 50.75(c) formula.

- The actual cost for radiological decontamination and dismantlement is about $82 million higher than the minimum decommissioning fund. One reason for this cost difference is that the formula does not take into account any remediation activities that may be required during the course of decommissioning. Thus, the $59 million remediation cost for MY is not included in the formula calculations. (It should be noted that the soil was remediated to stricter guidelines than NRC requirements to comply with local and state regulations. Had only NRC guidelines been used, remediation costs would have been less than $59 million.)

  A second factor contributing to the radiological decontamination and dismantlement cost difference is, as discussed previously, the difference between the total MY labor requirements and the labor assumptions for the formula.

Table 4.22. Comparison of Actual Costs with the Minimum Decommissioning Fund Requirement (Millions of 2010 Dollars)

Cost Category	Actual Cost[a]	Formula Cost[a]
Radiological Decontamination and Dismantlement		
Radiological decontamination and dismantlement	90.3	87.8[b]
Component removal	20.8	
Radiological site remediation (buildings and sub-surface)	59.0	NA[b]
Other Costs		
LLW packaging, transportation, and disposal	121.7	302.1[c]
Program management	228.0[d]	54.2
Insurance	8.6	4.5
Taxes	16.8	0.0[e]
Regulatory (NRC) fees	15.5	0.3
Final status survey	14.3	0.0[e]
Total	**575.2**	**449.0**

(a) Costs may not sum to total due to rounding.
(b) Formula does not provide for costs of remediation but does include component removal costs.
(c) Formula cost for LLW packaging, transportation, and disposal assumes direct disposal of Class B and C waste at the Barnwell disposal facility with vendor processing/disposal of Class A waste.
(d) Adjusted for DOC litigation (see text).
(e) Formula does not provide for taxes or for a final status survey.

- The actual cost of LLW disposition (i.e., packaging, transportation, and disposal is about $121.7 million, versus $302.1 million for the formula amount. Dividing each of these costs by the corresponding total volume in Table 4.18 yields $\$25/ft^3$ for the actual MY cost and $\$467/ft^3$ for the formula amount. This is admittedly a very rough calculation given the wide variety of waste types. However, lack of data regarding the disposal rates that were contracted between MY and the facilities at Clive and Barnwell and between MY and the waste processors preclude more refined calculations. Nevertheless, the calculation does illustrate that average disposal rates for MY are considerably lower than rates estimated by the formula. (It should be pointed out that the formula includes the cost of disposition of GTCC waste. But since the volume of such waste is extremely small, the inclusion or exclusion of GTCC costs makes no significant difference in overall waste disposal costs.)

- The actual MY decommissioning costs include a small credit of about $1 million resulting from the sale of surplus assets. The formula makes no allowances for such credits.

- No allowances for property taxes and final status surveys are provided for in the formula. Thus these two additional MY decommissioning costs would not be included in the formula calculations.

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4.4 Trojan Nuclear Plant

Trojan Nuclear Plant (TNP) was located in Columbia County, Oregon, approximately 42 miles north of Portland, Oregon. TNP was jointly owned by Portland General Electric (PGE); the City of Eugene through the Eugene Water and Electric Board; and Pacific Power and Light/PacifiCorp. PGE was the majority owner and had responsibility for operating and maintaining TNP.

4.4.1 Historical Background

TNP, Docket 50-344, achieved initial criticality in December 1975 and began commercial operation in May 1976. The reactor output was rated at 3411 MWt with an approximate net electrical output rating of 1130 MWe. The nuclear steam supply system was a four-loop pressurized water reactor designed by Westinghouse Electric Corporation. The ISFSI is located on approximately 10,000 square meters in the northeast corner of the TNP industrial area.

TNP was permanently shut down on November 9, 1992. On January 27, 1993, after approximately 17 years of operation, TNP notified the Nuclear Regulatory Commission (NRC) of its decision to permanently cease power operations. The owners' decision was predicated on both financial and reliability considerations. The NRC amended the TNP Facility Operating License (NPF-1) to a Possession Only License on May 5, 1993. On July 31, 1993, TNP submitted a request to revise the TNP Technical Specifications to reflect the permanently defueled status of the plant. On October 7, 1993, TNP transmitted an updated Safety Analysis Report for the Defueled Condition (DSAR). TNP submitted a proposed Decommissioning Plan and Supplement to the Environmental Report on January 26, 1995, which were approved by the NRC on April 15, 1996. On March 31, 1995, the NRC issued Amendment #194 to Facility Operating (Possession Only) License NPF-1. This amendment revised the TNP Technical Specifications to reflect the permanently defueled condition of the plant, and regulatory requirements and operating restrictions to ensure the safe storage of spent fuel in the spent fuel pool.

The TNP Decommissioning Plan, PGE-1061 (Reference 18), was submitted and approved (March 31, 1995) in accordance with the NRC's rule governing decommissioning and termination of license, 10 CFR 50.82. This rule was revised effective August 28, 1996. The revised rule resulted in the TNP Decommissioning Plan being considered the (newly required) PSDAR, and also added a new requirement for all power reactor licensees to develop and submit a license termination plan for NRC approval at least two years before termination of the license date. The NRC approved the TNP License Termination Plan, PGE-1078, on February 12, 2001. Because of the significant overlap in content between the two documents, the approved TNP License Termination Plan was incorporated into the Decommissioning Plan (Reference 1).

All spent fuel and GTCC waste have been transferred to the ISFSI licensed in accordance with 10 CFR 72, Subpart B.

4.4.2 Decommissioning Schedule (Timeline)

All activities required by the TNP License Termination Plan (LTP) have been completed and all non-ISFSI related areas have been released from the TNP license. Major milestones and timeline elements are represented below based primarily on information provided in the TNP LTP (References 2, 3, 4, and 18).

- On November 9, 1992, Trojan Nuclear Plant shut down the plant after 17 years of operation.
- On May 5, 1993, the NRC amended the facility operating license to a Possession Only License.
- On March 31, 1995, the NRC issued Amendment #194 to the Possession Only License NPF-1, revising the TNP Technical Specifications to reflect a permanently defueled status of the plant.
- On October 7, 1993, TNP transmitted an updated Safety Analysis Report for the Defueled Condition.
- On January 26, 1995, TNP submitted a proposed “TNP Decommissioning Plan and Supplement to the Environmental Report.” This was approved by the NRC on April 15, 1996.
- In 1995, PGE successfully completed removal and disposal of TNP’s four steam generators and pressurizer.
- On August 28, 1996, the TNP Decommissioning Plan (considered the PSDAR) was submitted and approved in accordance with the NRC’s rule governing decommissioning and termination of license, 10 CFR 50.82.
- On October 15, 1998, Oregon Energy Facility Siting Council approved the plan to move the reactor vessel to the US Ecology low-level radioactive waste disposal facility in Richland, Washington.
- On March 31, 1999, the NRC issued Materials License No. SNM-2509 for the Trojan ISFSI.

- On August 8, 1999, the reactor vessel was barged up the Columbia River to the US Ecology disposal facility for burial.

- On September 3, 2003, the 34th and final MPC was loaded and placed on the ISFSI pad.

- In July 2004, decommissioning activities were completed in the Fuel Building, Auxiliary Building, Turbine Building, and Control Building.

- In September 2004, radiological decommissioning and remediation activities were completed.

- In October 2004, final status surveys were completed.

- On December 20, 2004, PGE submitted an application for termination of the TNP facility operating (possession only) license.

- On May 23, 2005, the NRC formally terminated the TNP operating license (Reference 17).

Table 4.23 compares the actual experienced schedule for TNP decommissioning with the schedule originally estimated in the PSDAR. As can be seen from the table, decommissioning activities and the final status survey were completed about three years later than the original decommissioning plan schedule, due principally to the delay in transferring used fuel and GTCC waste from the spent fuel pool to the ISFSI.

4.4.3 License Termination Strategy

The TNP Decommissioning Plan was submitted to the NRC on January 25, 1995. This plan subsequently served as the PSDAR required by the revised 10 CFR 50.82. The Decommissioning Plan schedule showed radiological decommissioning activities being completed in late 2001. PGE submitted, on August 5, 1999, the original TNP LTP, PGE-1078, to the NRC. The NRC subsequently approved the TNP LTP via a license amendment on February 12, 2001. The LTP was subsequently revised over 20 times prior to completion of TNP decommissioning (References 1 through 4, 14).

The original goal of the TNP decommissioning project was to release the site for unrestricted use using the guidance and criteria in Regulatory Guide 1.86 (Reference 19), NUREG/CR-5512 (Reference 20), and NUREG/CR-5849 (Reference 21). Following revisions to the Code of Federal Regulations in 1997 establishing new release criteria for license termination (10 CFR 20 Subpart E), the goal of the TNP decommissioning project was revised to release the site for unrestricted use in compliance with the new NRC annual dose limit of 25 mrem/y plus ALARA. Dose assessment methods per the guidance in NUREG-1575 (Reference 22) were used to determine DCGLs to verify that allowable release criteria are met.

Table 4.23. Comparison of PSDAR and Actual Trojan Decommissioning Schedule

Activity	PSDAR Schedule	Actual Schedule
PSDAR to NRC	not in schedule	August 1996 (original Decommissioning Plan – January 1995)
Updated DSAR	October 1993	October 1993
Large Component Removal (RPV, RPV internals, SGs, and Pressurizer)	Late 1994–Late 1995 Early 1997–Early 1998 Reactor Vessel and Internals Removal	1995 1996–August 1999
Complete planning/building an ISFSI	Late 1996–Mid 1998	March 1999
Removal of used fuel from Spent Fuel Pool to ISFSI	Mid 1998	December 30, 2002–September 3, 2003
System/Building Decontamination and Dismantlement	Mid 1998–late 2001	1999–September 2004
Final Status Survey	Late 2001	2003–October 2004
Demolish Non-Contaminated Buildings	Mid 2018–Late 2019	not applicable
Site Restoration Complete	2019	not applicable

TNP decommissioning was divided into two broad periods: a transition period and a decontamination and dismantlement period. Decommissioning was followed by site restoration. The transition period began with permanent plant shutdown in January 1993 and continued until spent fuel was transferred to the ISFSI licensed independently in accordance with 10 CFR 72. The decontamination and dismantlement period began after the spent fuel was transferred to the ISFSI. Site restoration was conducted in parallel with the process of termination of the 10 CFR 50 license and involved the final disposition of structures, systems, and components.

Major activities planned during the decontamination and dismantlement period included removing the remaining contaminated systems and components, and continuing the decontamination of structures and final radiation surveys. The final survey was performed to demonstrate that radiological conditions at TNP satisfy the final site release criteria of 10 CFR 20.1402 to support unrestricted release of the TNP site and license termination. Upon completion of the final survey, the final survey report was be submitted to the NRC.

For the ISFSI, TNP submitted the Final Site Survey Report (FSSR) for the Trojan ISFSI Site in October 1996. The staff accepted the report and approved the release of the area for use as an ISFSI in November 1996. The staff concluded that the FSSR for the limited area of the ISFSI complied with the requirements of 10 CFR 50.82. The staff's conclusion was based on its review of TNP's FSSR and the results of a confirmatory survey.

The non-radiological site remediation activities are to be completed following termination of the Facility Operating (Possession Only) License NPF-1. The primary non-radiological site remediation effort is scheduled to begin around 2018 and conclude in 2019. Some site restoration activities have been completed, and some may continue to be conducted during the transition and decontamination and dismantlement periods of decommissioning currently underway.

On May 23, 2005 the NRC concluded that 1) the remaining dismantlement had been performed in accordance with the approved LTP; 2) the Final Site Survey and associated documentation, including an assessment of dose contributions associated with parts released for use before approval of the LTP, demonstrated that the facility and site had met the criteria for decommissioning in 10 CFR part 20, subpart E; and 3) TNP had met the 10 CFR Parts 30, 40, and 70 requirements for forwarding of specific records to NRC prior to license termination.

4.4.4 Project Management

TNP reviewed the decommissioning alternatives described in NUREG-0586, “Final Generic Environmental Impact Statement on Decommissioning of Nuclear Facilities” (Reference 6) and selected several DECON and SAFSTOR implementation methods for detailed review and analysis (Reference 1). DECON is the alternative in which equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of facility operations and SAFSTOR is the alternative in which the nuclear facility is placed and maintained in a condition that allows the nuclear facility to be safely stored and subsequently decontaminated to levels that permit release for unrestricted use. TNP chose the DECON alternative for decommissioning (Reference 1) because this alternative minimizes financial uncertainties associated with waste disposal and other decommissioning costs. In addition, the DECON alternative allows the use experienced plant personnel and it allows for prompt site remediation and release for unrestricted use.

PGE decided to self-perform the decommissioning of TNP rather than use a DOC. The TNP organization and staffing level in February 2000 is provided in Table 4.24. The Trojan Site Executive and Plant General Manager had corporate responsibility for overall nuclear safety and decommissioning activities at TNP. The General Manager for Nuclear Oversight was responsible for quality assurance and quality control. The General Manager for Engineering and Decommissioning had responsibility for decommissioning planning, engineering, and cost control. The General Manager for Plant Support and Technical Functions had responsibility for purchasing, nuclear security, licensing, and training. The Manager for Maintenance had responsibility for overall maintenance of plant equipment used to support facility operations and decommissioning activities, radwaste workers, maintenance planning, plant storeroom, and remediation of the surfaces of ISFSI casks to repair a faulty paint coating on the interior surface of the concrete casks. The Manager for Operations had responsibility for operation of plant systems and for loading of the ISFSI casks. The Manager for Personnel/Radiation Protection had responsibility for personnel safety, emergency preparedness, water chemistry, personnel radiation protection, final status surveys, dosimetry, and hazardous materials program. Records management was provided by corporate support staff.

Table 4.24. TNP Organization and Staffing Level in February 2000

Level 1	Level 2	Level 3	Number of Staff
Trojan Site Executive and Plant General Manager	General Manager's Office	Not Applicable	PGE – 2
	Nuclear Oversight	Managers, Engineers, Specialists	PGE – 6 Contract – 3
	Plant Support and Technical Functions	General Manager's Office	PGE – 3 Contract – 1
		Cost Control	PGE – 3
		Nuclear Security	PGE – 31 Contract – 2
		Nuclear Regulatory Affairs	PGE – 4 Contract – 1
		Total	PGE – 41 (2 temporary) Contract – 4
	Engineering/ Decommissioning	General Manager's Office	PGE – 3
		Decommissioning Projects	PGE – 8 Contract – 86
		Engineering	PGE – 12 Contract – 10
		Decommissioning Planning	PGE – 6 Contract – 1
		Project Controls	PGE – 1 Contract – 5
		Total	**PGE – 30** **Contract – 102**
	Independent Spent Fuel Storage Installation	Manager's Office and Specialists	PGE – 11
	Maintenance	Manager's Office	PGE – 1
		Mechanical	PGE – 13
		Decommissioning 1	PGE – 32
		Decommissioning 2	PGE – 28
		Instrumentation and Electrical	PGE – 8
		Radwaste Worker	PGE – 21
		Project Planning	PGE – 9
		Storeroom	PGE – 3
		Surface Remediation	PGE – 11 Contract – 1
		Total	**PGE – 126 (41 temporary)** **Contract – 1**

Table 4.24. (contd)

Level 1	Level 2	Level 3	Number of Staff
	Operations	Manager's Office	PGE – 2
		Shift Managers (control and auxiliary operators)	PGE – 13
		ISFSI Loading	PGE – 1 Contract – 5
		Total	**PGE – 16** **Contract – 5**
	Radiation Protection	Manager's Office	PGE – 2 Contract – 1
		Chemistry/Radiation Protection	PGE – 47 Contract – 17
		Radiation Protection Technical Support	PGE – 8 Contract – 3
		Total	**PGE – 57** **Contract – 21**
	Corporate Support	Not Applicable	PGE – 5 Contract – 2
	TOTAL	**Not Applicable**	**PGE – 294 (43 temporary)** **Contract – 138**

Prior to permanent shutdown of TNP in December 1992, the number of regular TNP full-time employees at TNP was about 950 with a total of about 1400 staff including contractors. This was reduced to about 190 PGE full-time staff within about one year after permanent shutdown, with a further reduction to about 150 PGE full-time staff by December 2005. As shown in Table 4.24, permanent PGE staffing levels then increased to about 250 by February 2000 with another about 40 temporary staff and about 140 subcontractor staff.

The capability to isolate or to mitigate the consequences of a radioactive release was maintained during decontamination and dismantlement activities. Isolation consisted of the closure of penetrations and openings to restrict transport of radioactivity to the environment. Airborne radioactive particulate emissions were filtered as applicable and effluent discharges monitored and quantified. This included 1) the operation of appropriate portions of building ventilation systems, or approved alternate systems, as necessary during decontamination and dismantlement activities; and 2) use of local high efficiency particulate air (HEPA) filtration systems for activities expected to result in the generation of airborne radioactive particulates (e.g., grinding, chemical decontamination, or thermal cutting of contaminated components).

The Radiological Environmental Monitoring Program was periodically reviewed to address changing plant conditions and regulatory requirements in accordance with plant procedures. As specified in the TNP Nuclear Quality Assurance Program, the procedures for personnel radiation protection were prepared consistent with the requirements of 10 CFR 20.

Plant and radiation protection implementing procedures directed the use of various practices and equipment to ensure general plant area contamination was controlled at the source to the greatest extent possible. Additional contamination controls were specified for jobs involving high levels of contamination (e.g., a double step-off pad, additional surveys, etc.). Appropriate contamination controls were used when carrying contaminated tools and equipment between areas. Geiger-Mueller count rate meters (friskers) were located within the plant so that personnel could determine if they had been contaminated prior to entering another area of the plant. The final checkpoint for personnel leaving controlled areas of the plant was the access control point. Temporary exit points were established at remote control areas as needed.

4.4.5 Decommissioning Issues/Approaches

The technology used for decontamination, dismantlement, and disposal was as follows:

Spent Fuel Pool Island

Modifications were designed and installed to isolate the spent fuel pool active systems from the remainder of the plant. Modifications included installing a modular spent fuel pool cooling system and isolating spent fuel pool piping, including that used by the original spent fuel pool cooling and demineralizer system. The modifications provided physical isolation between decommissioning activities and the spent fuel pool.

Large Component Removal (LCR)

- Reactor Vessel and Internals Removal and Disposal

  During 1999, the reactor vessel with internals intact (reactor vessel package) was transported for disposal at the US Ecology facility near Richland, Washington. TNP packaged the reactor vessel and its internals as its own radioactive material shipping container, removed the package from containment, barged it up the Columbia River, and buried it at the same burial facility as the steam generators and pressurizer. The most challenging aspect of the project was obtaining the many state and federal approvals needed for this disposal option. Approvals were required from the following (Reference 7):

  - Nuclear Regulatory Commission – Certificate of Compliance for the reactor pressure vessel to be shipped as a Type B package (based on alternate transport conditions) in accordance with 10 CFR 1.12(c)(3).

  - U.S. Department of Transportation – Exemption from DOT-E 12147 which then allowed for a one-time shipment of the reactor pressure vessel.

  - State of Oregon – Approval of the State of Oregon Energy Facility Siting Council for a change to the original Trojan Nuclear Plant Decommissioning Plan

  - State of Washington – Approval of the reactor pressure vessel and internals classification as Class C waste was required so that they could be buried in a low-level radioactive waste disposal facility. TNP had to demonstrate that the package met the exposure and stability requirements of 10 CFR 61, Subpart C, “Performance

Objectives," and equivalent state of Washington regulations. TNP submitted this analysis to the Washington State Department of Health and answered numerous questions by both the Department of Health and the NRC. In November 1998, the Department of Health gave final approval.

Removal of the reactor vessel package from the 10 CFR 50 licensed area of the TNP site eliminated approximately 2 million curies of activity. Except for the spent nuclear fuel in the ISFSI, removal of the reactor vessel and internals resulted in elimination of greater than 99% of the remaining radioactivity at the TNP facility (Reference 1).

The consolidation of reactor vessel and internals had many advantages compared to separate reactor vessel removal and internals segmentation. They included (Reference 7):

- Less Waste Volume – This resulted in 8,341 ft^3 of Class C waste compared to a projected volume of 18,320 ft^3 of low and GTCC waste for the segmentation option.

- Less Personnel Exposure – This resulted in 67 person-rem for onsite occupational workers compared to a projected 133 person-rem for the segmentation option. General public and disposal facility personnel exposures were also less.

- Fewer Radioactive Shipments – The project involved only one radioactive shipment compared to an estimated 45 shipments with the segmentation option.

- Less Cost –The actual cost of reactor vessel and internals removal and disposal was $21.5 million (1997 dollars), compared to an estimated $38.4 million for the segmentation option. The actual disposal cost was $4.2 million under budget.

The project was both a technical and a financial success. The US Ecology facility is currently available only to the Northwest and Rocky Mountain compact states. Without state regulatory changes, the option to dispose of the reactor pressure vessel and internals in a single package will not be available to other commercial nuclear plant decommissioning projects.

- Steam Generator Removal

Removal of the four steam generators and pressurizer was completed 1995. These components were disposed of at the US Ecology low-level radioactive waste disposal facility near Richland, Washington. Removal of the steam generators and pressurizer was accomplished through the south face of the Containment Building. That opening was covered so that the Containment Building could be maintained closed. Each component was moved onto a barge at the TNP barge slip and shipped up the Columbia River to the Port of Benton, Washington, where it was off-loaded and transported for disposal at the US Ecology low-level radioactive waste disposal facility near Richland, Washington. The Containment Building door control was maintained in accordance with the TNP security plan.

Decontamination and System Dismantlement Activities

These activities involve the reduction of radioactivity to acceptable levels, to allow the release of the site for unrestricted use. Contaminated systems and components were decontaminated or removed, packaged, and either shipped to an offsite processing facility, shipped directly to a low-level radioactive waste disposal facility, or handled by other alternatives in accordance with applicable regulations.

Contaminated structural concrete, steel, and other building materials and remaining components of systems were removed or decontaminated in place in a manner consistent with the LTP. The spent fuel pool itself was remediated following removal of fuel and draining of the water. Decontamination of the structures was performed on an area-by-area basis, with the majority of the decontamination activities occurring following completion of equipment removal from an area. Demolition of the building structures was scheduled to be completed after the termination of the TNP 10 CFR 50 license.

Decontamination of plant structures were completed concurrently with equipment removal. Decontamination of structures included a variety of techniques ranging from water washing to surface material removal. Contaminated structural material was packaged and either shipped to a processing facility, or shipped directly to a low-level radioactive waste disposal facility.

Following the removal or decontamination of contaminated systems, components, and structures, a comprehensive final radiation survey was completed. The survey verified that radioactivity had been reduced to sufficiently low levels, as stipulated in 10 CFR 20.1402, to allow the release of the site for unrestricted use. Upon completion of the final survey, TNP submitted the final survey report to support license termination.

- RCS Chemical Decontamination

  The method used was identified as the Electric Power Research Institute Decontamination for Decommissioning (EPRI DFD) Process and involves circulating chemically treated water though the system or component requiring decontamination. Addition of oxalic acid removes manganese dioxide, and is followed by permanganate to destroy any excess oxalate. PN Services Inc. of Richland, Washington, applied the EPRI DFD Process to a number of stainless steel tanks and heat exchangers at the TNP plant in April and May 1998. Good results were achieved, particularly with the heat exchangers, where an overall decontamination factor of 66 and dose reduction factor of 33 was achieved with 8 cycles of the process (Reference 8).

- Decontamination Methods

  The radioactivity on most plant surfaces was conservatively estimated by assuming that the maximum amount of radioactive surface contamination allowed by the Final Survey Plan (i.e., surface DCGL) was present and releasable. Specifically, it was assumed that radioactivity amounts at the applicable surface DCGL limit were present on floors, walls, and ceilings of the Auxiliary Building, Fuel Building, pipe penetration area, Main Steam Support Structure, electrical penetrations area, Turbine Building, and the Containment Building.

The surfaces of walls and slabs in traffic areas had protective coatings. Concrete was decontaminated by water or chemical washing. Surfaces that could not be decontaminated were scabbled or ground down to non-contaminated depths.

Sealed sources were designed specifically to prevent the release of the contents and therefore not considered in the release analysis. Unsealed sources remaining at the TNP were of extremely low radioactivity levels, such that they did not contribute significantly to the total releasable source term considered in this analysis.

Gaseous radioactivity was limited primarily to airborne radioactive particulates generated during decontamination and dismantlement activities. Airborne radioactive particulates were filtered through HEPA filters in the portions of building ventilation system(s) that were required to be maintained in operation to support activities in those buildings. As the decontamination and dismantlement activities were underway in the Fuel and Auxiliary Buildings, the ventilation systems for these buildings continued to be operable. Local temporary ventilation systems with HEPA filtration, or other approved alternate systems, were used in lieu of or to supplement building ventilation for activities expected to result in the generation of airborne radioactive particulates. Radioactive gaseous effluents were monitored and release limits adhered to in accordance with the methodology and parameters in the Offsite Dose Calculation Manual.

Liquid radioactive waste was generated as a result of draining, decontamination, and cutting processes during plant decommissioning. Liquid radioactive waste treatment systems (plant effluent system, clean radioactive waste system, and dirty radioactive waste system) were maintained operable during decommissioning to process liquid radioactive wastes by filtering, demineralizing, and providing for holdup or decay of the radioactive wastes for the purpose of reducing the total radioactivity prior to release to the environment.

Solid radioactive waste generated during decommissioning included neutron-activated materials, contaminated materials, and radioactive wastes. Neutron-activated materials include the reactor pressure vessel, reactor vessel internals components, and the concrete biological shield. Contaminated material and radioactive wastes included pipe sections, valves, tanks, other plant equipment, concrete surfaces, contaminated air filters, wet solid wastes from the processing of contaminated water volumes (ion exchange resins, cartridge filters), and dry solid wastes (rags and wipes, plastic sheeting, contaminated tools, disposable protective clothing).

The solid radioactive waste system spent resin transfer system, filter handling vehicle, solid waste compactor, and spent resin compactor were maintained in operation as necessary during decommissioning to process solid waste.

Solid radioactive waste was processed in accordance with the TNP Radiation Protection Program, Process Control Program, and plant procedures. The Process Control Program provided requirements to ensure that shipping and burial ground requirements were met. To the maximum extent practicable, solid radioactive waste was decontaminated and compacted to reduce the volume to be packaged for shipment to an offsite disposal facility.

Waste container selection was determined by the type, size, weight, classification, and activity level of the material to be packaged. Examples of containers used at TNP include drums, metal boxes, C-vans (container vans), and high-integrity containers.

Mixed wastes contained both a hazardous waste component regulated under Subtitle C of the Resource Conservation and Recovery Act and a radioactive component consisting of source, special nuclear, or byproduct material regulated under the Atomic Energy Act. Plant procedures provided guidance for the minimization, control, and storage of mixed waste in accordance with the EPA and NRC regulations. The use of potentially hazardous materials in radiologically controlled areas was reviewed to minimize the generation of mixed waste.

- Dismantlement Methods

During the decontamination and dismantlement period, dismantlement activities were reviewed to ensure they did not impact the safe storage of fuel in the ISFSI licensed under 10 CFR 72. Design change work packages were implemented in accordance with administrative controls that required evaluations in accordance with the requirements of 10 CFR 50.59.

Disassembly and cutting were the methods used for contaminated systems. Disassembly generally means removing fasteners and components in an orderly non-destructive manner (i.e., the reverse of the original assembly).

Systems and components removed and released from the secondary side of the plant for commercial disposal were surveyed in accordance with plant procedures based upon a no detectable radioactivity standard. Generally, systems and components removed from the primary (radiologically controlled) side of the plant were packaged and either transported to an offsite processing facility, LLW disposal facility, or an appropriate disposal facility. Application of coatings and hand wiping was used to stabilize or remove loose surface contamination. Potentially contaminated components (i.e., lighting ballast, mercury switches, etc.) were decontaminated onsite for release in accordance with plant radiological monitoring procedures for release.

Tanks and vessels were evaluated and, if required, flushed or cleaned to reduce contamination levels and remove sludge prior to sectioning and/or removal.

Asbestos Removal

Asbestos containing materials included Marinite board used in the plant as a fire barrier; electrical cable with a wrap containing asbestos; piping systems with a wrap containing asbestos; the cooling tower mist eliminators and distribution piping fabricated from an asbestos cement material; and roof flashing sealant containing asbestos fibers. Other materials suspected of containing asbestos were sampled and analyzed before work was done on the material. Asbestos material was removed and disposed of in accordance with plant safety procedures, federal and state OSHA regulations, and federal and state hazardous air pollutant and solid waste regulations.

Decontamination and Disposition of Site Buildings

The contamination consisted of radioactive material incorporated (fixed) into the upper layer of concrete/block and deposited on the surface (loose). Although the levels of radioactivity were generally low, structures within what was the radioactive contamination area in 1993, including building surfaces and piping, were considered potentially contaminated and required, at least a, wipe or wash down.

Some plant systems contained deposited radioactive material due to plant operation. The majority of the radioactive material was contained in RCS piping and systems directly connected to the RCS (e.g., chemical and volume control system, safety injection system, and residual heat removal system).

Activated components contained the vast majority of the radioactive material (not considering the fuel). Most activity was primarily concentrated in the vessel internals and shield wall. The reactor vessel lower internals contained the highest activity. Although radionuclide distributions were provided for the reactor vessel and vessel internals, they had to be removed before the final survey data collection in the Containment. Neutron activation products were found in samples of containment concrete in various structures, including the reactor vessel shield wall, steam generator missile shields, and the containment wall itself. Remediation of the activated components was required to meet the site release criteria and facilitate license termination.

Finally, the environmental survey results indicated that no radioactive material requiring remediation was present in the various materials sampled, and that no radioactivity requiring remediation had spread to the environment outside the TNP industrial area. The final survey required additional background data for a number of the sample media. Results indicated no radioactivity at TNP has been spread to the environment inside the industrial area in quantities requiring remediation.

4.4.6 Non-Decommissioning Fund Activities

ISFSI

Trojan constructed an ISFSI for $74 million (1997 dollars). PGE selected the TranStor™ dry fuel storage system because this system uses dual-purpose (storage and transportation) concrete casks, which allows for removal of used nuclear fuel from the Trojan ISFSI without the need to return to the spent fuel pool and with no further handling of the used fuel. Use of this cask storage system was delayed in 1998 until the NRC was assured that the cask vendor had corrected safety problems found at other sites. The NRC issued Materials License No. SNM-2509 for the Trojan ISFSI on March 31, 1999 (Reference 1). A further delay in loading of used fuel into the concrete casks was experienced starting in the summer of 1999 when the spent fuel pool clouded and filled with bubbles during fuel loading, limiting visibility to less than one foot. An investigation determined that faulty paint coating on the casks' interior allowed carbon steel to come in contract with boric acid causing excessive hydrogen to bubble to the surface. Fuel loading was delayed about another two years to design and fix the coating.

The completion of fuel transfer to the ISFSI in September 2003 allowed the removal or decontamination in place of systems and components that support the spent fuel pool or wet fuel storage, including the pool itself.

During the decontamination and dismantlement period, dismantlement activities were reviewed to ensure they did not impact the safe storage of fuel in the ISFSI licensed under 10 CFR 72. Design change work packages were implemented in accordance with administrative controls that require evaluations in accordance with the requirements of 10 CFR 50.59 to ensure protection of the fuel.

Asset Recovery Program

Although not strictly part of the decommissioning of the TNP site, PGE established a program to sell usable equipment no longer needed. Specifically, PGE sold the TNP simulator to the NRC and sold new (unused) parts/equipment from the warehouse.

4.4.7 Soil and Groundwater Remediation

TNP site characterization was conducted in two phases: 1) Phase I, scoping survey/site characterization, and 2) Phase II, radiological surveys to support TNP dismantlement and decommissioning (Reference 1). During Phase I of site characterization, soil, sediment, and surface water were sampled. Exposure rates were measured wherever soil was sampled, except where exposure rates were influenced by onsite structures. Paved areas onsite were scanned for beta contamination or sampled and analyzed for gamma emitters. Biased sample locations were determined from reviewing plant records that documented radiological events at TNP from 1975 to 1993. Corrective action programs were reviewed and interviews conducted with TNP personnel to help determine potential sample locations.

For soil background measurements, the mean background ^{137}Cs concentration was 0.49 pCi/g with a standard deviation of 0.4 pCi/g and a range of 0.01 to 1.3 pCi/g. Substantial variations in background ^{137}Cs concentrations were observed between varying soil types. Sandy soils found near the river contained low ^{137}Cs concentrations, while clay soils contained higher concentrations. For the survey of unaffected soil areas, the mean ^{137}Cs concentration was 0.77 pCi/g with a standard deviation of 0.86 pCi/g and a range of 0.01 to 2.94 pCi/g. Primarily, the non-naturally occurring isotopes found in soil samples were ^{137}Cs and ^{90}Sr. Fallout from atmospheric weapons tests and the Chernobyl accident are the major sources of ^{137}Cs and ^{90}Sr in the environment. Strontium-90 results averaged 0.2 pCi/g with a standard deviation of

0.16 pCi/g and a range of 0.02 to 0.32 pCi/g. The ^{90}Sr levels measured during the preoperational period ranged from 0.01 to 1.28 pCi/g with a mean of 0.30 pCi/g.

Biased survey soil samples were taken onsite where potential soil contamination may have occurred. Subsurface soil samples taken in 1991 from the tank farm area were also reviewed as part of the analysis. The predominant non-naturally occurring isotope detected was ^{137}Cs. The mean ^{137}Cs concentration in affected soil samples was 0.10 pCi/g with a standard deviation of 0.098 pCi/g. The ^{137}Cs content of the 1991 samples was below the cleanup criteria.

Groundwater Monitoring

In the original site characterization, no groundwater contamination was found, so TNP adopted the NRC screening level DCGLs versus the development of site specific DCGLs. This simplified the approach for demonstrating that the residual radioactivity would be less than the 25 mrem/yr criteria. The goal for the TNP project was to release the site for unrestricted use (Reference 5).

The groundwater monitoring program was implemented in a phased manner (Reference 1). The first phase (i.e., Phase I) of the program involved the installation of seven monitoring wells in the vicinity of the power block (Trojan Hill) to determine the following:

- Directions of groundwater movement in the vicinity of the power block
- Rates of groundwater movement in the vicinity of the power block
- Presence above background, if any, of radionuclides associated with plant operations.

The analytical results for each monitoring well were compared with background groundwater quality to determine if any radionuclides were present above background levels. The identification of groundwater moving toward the buried valley and the tritium in MW-8 met the requirements of the TNP license condition to implement the second phase of the groundwater monitoring program.

A second phase (i.e., Phase II) was implemented when radionuclides were detected above background levels and it was determined that there was a potential for these radionuclides to migrate into the buried valley at concentrations that would require additional groundwater monitoring.

Seven additional wells were drilled to support Phase II activities (Reference 4). Two groups of nested wells were installed in the buried valley just west of the Trojan access road. The nested wells consisted of two wells, a shallow well approximately 25 feet deep and a deep well approximately 55 feet deep. The intent of the nested wells was for the shallow well to target the top of the groundwater table and the deep well to reach the bedrock. Two wells were installed in the upper parking lot on the north and south end. A seventh well was installed on the east side of the Industrial Area near the area where the diesel fuel oil tanks were located. The well in the Industrial Area was drilled to approximately 22 feet to provide down gradient sampling for Phase I well MW-8. Sampling and analysis methods were repeated for Phase II wells. Phase I wells were also re-sampled to ensure the time period between sampling Phase I wells and

Phase II wells would not lead to errors in radionuclide concentration determination due to the time elapsed between the Phase I and Phase II activities. A total of 17 wells were installed at Trojan.

Surface Water Monitoring

Surface water was sampled from indicator sites on TNP property surrounding TNP. A 1-gallon sample was obtained from each site for gamma and ^{90}Sr analysis and a 60-ml sample for tritium analysis. The water samples were analyzed for gamma emitters using a gamma spectroscopy system located onsite. Water samples were analyzed for tritium in the onsite counting laboratory. Selected samples were analyzed for ^{90}Sr. To determine background, water samples were collected from four locations around TNP.

Analyses for gamma emitters and tritium were completed on the samples. No gamma emitters other than naturally occurring radionuclides were identified in the samples. Tritium values were less than detectable. The four samples analyzed for ^{90}Sr were less than detectable. Minimum detectable activity (MDA) for ^{137}Cs, tritium, and ^{90}Sr was approximately 4, 450, and 0.3 pCi/l, respectively.

For the survey of unaffected water areas, samples were collected from random locations in Whistling Swan and Reflection Lakes located on PGE-owned property surrounding the TNP site. No non-naturally occurring radionuclides were detected in the samples by gamma spectrometry. Neither tritium nor ^{90}Sr was detected in the samples.

For the biased survey, samples were taken from the potentially affected Recreation Lake, also located on PGE-owned property surrounding the TNP site. No non-naturally occurring radionuclides were detected in the samples.

Bottom Sediment Survey

Bottom sediment samples were taken from PGE property around TNP. Approximately 1 liter of sediment was obtained at each sampling site. The sediment samples were dried and analyzed for gamma emitters using a gamma spectroscopy system located onsite. Selected sediment samples were analyzed for ^{90}Sr. Specific isotopic background sediment samples were not collected. Instead, soil background results were used as sediment background. Background soil samples were analyzed as part of the site characterization effort, and the mean ^{137}Cs concentration was 0.49 pCi/g. A comparison of the ^{137}Cs concentration in preoperational sediment samples to the background soil sampling showed a high correlation with the sediment mean equal to 0.51 pCi/g and the soil mean equal to 0.49 pCi/g.

The results were within the preoperational range of ^{90}Sr which was from 0.01 to 0.44 pCi/g with a mean of 0.08 pCi/g. The ^{90}Sr content of the sediment samples was also below the corresponding screening release level. For the biased sediment survey sample population, samples were taken from the berm and main areas of Recreation Lake. Results of the analyses indicated a mean of 0.28 pCi/g with a standard deviation of 0.37 pCi/g and a range of 0.04 to 1.12 pCi/g. The affected area samples contained ^{137}Cs in amounts below the release level. No other gamma emitters were detected.

Site Characterization Conclusion

The environmental survey results indicated that no radioactivity at TNP had spread to the environment either inside or outside the plant industrial area, including surface water and groundwater, in quantities requiring remediation (Reference 4).

4.4.8 Radioactive Waste Volumes and Activity

This section provides the total volume of LLW generated from the decommissioning of TNP that was shipped offsite, to either direct disposal or to waste processors, and the total volume of LLW that was shipped directly to disposal. The volume shipped for disposal is compared to the LLW volume assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

LLW Volume and Activity Shipped Offsite for Disposal

Table 4.25 reports the volume and activity of LLW generated from the decommissioning of TNP and shipped directly to the US Ecology commercial LLW disposal site for disposal. This information was obtained from the DOE MIMS, which is a database of LLW information derived from the manifests for waste shipments as reported to the DOE by each of the commercial LLW disposal sites (Reference 9). Table 4.25 also provides a column reporting the annual volume of radwaste generated and shipped offsite during the TNP decommissioning project (Reference 10). Waste volume comparisons between Reference 9 and Reference 10 are shown in gray. The total volume of radwaste reported by these two sources of information as being generated and disposed of over the life of the decommissioning project is different by less than 1% (i.e., 12,520 m^3, or 442,100 ft^3, compared to 12,376 m^3, or 437,044 ft^3). The similarity in this data indicates that waste processors were used very little if at all on the TNP decommissioning project. It is noted that TNP reported significantly less radwaste volume in 1993 (23%) and 1994 (15%) than did MIMS, while TNP reported significantly more radwaste volume in 2003 (31%) than did MIMS. The reasons for these discrepancies are unknown.

Based on the information in Tables 4.25, the following observations are made:

- The 1,544,398 Ci of Class C LLW shown to have been shipped to the US Ecology facility in 1999 corresponds to the RPV and reactor internals shipment that was made that same year, which was reported to have included 1,544,381 Ci in the Class C waste package.

- The total activity disposed of at the US Ecology disposal facilities is 1,548,050 Ci. Since similar information was not available on the activity of waste shipped from the TNP site, no comparison of the two quantities is possible.

- The total volume of LLW disposed of at the US Ecology facility is reported to be less than 1% different from the total volume reported to have been shipped off of the TNP site, implying little or no waste was shipped to radwaste vendors for further processing and disposal or, in other words, essentially 100% of the total volume of waste reported to have been shipped from the TNP site was directly disposed of at the US Ecology disposal facility.

Table 4.25. Trojan Radwaste Volume and Activity Generated During Decommissioning[(a)]

	Class A		Class B		Class C		Totals			
Year Received	Volume m^3 (ft^3)	Activity Ci	Volume m^3 (ft^3)	Activity Ci	Volume m^3 (ft^3)	Activity Ci	Volume m^3 (ft^3)	Volume[(b)] m^3 (ft^3)	Variance (Δ%)	Activity Ci
1993	80[(c)] (2817)	NA[(d)]	7 (265)	NA	16 (550)	NA	103 (3,631)	133 (4,690)	-23	313
1994	291[(c)] (10,265)	NA	0	NA	0	NA	291 (10,265)	342 (12,074)	-15	2
1995	1,363[(c)] (48,133)	NA	0	NA	0	NA	1,363 (48,133)	1362 (48,099)	0	1,276
1996	710 (25,070)	35	11 (397)	320	0	0	721 (25,467)	721 (25,466)	0	355
1997	676 (23,864)	24	0	0	0	0	676 (23,864)	673 (23,774)	0	24
1998	1,923 (67,906)	59	1 (51)	6	16 (572)	427	1,941 (68,529)	1939 (68,486)	0	493
1999	1,659 (58,569)	21	2 (78)	812	245 (8,644)	1,544,398	1,906 (67,290)	1906 (67,300)	0	1,545,231
2000	2,835 (100,110)	185	4 (154)	24	4 (154)	51	2844 (100,417)	2841 (100,326)	0	260
2001	852 (30,101)	7	4 (154)	25	0	0	857 (30,255)	858 (30,293)	0	32
2002	361 (12,762)	0.08	3 (102)	40	0	0	364 (12,864)	364 (12,869)	0	40
2003	919 (32,467)	5	1 (51)	18	1 (51)	1	922 (32,570)	706 (24,943)	31	24
2004	533 (18,807)	1	0	0	0	0.27	533 (18,815)	530 (18,724)	1	1
Total[(e)]	12,202 (430,870)	339	35 (1,252)	1,244	283 (9,977)	1,544,877	12,520 (442,100)	12,376 (437,044)	1	1,548,050

(a) Information is from DOE Manifest Information Management System (Reference 9).
(b) Provided in personal communication with Jay Fischer (Reference 10).
(c) For 1993 through 1995, total waste volume is reported for some shipments but not by waste class. For these shipments the activity reported is very small, therefore the waste volume for these shipments is included as Class A waste in this table.
(d) NA = Information was not available. From 1993 to 1995 only total activity is available, not by waste class.
(e) Totals may not add due to rounding.

- The total volume of Class B and C LLW disposed of at the US Ecology disposal facility is reported to be 1,252 ft^3 (35 m^3) and 9,977 ft^3 (283 m^3), respectively. The volume of Class B waste is about 12% of the volume of Class C waste disposed.

The total volume of LLW generated from the decommissioning of TNP and shipped for disposal as LLW was estimated in the TNP Decommissioning Plan, or PSDAR, to be 313,000 ft^3 (8,850 m^3). The LLW volume actually shipped directly to disposal was about 40% higher. While insufficient information is available to delineate all of the reasons for this increase, it is apparent that decontamination and decommissioning of the Containment Building contributed at least 30%, 40,000 ft^3 (1,100 m^3) of the increase.

Decommissioning LLW Volume Comparison to Minimum Decommissioning Fund Requirements

The cost basis for the 10 CFR 50(c) minimum decommissioning fund formula includes assumptions with regard to the volume of LLW generated during decommissioning. The cost bases and assumptions for the formula are provided in NUREG/CR-0130 (Reference 11) and subsequent Addendums 3 and 4 to that report (References 12 and 13). The volume of LLW assumed in the formula is provided in Table 4.26, which provides a breakdown of the total LLW volume generated and shipped to the US Ecology LLW facility in Richland, Washington. Table 4.26 also provides a comparison of the formula LLW volume assumptions to the actual LLW volumes generated during decommissioning TNP, as summarized from Table 4.25. The following observations are made:

- The volume of Class A waste actually shipped from TNP was about two-thirds the amount predicted by the formula.
- The volume of Class B waste actually shipped from TNP was about one-sixth the amount predicted by the formula.
- The volume of Class C waste actually shipped from TNP was almost seventeen times the volume predicted by the formula. This high volume of Class C waste was actually the result of using the RPV as the burial container for the normally GTCC reactor vessel internals. This combination of a small volume of highly activated waste surrounded by a large volume of Class A waste resulted in an effective overall classification of Class C waste.
- The total volume of waste shipped for disposal was about 70% of the volume predicted by the formula.

Table 4.26. Comparison of Formula and Actual LLW Volumes

	Formula Volumes		Actual Volumes	
LLW Shipped/Received	m^3	ft^3	m^3	ft^3
Class A	17,964	634,392	12,202	430,870
Class B	214	7,564	35	1252
Class C	17	600	283	9,977
GTCC	133	4,700	0	0
Total	**18,328**	**647,256**	**12,520**	**442,100**

4.4.9 Cost of Decommissioning and License Termination

This section provides a discussion of the decommissioning fund status, decommissioning cost estimates based on two TNP license termination plans, and a comparison of actual decommissioning costs to the minimum decommissioning fund requirement.

Estimated Decommissioning Cost

Table 4.27 provides a breakdown of the estimated cost to decommission TNP as provided in the TNP Decommissioning Plan or PSDAR (Reference 18). The total cost to complete radiological decommissioning was estimated to be about $217 million (1997). A site-specific decommissioning cost estimate and the TNP Decommissioning Plan (PSDAR) were subsequently updated and incorporated, including updated costs, in the LTP, Rev. 0 (Reference 23), which is also provided in Table 4.27 for comparison. As can be seen, the cost of radiological decommissioning increased from about $217 million to $240 million. Spent fuel management costs also increased, from $113 million to $133 million. Insufficient information was available to ascertain the reasons for these estimated cost increases. However, the LTP decommissioning cost estimate is based on actual decommissioning progress and an estimate of remaining costs based on the best available information about the remaining scope of the decommissioning effort.

Table 4.27. Decommissioning Costs from TNP LTPs (Millions of 1997$)

Decommissioning Cost Category	Decommissioning Plan (PSDAR) Rev. 0 (References 18)[a]	LTP Rev. 0 (Reference 23)
Radiological (NRC) Decommissioning Costs		
Reactor Vessel and Internals Removal and Disposal	23.6	25.9
Large Component Removal (steam generators and pressurizer)	20.4	Not Provided
Dismantlement, Decontamination, and Remediation	144.0	157.2
Waste Disposal	28.7	38.2
Final Status Survey	Not Provided	18.6
Total	**216.7**	**239.9**
Non-Radiological Decommissioning Costs		
Site Restoration	46.4	51.1
Total	**46.4**	**51.1**
Dry Spent Fuel Management Costs		
ISFSI Construction and Decommissioning	40.3	62.9
ISFSI Operation and Maintenance	72.2	69.6
Total	**112.5**	**132.5**
Financing Costs		
Financial Assurance	0.6	0.5
Decommissioning Bridge Loans	7.3	9.1
Total	**7.9**	**9.6**
Total Decommissioning Expenditures	**383.6**	**433.1**

(a) Costs provided in 1993 dollars were multiplied by a conversion factor of 1.1 to obtain 1997 dollars.

Actual Decommissioning Cost

The actual costs to decommission TNP are shown in Table 4.28 (Reference 10). Since site restoration (non-radiological decommissioning activities) and ISFSI operations and maintenance are not completed, the total decommissioning costs includes estimates for the remaining costs to be incurred in these areas. The total actual cost of radiological decommissioning activities to terminate the TNP license is $208 million in 1997 dollars. This is very close to the cost estimated in revision 0 of the TNP Decommissioning Plan (PSDAR) and about 13% less than that estimated in revision 0 of the LTP. It is noted that the actual costs incurred are similar to the original cost estimates even though the schedule to complete radiological decommissioning activities took about 3 years longer than originally assumed. The annual cost incurred for radiological decommissioning activities is provided in Table 4.29.

Table 4.28. Decommissioning Costs from TNP Decommissioning Plan, Rev. 28 (Reference 10) (Millions of 1997$)[(a)]

Decommissioning Cost Category	Total (Actual + Estimated Remaining)	Remaining as of December 31, 2001
Radiological (NRC) Decommissioning Costs		
Reactor Vessel and Internals Removal and Disposal	21.6	0
Dismantlement, Decontamination, and Remediation	139.8	0
Waste Disposal	38.6	0
Final Status Survey	7.6	0
Total	**207.6**	**0**
Non-Radiological Decommissioning Costs		
Site Restoration	16.0	2.4
Total	**16.0**	**2.4**
Spent Fuel Management Costs		
ISFSI Construction	74.4	0
ISFSI and Spent Fuel Pool Operation and Maintenance	81.1	62.8
ISFSI Decommissioning	10.5	10.5
Total	**166.1**	**73.3**
Total Decommissioning Expenditures	**389.7**	**75.8**

(a) Costs provided in 2008 dollars were divided by a conversion factor of 1.31 to obtain 1997 dollars. Total costs do not include project management reserve and financing costs.

Table 4.30 provides a further breakdown of the actual Radiological Decommissioning Costs shown in Table 4.28. The total costs for Reactor Vessel and Internals Removal and Disposal and for Dismantlement, Decontamination, and Remediation are divided into three categories: 1) PGE Supervision and Overheads, 2) PGE and Contract Support Labor, and 3) Contract Labor, Materials, and Equipment. The costs for Waste Disposal are divided into the following three categories: 1) Transportation, 2) Disposal in the LLW Disposal Facility, and 3) Waste Packaging/Volume Reduction/Miscellaneous.

Table 4.29. Annual Actual Radiological Decommissioning Costs from TNP Decommissioning Plan, Rev. 28 (Reference 10)

Year	Actual Cost (Millions of 1997$)[(a)]
1993	2.7
1994	5.3
1995	15.9
1996	9.1
1997	19.3
1998	34.4
1999	38.1
2000	33.3
2001	8.4
2002	8.4
2003	13.9
2004	17.1
2005	1.7
Total	**207.6**

(a) Costs provided in 2008 dollars were divided by a conversion factor of 1.31 to obtain 1997 dollars.

Table 4.30. Actual Radiological Decommissioning Costs from Jay Fischer (Reference 10) (Millions of 1997$)[(a)]

Decommissioning Cost Category	Total (Actual)
Decommissioning Costs (Reactor Vessel and Internals Removal and Disposal; Dismantlement, Decontamination, and Remediation)	
PGE Supervision and Overheads	58.9
PGE and Contract Support Labor	45.5
Contract Labor, Materials, and Equipment	57.0
Total	**161.4**
Waste Disposal Costs	
Transportation	11.1
Disposal in a LLW Facility	13.1
Packaging/Reduction/Misc.	14.4
Total	**38.6**
Final Status Survey	7.6
Total	**207.6**

(a) Costs provided in 2008 dollars were divided by a conversion factor of 1.31 to obtain 1997 dollars.

Decommissioning Fund Status

Since the decommissioning of TNP is completed and the 10 CFR Part 50 license has been terminated, a decommissioning fund is no longer maintained for TNP decommissioning. However, as a condition of the termination of the TNP license, PGE is required by NRC to maintain $100 million in nuclear liability insurance coverage until all radioactive material, including used fuel, is removed from the ISFSI site (Reference 17).

Decommissioning Cost Comparison to Minimum Decommissioning Fund Requirements

Actual decommissioning costs were known in 2005, but the utility reported these costs in constant 1997 dollars (Reference 14). To obtain 2010$, a yearly 1.035 escalation factor was applied. In Table 4.31, these two sets of "actual" costs are compared with the minimum decommissioning fund requirements for the same two years (1997 and 2010). The minimum decommissioning fund requirement is specified by the formula in 10 CFR 50.75(c). For the year 1997, data from Reference 15 was used; for 2010, data from Reference 16 was used. The inputs to the formula are shown in the table below (the B_x factor is for direct disposal of Class A, B, and C waste at the US Ecology):

Inputs to Formula in 10 CFR 50.75(c) for TNP

Year	Power (MWt)	L_x (Western U.S.)	E_x (PWR)	B_x	NUREG/CR-1307 Revision
1997	3411	1.541	1.038	3.112	7
2010	3411	2.29	2.139	8.035	14

Using these inputs, the 10 CFR 50.75(c) formula costs for 1997 and 2010 were obtained and are presented in Table 4.31.

Because of differences in how costs are categorized, a detailed comparison of the actual TNP decommissioning cost to the minimum decommissioning fund is not possible. However, high level comparisons do provide some insight into the differences. A discussion (based on Table 4.29) of the differences and the potential reasons for the differences follows:

- The actual dismantlement, decontamination, and remediation (DD&R) costs are almost exactly the same as predicted by the formula; the formula amount is only -0.7% lower for 1997 and only 0.6% higher for 2010. This would seem to indicate that the cost assumptions for labor and materials used in the original study of the TNP decommissioning (References 11, 12, and 13), upon which the PWR formula is based, are reasonably valid. The fact that TNP apparently experienced no significant radiological remediation problems held costs down and kept them in line with the formula cost, which makes no provision for remediation costs.

- Actual project management costs are roughly 2.8 times (1997) and 2.5 times (2010) the costs predicted by the formula for these years. This is consistent with the results for Haddam Neck and Maine Yankee, where project management costs are seven and one-half times higher and four times higher, respectively, than the corresponding formula amounts. (Insufficient cost detail for Ranch Seco precludes a cost comparison for that plant.) The fact that TNP costs are only about two and one-half times higher may be because TNP (unlike Maine Yankee and Haddam Neck) did not use a DOC and did not have to contend with DOC oversight expenses or with additional costs resulting from dissolution of the DOC contracts part way through decommissioning and the subsequent in-house decommissioning oversight by TNP.

- The burial cost predicted by the formula in 2010 is 2.582 times the predicted cost in 1997. This is the ratio of B_x for these years. Over the years from 1995 through 2005 (the period of active TNP decommissioning), the value of B_x ranged from a minimum of 2.015 in 1995 to a maximum of 5.374 in 2004 (References 15 and 16). If the lowest value of B_x is used (2.015), and allowance is made for the fact that the actual volume of waste disposed of is only 68% of the amount assumed in the formula (Table 4.4), a waste burial cost of $31.5 million is obtained ((12501/18328)*(2.015/3.112)*71.3). This is still about 2.4 times the actual cost. The high cost predicted by the formula can be traced to the algorithms used to determine B_x. The B_x factor is developed from a published rate schedule that includes a charge for each cubic foot disposed, a charge for each shipment, a charge for each container in each shipment, a dose-rate charge for each container, and various surcharges and special charges. The B_x factor does not account for an annual revenue constraint that limits the amount of revenue that US Ecology is allowed to collect each year from providing disposal services at the US Ecology disposal facility. The cost of disposal of LLW generated from the TNP decommissioning project was significantly limited by this annual revenue constraint.

Table 4.31. Comparison of Actual Costs with the Minimum Decommissioning Fund Requirement

Cost Category		Actual Cost[a] (1997$)	Formula Cost (1997$)	Actual Cost[b] (2010$)	Formula Cost (2010$)
Dismantlement, Decontamination, and Remediation[c]	*Reactor Vessel Removal*	*17.3*		*27.0*	
	Other Equipment Removal and Surface Decontamination	*40.6*		*63.3*	
	Subtotal	**57.9**	**58.7**	**90.3**	**87.3**
Project Management		103.5	37.7	161.5	61.0
Waste Management	Packaging	14.4	17.1	22.5	25.4
	Waste Shipping	11.1	6.4	17.3	13.3
	Burial	13.1	71.3[d]	20.4	184.1[d]
	Subtotal	**38.6**	**94.8**	**60.2**	**222.8**
Final Status Survey[e]		7.6	0	11.8	0
Totals		**207.6**	**191.2**	**323.8**	**371.1**

(a) From Reference 10.
(b) Escalated from 1997$ using a yearly 1.035 escalation factor.
(c) Formula does not provide for costs of remediation but does include component removal costs.
(d) Formula cost for LLW burial assumes direct disposal of Class A, B, and C waste at the US Ecology disposal facility.
(e) Formula does not provide for a final status survey.

4.4.10 References

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4.5 Rancho Seco Generating Plant

The Rancho Seco Generating Plant was a 913 MWe (2772 MWt) PWR designed by Babcock & Wilcox (B&W). The Sacramento Municipal Utility District (SMUD) operated Rancho Seco from start of operations in April 1975 through permanent plant shut down in June 1989. The facility was located at 14440 Twin Cities Road, Herald, California, in the southeast part of Sacramento County, approximately 26 miles north-northeast of Stockton and 25 miles southeast of Sacramento. The Rancho Seco facility comprised approximately 87 acres situated within a 2480-acre plot of land owned and controlled by SMUD. The area around the former facility is almost exclusively agricultural.

4.5.1 Historical Background

Rancho Seco began commercial operation in April 1975 under Atomic Energy Commission Docket No. 50-309, License No. DPR-54. In accordance with the results of a public referendum on June 6, 1989, SMUD decided to permanently shut down the plant. With its permanent shutdown in June 1989, Rancho Seco had operated for seven refueling cycles and a total of 2,149 (<6 years) effective full power days. On August 29, 1989, SMUD notified the NRC of its intent to seek amendments to the Rancho Seco operating license to decommission the facility. The Commission acknowledged the notification on November 27, 1989. In May 1991, SMUD submitted the proposed Decommissioning Plan for Rancho Seco, along with a Revised Financial Assurance Plan (Reference 22). On March 20, 1995, the NRC issued Rancho Seco's Decommissioning Order authorizing SMUD to decommission Rancho Seco in accordance with the Decommissioning Plan.

Due to revisions to 10 CFR 50.82, SMUD submitted the PSDAR for Rancho Seco in March 1997, which superseded the original Decommissioning Plan.

SMUD continued to assess the cost of decommissioning and determined that the availability of the Envirocare (now Energy*Solutions*) disposal facility presented the possibility of significant cost savings; the cost estimates in the PSDAR were based on the estimated cost of LLW disposal at the future Ward Valley disposal facility, which was never approved, that was significantly higher cost than disposal at the Envirocare facility. On January 9, 1997, the SMUD Board of Directors approved an incremental decommissioning project for Rancho Seco. Incremental decommissioning began in February 1997. Incremental decommissioning involved performing some decommissioning activities earlier than 2008 as originally described in the Decommissioning Plan. SMUD used the decommissioning funds accumulated to-date to accomplish incremental decommissioning.

On July 1, 1999, the SMUD Board of Directors voted to continue the decommissioning process at Rancho Seco until termination of the 10 CFR 50 license, which was anticipated by 2008. Amendment 2 to the PSDAR was submitted to the NRC on November 4, 1999 to reflect this decision (Reference 33). Amendment 2 assumed that Class B and C LLW would be disposed of either at the Barnwell disposal facility or some other facility licensed to dispose of this LLW. However, due to the lack of suitable waste disposal options, SMUD decided to store Class B and C LLW in the Interim Onsite Storage Building until a suitable disposal facility becomes available. The PSDAR was updated to Amendment 4 to reflect this change and submitted to NRC on July 31, 2003 (Reference 2).

Virtually all decommissioning work was completed in 2009 when the majority of the facility was released from the 10 CFR 50 license. The only portion of the facility still under the 10 CFR 50 license is one acre of land containing the Interim Onsite Storage Building (IOSB), within which is stored Class B and C waste. The IOSB is a large facility originally designed to provide storage for five years of LLW generated from operation of the Rancho Seco plant. The stored Class B and C LLW occupies just a small portion of this facility. When a suitable disposal facility becomes available, the waste will be shipped for disposal, and the facility decommissioning will be completed. In 2002 transfer of fuel to the onsite ISFSI was completed. The ISFSI is being maintained under a 10 CFR 72 license (References 1 and 2).

4.5.2 Decommissioning Schedule (Timeline)

In the original decommissioning plan, SMUD proposed to decommission Rancho Seco using SAFSTOR until 2008, which would be followed by Deferred-DECON.

Maintaining Rancho Seco in SAFSTOR until at least 2008 allowed additional time to accumulate sufficient funds to complete decommissioning. Since submitting the original Decommissioning Plan in May 1991, the cost to decommission Rancho Seco continued to escalate primarily because of rising low-level waste disposal cost projections for the Southwest Compact, and increasing facility maintenance and staff costs. In response, SMUD continued to review options for decommissioning Rancho Seco. When alternative waste disposal options became available, SMUD found that it was possible to reduce risk and costs associated with maintaining radioactive systems by starting some decommissioning activities in 1997, instead of waiting until 2008. Initial decommissioning activities included dismantling and disposing of the least contaminated portions of the plant, in what SMUD called “incremental decommissioning.” Due to the success of incremental decommissioning, on July 1, 1999, the SMUD Board of Directors decided to continue decommissioning until the NRC terminates Rancho Seco’s 10 CFR 50 license and releases the site for unrestricted use. However, because of the lack of suitable offsite waste disposal options, Class B and C radioactive waste is being stored in the IOSB until a suitable disposal facility becomes available (Reference 2).

Major milestones are presented below (References 3 and 4).

- On June 7, 1989, Rancho Seco permanently shut down due to public referendum.
- In February 1997, decommissioning began.
- From April 2, 2001 to August 21, 2002, fuel transfer from the pool to the ISFSI was completed. Over the 16-month period, the spent fuel was loaded into 21 NUHOMS dry storage modules and transported to the ISFSI.
- In 2002, the main reactor coolant piping and the reactor coolant pumps were removed and shipped to the Energy*Solutions* facility for disposal.
- In 2003, the reactor head was segmented into five sections and shipped offsite to a processor for disposition.
- In April 2004, the pressurizer was shipped to Energy*Solutions* for disposal.

- In December 2004 and April 2005, the steam generators were shipped to Energy*Solutions* for disposal after being cut into two sections each.

- From March 2005 to May 2006, the reactor vessel internals were segmented, packaged, and either stored onsite or shipped to Energy*Solutions* for disposal.

- From June 2006 to January 2007, the reactor vessel was drained, segmented by abrasive water jet, and shipped to Energy*Solutions* for disposal.

- On August 22, 2006, the canister containing GTCC waste (irradiated steel removed from the reactor vessel) was loaded into the twenty-second storage module and transferred to the ISFSI. A total of 493 spent fuel assemblies were placed at the ISFSI, including 13 damaged assemblies.

- In June 2006, reactor vessel segmentation was completed.

- On April 12, 2006, SMUD submitted the LTP to NRC (Reference 3). On November 27, 2007, the NRC approved the LTP. Revision 1 of the LTP incorporating responses to NRC staff requests for additional information was submitted to NRC on July 10, 2008 (Reference 31).

- In December 2008, physical decommissioning was completed.

- On September 25, 2009, the NRC certified the successful completion of decommissioning when it released the majority of the site for unrestricted public use. Approximately 11 acres of land including a storage building for low-level radioactive waste (1 acre) and a dry-cask spent fuel storage facility (10 acres) remain under NRC licenses.

Since SMUD changed the decommissioning strategy for Rancho Seco from extended SAFSTOR to DECON after the Decommissioning Plan and subsequent PSDAR were submitted, a comparison between the planned schedule and the actual schedule is not provided as it would provide no value in assessing actual performance against planned performance.

4.5.3 License Termination Strategy

SMUD submitted the proposed Decommissioning Plan (Reference 22) for Rancho Seco on May 20, 1991, following premature closure or permanent shutdown of Rancho Seco. The Decommissioning Plan outlined SMUD’s intent at the time to store the used fuel in the spent fuel pool during an initial phase of decommissioning, referred to as Custodial-SAFSTOR, and later move the used fuel to dry storage at an onsite ISFSI during the Hardened-SAFSTOR phase of decommissioning. Because inadequate decommissioning funds had been collected to complete decommissioning of Rancho Seco, SMUD intended to accumulate additional decommissioning funds through the end of the Rancho Seco operating license in 2008. Decontamination and dismantlement of Rancho Seco would then commence thereafter, referred to as

Deferred-DECON. Termination of the 10 CFR 50 license was anticipated by 2011, with non-radiological facility demolition and site restoration completed in 2013.

However, the cost to decommission Rancho Seco continued to escalate due primarily to the rising LLW disposal cost projections for the Southwest Compact and increasing facility maintenance and staff costs. As a result, when alternative waste disposal options became available and the possibility for significant cost savings by using the Envirocare (now Energy*Solutions*) disposal facility, a 3-year incremental decommissioning project was initiated in February 1997 to dismantle the Turbine Building systems and a portion of the tank farm systems (Reference 15). This work was successfully completed leading to approval of full dismantlement in July 1999. The PSDAR was subsequently amended (Amendment 2) in November 1999 to reflect SMUD's intent to proceed with full decommissioning of Rancho Seco. However, due to the lack of suitable waste disposal options, SMUD decided to store Class B and C LLW in the Interim Onsite Storage Building until a suitable disposal facility becomes available. The PSDAR was subsequently amended (Amendment 4) on July 31, 2003, to reflect this change (Reference 2).

The objective of the Rancho Seco decommissioning project was to reduce the level of residual radioactivity to levels that permit the use of the site for unrestricted use and allow for the termination of the 10 CFR Part 50 license. Decommissioning involves the systematic removal of structures, systems, and components (SSCs) that comprise the radioactive portions of the site. SMUD's decommissioning approach was to remove and dispose of radiologically contaminated systems and components, decontaminate the surfaces of structures to meet the release criteria, and leave the major concrete buildings in place for later non-radiological demolition and site restoration. SMUD conducted decommissioning activities in accordance with the NRC's Decommissioning Rule, the Rancho Seco 10 CFR Part 50 license, plant Licensing Basis Documents, and approved procedures.

SMUD used dose modeling to develop DCGLs that demonstrate compliance with the dose-based release criteria. The District then demonstrated through the FSS that the levels of residual radioactivity at the site were equal to or below the DCGLs (i.e., below the dose-based release criteria) with a pre-specified degree of confidence.

SMUD intends to release the Rancho Seco site for unrestricted use in two phases, with the license terminated after completion of the second phase in accordance with the release criteria in 10 CFR 20.1402 (i.e., annual dose limit of 25 mrem plus ALARA for all dose pathways) (Reference 3). The first phase includes the majority of the site, including impacted and non-impacted areas, except for the IOSB. In general, each location will be released after the completion of the associated final status surveys. Virtually all decommissioning work was completed in 2009 when the majority of the facility was released from the 10 CFR 50 license. The only portion of the facility still under the 10 CFR 50 license is one acre of land containing the IOSB, within which is stored Class B and C waste. In the second phase, when a suitable disposal facility becomes available, the waste will be shipped for disposal, and the facility decommissioning will be completed.

In 2002, transfer of fuel to the onsite ISFSI was completed. The ISFSI is being maintained under a 10 CFR 72 license (References 1 and 2).

4.5.4 Project Management

PGE decided to self-perform the decommissioning of Rancho Seco rather than use a DOC. The Rancho Seco organization in April 2004 is provided in Table 4.32. The Rancho Seco Nuclear Plant closure and decommissioning manager had responsibility for overall nuclear safety and decommissioning activities at Rancho Seco. The superintendent for nuclear quality, licensing, and administration was responsible for quality assurance, quality control, and licensing. The project manager for decommissioning had responsibility for decommissioning planning, engineering, decontamination and dismantlement activities, radwaste operations, and cost control. The superintendent for plant support had responsibility for purchasing, nuclear security, and training. The superintendent for nuclear maintenance had responsibility for overall maintenance of plant equipment used to support facility operations and decommissioning activities. The superintendent for nuclear radiation protection/chemistry had responsibility for personnel safety, emergency preparedness, water chemistry, and personnel radiation protection. Total staffing providing planning and oversight of the decommissioning project was about 100 SMUD staff (including security) and about 80 contractors (Reference 23).

Table 4.32. Rancho Seco Decommissioning Organization in April 2004

Level 1	Level 2	Level 3
Nuclear Plant Closure and Decommissioning Manager	Quality Assurance/ Licensing/Administration	Not Applicable
	Decommissioning	Radiological Engineering
		Radwaste Operations
		Dismantlement
		Project Controls
	Plant Support	Not Provided
	Nuclear Maintenance	Not Provided
	Nuclear Radiation Protection/Chemistry	Not Provided

During decommissioning, Rancho Seco continued to implement its Radiological Controls Program. The objectives of the Radiological Controls Program were to control radiation hazards, avoid accidental radiation exposures, maintain worker total effective dose equivalent (TEDE) to less than 5 rem/year, and maintain doses to workers and the public ALARA. The philosophies, policies, and objectives of the Radiological Controls Program were based on federal regulations and associated regulatory guidance.

The Rancho Seco ALARA program was implemented in accordance with the requirements of 10 CFR Part 20 and additional NRC regulatory guidance. The ALARA policy states management’s commitment to maintain exposures to workers and the public ALARA. This commitment was contained in the defueled safety analysis report (DSAR) and was implemented by plant administrative procedures and Radiation Protection Department implementing procedures.

4.5.5 Decommissioning Issues/Approaches

The technology used for decontamination, dismantlement, and disposal of the Rancho Seco plant is summarized below and is based primarily on information provided in the LTP (Reference 3).

Spent Fuel Pool Island (Reference 25)

To allow the removal of normal plant cooling systems and the isolation of the spent fuel pool, a small self-contained cooling and water cleanup system was designed and installed. The system is unique in that it uses a refrigeration system for cooling. All of the equipment sits next to the pool, except for the condensing unit that is just outside the building. The system includes a filter and a portable demineralizer unit.

The pool had a relatively constant leak rate of approximately 50 gallons per day that was directed to the liquid radwaste system. To avoid treating this water a return system was also installed that passed through a filter and demineralizer. This also stops the reduction in boron concentration that was occurring from the leakage and replacement with demineralized water.

System Removal

System removal began in 1997 with secondary system components primarily in the Turbine Building. In 2000, system removal moved to the tank farm and the Auxiliary Building, both containing significantly more contaminated systems. After an initial building decontamination, work moved to the Reactor Building in 2002. Most contaminated systems had been removed by mid-2004 with the exception of large components. Remaining radioactive liquids were processed in temporary systems.

Large Component Removal (LCR)

- Reactor Coolant Pumps

  Main reactor coolant piping and the reactor coolant pumps were removed and shipped in 2002 with the exception of piping sections attached to the reactor vessel remaining in the primary shield walls. Primary piping was cut with machine tooling into short sections that could be filled with other piping and placed into standard shipping containers. The four reactor coolant pumps were removed and packaged for shipment to Energy*Solutions* in two rail cars. Packaging included welded covers on piping connections and stuffing boxes, paint for contamination control, and heavy bags for final packaging. The pumps were blocked and braced in the rail cars with heavy cables and steel cradles.

- Reactor Head

  A major work activity during 2003 involved the disposition of the reactor head. This work began with removal of the Service Structure (weighing 35,000 pounds), which was removed from the reactor head (weighing 160,000 pounds) after flame cutting the lower shroud. The Service Structure was removed from the refueling cavity and taken to an adjacent work area where it was segmented. These sections were packaged into a 20-foot Seavan, which was subsequently sent to a processor for dispositioning.

The next step was to remove the 69 control rod drive mechanisms (CRDMs) from the reactor head. There was very little radiological data associated with the CRDMs and leadscrews, which connected to the control rods, thus the dismantlement crew proceeded very carefully during removal of the CRDMs. The CRDMs were removed by cutting the nozzles just below the mounting flange by use of a machine tool. Once cut, the CRDM was lifted from the cavity, surveyed and placed in a processing area where it was segmented into box-sized lengths, packaged within a metal container, and sent for direct disposal after segmentation.

The reactor head was segmented with use of a diamond wire cable supplied by the segmentation vendor. The five segmented sections included three sections of the flange and two sections of the top portion of the Head, cut just off-center through a clear path around the remaining portions of the CRDM nozzles.

- Pressurizer

The pressurizer, a 45-foot long, 150-ton component, was disposed of at the Energy*Solutions* disposal facility in May of 2004. Preparation for this project included removal of piping systems with subsequent plugging of the penetrations. Contracts were established for rigging and removal of the Pressurizer from the Reactor Building and for railroad transport to Energy*Solutions*. Exterior dose rates were 0.2 mrem/h or less except for a hot spot at the pressurizer bottom where the surge line exits the vessel. To ensure 49 CFR 173.441 radiation limits were met, a carbon steel shielding cover was placed over the surge line and welded to the exterior of the vessel reducing the contact dose rate to less than 200 mrem/h. To prepare the vessel for contamination control while handling onsite, a polymer-based latex paint was applied to the exterior rendering loose contaminant levels to less than 1,000 dpm/100 cm^2. The pressurizer was shipped as a surface contaminated object within a soft-sided strong-tight container.

- Steam Generators

The Rancho Seco steam generators are of Babcock & Wilcox (B&W) design and commonly known as once-through steam generators (OTSGs). The B&W design consists of two such steam generators, each approximately 80 feet in height, 12 feet in diameter, and over 550 tons in weight. The OTSGs were too large to ship to the Energy*Solutions* disposal facility in their intact state due to rail clearances with respect to the length of the generator and certain radii of track along the required route to the disposal facility. Rancho Seco cut the OTSGs in the latitudinal direction at approximately the halfway point and capped the cuts with large steel plates to meet rail requirements and enable the OTSGs to be shipped directly for disposal to Energy*Solutions*.

Rancho Seco staff evaluated each section of the OTSG as its own package and included other documentation to submit with the request for the U.S. Department of Transportation (DOT) exemption which was approved by the DOT in May 2004. The first OTSG was segmented and removed from the Reactor Building in the last quarter of 2004 and loaded onto railcars. Blocking and bracing work was completed and shipment of the OTSG sections was performed in December 2004. The second OTSG was similarly prepared and shipped in January 2005.

- Outside Tanks

  Two large stainless-steel tanks and two lined carbon-steel outdoor tanks were dismantled, packaged and shipped for direct disposal in 2003. The four tanks included the:

  1. Borated Water Storage Tank (BWST),
  2. Demineralized Reactor Coolant Storage Tank (DRCST),
  3. The A Regenerant Hold-Up Tank (RHUT), and
  4. The B Regenerant Hold-Up Tank.

  The process for tank removal was the same for all four – layout of cut locations, lead paint abatement of these locations (if required), plasma arc segmentation of the stainless-steel sections or cutting torch segmentation of the carbon steel sections, and packaging the sections in open-top 20-foot Seavans. The BWST and DRCST presented minor contamination control challenges regarding radioactivity within the tanks - up to 400,000 dpm/100 cm^2 beta-gamma was discovered on the surfaces of the inner walls and floors. A wash-down of the interior was conducted prior to segmentation and the wash water with gross contamination was sent to a holding tank for processing.

  The original plan for the RHUTs was to attempt free release, however residual activity prevented this. The inside of the RHUTs were lined with a rubber barrier, which was removed and placed within a Seavan with segmented sections of the tank. The barrier was only slightly contaminated and the desire was that the inner tank would be free of detectable contamination and could thus be free released. Small amounts of radioactive contamination were discovered in many areas inside the tank and the decision was made not to pursue free release.

  The BWST and the DRCST each weighed 112,000 pounds while the A RHUT weighed 38,000 pounds and the B RHUT weighed 56,000 pounds. The segmented waste from these tanks was packaged into eight open-top 20-foot Seavans; each Seavan contained approximately 300 cubic feet of waste and was shipped for disposal at the Energy*Solutions* disposal facility.

Underground Pipe Removal

Most of the underground pipe of highly contaminated systems was removed prior to 2006 except for a small portion removed in 2006. These systems include the decay heat system, borated water system, radioactive waste system, and the spent fuel cooling system. Other minimally contaminated systems were also removed, or sampled and surveyed to ensure that they could remain. These include the component cooling water system, auxiliary feedwater system, main condensate and make-up system, and portions of the clean drain system used for radioactive effluents. Portions of non-impacted systems in close proximity to the target piping were also removed. The radioactive discharge line from the RHUTs to the retention basins was removed in 2007.

Reactor Vessel and Internals Removal and Disposal

- Reactor Vessel Internals

  The final activation analysis and radiological characterization of the reactor vessel and internals was completed in June of 2003. Mechanical cutting and milling (and brute force) were used to remotely segment the internals underwater. Segmentation and packaging of the internals commenced in March 2005 and was completed 14 months later in May 2006. Core baffles and formers (GTCC waste) totaled approximately 50,000 curies with 28,000 curies attributable to ^{60}Co. The GTCC waste weighs approximately 25,000 pounds and was packaged into a single canister that is being stored within the onsite ISFSI alongside the spent fuel under the separate Part 72 license.

  The plenum (mostly Class A) was cut out of the water using diamond wire with the Class C portion returned to the water for further cutting. Final cutting on the plenum pieces was done mechanically and with plasma. Class A pieces were shipped in boxes and liners to the Energy*Solutions* disposal facility.

  With the exception of the plenum, the vessel internals were cut or disassembled underwater with mechanical milling or cutting devices designed to minimize the production of fine material that could be dispersed in the water or air. This Class B and C waste, approximately 16,000 curies (as of January 1, 2006), is being stored in liners in the IOSB under the Part 50 license until acceptable disposal is arranged.

- Reactor Vessel

  Draining of the reactor cavity water and vacuuming of the reactor cavity was completed in June 2006 after completion of the reactor vessel internals removal project. Robotically-controlled high-pressure water/grit cutting was used to segment the reactor vessel for packaging and disposal. The cut plan for the reactor vessel is provided in Figure 4.1. Segmenting of the reactor vessel was completed in January 2007. All pieces except the six beltline pieces were shipped in sealand containers for disposal at the Energy*Solutions* disposal facility. The beltline pieces were placed in two boxes and grouted, then shipped by rail to the Energy*Solutions* disposal facility. No DOT exemptions were needed for the shipment.

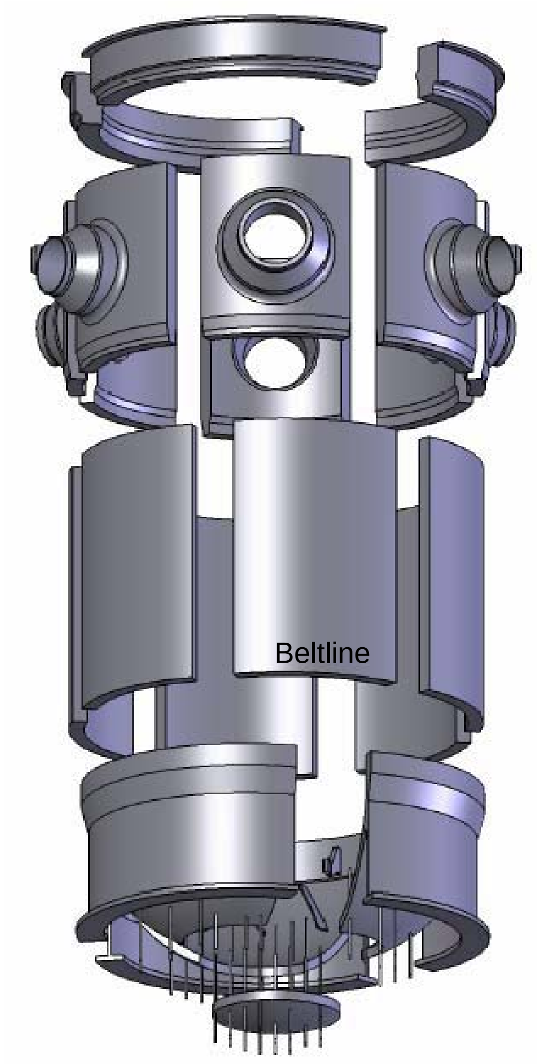

Figure 4.1. Reactor Vessel Cut Plan (Reference 24)

Decontamination and System Dismantlement Activities

Following the removal of equipment and components, structures were surveyed as necessary and contaminated materials were remediated or removed and disposed of as radioactive waste. Contaminated structural surfaces were remediated to a level that met the established radiological criteria.

Decontamination methods include wiping, washing, pressure washing, vacuuming, scabbling, spalling, and abrasive blasting. Selection of the preferred method was based on the specific situation. Other decontamination technologies were considered and utilized, as appropriate. Approved administrative procedures and processes controlled decontamination. These controls ensured that wastewater is collected for processing by liquid waste processing systems. Airborne contamination control and waste processing systems were used as necessary to control and monitor releases.

The principal remediation method used for removing contaminants from concrete surfaces was scabbling and shaving. Scabbling is a surface removal process that uses pneumatically operated air pistons with tungsten-carbide tips that fracture the concrete surface to a nominal depth of 0.25 inch at a rate of about 20 ft^2 per hour. A second form of scabbling used was needle guns. The needle gun is a pneumatic air-operated tool containing a series of tungsten carbide or hardened steel rods enclosed in a housing. A third form of scabbling used was chipping, which includes the use of pneumatically operated chisels and similar tools couplet to vacuum-assisted devices. Shaving uses a series of diamond cutting wheels on a spindle, and performs at similar rates to scabbling.

Most contaminated piping was removed and disposed of as radioactive waste. Any remaining contaminated piping buried or embedded in concrete was remediated using methods such as grit blasting. Grit blasting uses grit media such as garnet or sand under intermediate air pressure directed through a nozzle that is pulled through the closed piping at a fixed rate. The grit blasting action removes the interior surface layer of the piping. A HEPA vacuum system maintains the sections being cleaned under negative pressure and collects the media for reuse or disposal. The final system pass is performed with clean grit to remove any residual contamination.

Decontamination and Disposition of Site Buildings

- Reactor Building Internal Structure Removal

  Once the reactor vessel was removed, work began on the removal of almost all concrete and internal structures in the Reactor Building. Removal of the concrete to the liner plate minimized the need for decontamination and simplified the FSS. Some liner decontamination was required to meet the DCGL. Structure removal included the activated steel and concrete around the vessel, and the polar crane. About the only item remaining in the structure was the building liner.

- Auxiliary Building

  Extensive decontamination was required for rooms belowgrade level in the Auxiliary Building. Many of the rooms were exposed to leaking or spraying water systems and decontamination included extensive surface removal including core boring and sawing.

- Spent Fuel Pool

  The 11 spent fuel racks were removed from the pool during the first quarter of 2003 and shipped to Energy*Solutions* for direct disposal. The process for removal and disposal began with vacuuming the debris from each cell, followed by a radiological survey for hot spots and further rack decontamination during removal from the pool. A vacuuming unit coupled with high-loading filters was used to collect the loose debris from the racks.

  Upon removal each rack was placed on the cask wash-down platform, where a thorough decontamination and survey of each cell and outer surface was performed. The racks were then removed from the wash-down platform and staged for drying, followed with a coating of spray adhesive, and wrapped in 12-mil plastic. The 12-mil plastic served for contamination control during packaging, which occurred outside on the plant turbine deck.

The racks were then moved to a laydown area outside the fuel building, down-ended, and placed in a watertight shipping bag. The final step involved re-rigging the rack for placement in a large metal strong-tight container. Each rack had a sufficiently low quantity of radioactivity that use of the strong-tight container was allowed. Radiological surveys were performed to ensure DOT radiation limits were met, communications applied, and the package placed on the transport vehicle for disposal. Each transport package contained only one rack and was transported by highway for disposal at Energy*Solutions*.

Dose rates on the rack exteriors ranged from 2 mrem/h on the top to 15 mrem/h in the middle, and 50 to 80 mrem/h on the bottom. Hotspots within the cells ranged from 1 to 4 rem/h. The hotspots were easily removed through decontamination using high-pressure washing except for the 4-rem/h hotspot, which was found between the cells and was found to be mobile. After making several attempts to remove the hot spot, ready-mix grout was poured into the cell matrix, to fix the hotspot in place. The introduction of grout lowered the measured dose rate to less than 80 mrem/h.

Prior to decontamination, loose surface contamination ranged from 300,000 to 500,000 dpm/100 cm^2 beta-gamma, and less than 20 dpm/100 cm^2 alpha. Post-decontamination levels were found to be no more than 30,000 dpm/100 cm^2 beta-gamma.

Following successful completion of the rack project, the remaining pool water was drained, and the pool walls and floor were pressure washed. Loose contamination levels on the floor and walls after washdown ranged from 1,000 to 3,000 dpm/100 cm^2. The remaining water and wash water was sent to a holding tank for processing. Work then commenced on removal of the pool liner plate, which was constructed of ¼-inch-thick stainless steel and was connected to the concrete wall with numerous embedded supports positioned at 6-foot centers in the horizontal and vertical direction. Various methods for removal were considered including plasma cutting and machine cutting the plates. Plasma cutting would have involved a tremendous effort to construct an enclosed area to control smoke and potential hazardous fumes (chromium +6) generated by the flame cut. Although a slow process, machine cutting was selected because it generated little secondary waste, involved no industrial hygiene concerns and was proven to be capable of performing the cuts.

The machine cutting was performed with a carbide bit installed on a hydraulically operated milling unit track which could be positioned horizontally or vertically depending on the cut to be made. The carbide bit travels along the milling unit track machining the stainless steel as it travels. The milling unit was affixed to the wall by use of fasteners installed with a stud gun.

The milled sections of the liner plate were loaded into top-loading 20-foot Seavans and shipped for direct disposal. Dose rates on a loaded Seavan were no greater than 0.2 mrem/h.

Once the liner plate was removed, the underlying concrete structure and subsurface soil was sampled to ascertain if pool water leakage (known to have occurred) would require their excavation and packaging for disposition. One interior wall where significant pool liner leakage occurred was removed. After the wall was removed the remaining wall and floor surfaces were decontaminated, as well as embedded leak chases and through-wall pipes. No significant activity was found below the concrete floor.

- Turbine Building

  The Turbine Building had only minor contamination levels requiring little decontamination, with the exception of selected floor drain piping segments and sumps.

- Embedded Piping

  Embedded pipe systems were located in all of the impacted buildings identified above. Most embedded system piping was for floor drains. These embedded piping was cleaned with an initial high-pressure wash to remove debris followed by an abrasive grit blast process as required. Once cleaned to acceptable limits most embedded piping was grouted to mitigate reuse or transport of remaining residual activity.

4.5.6 Non-Decommissioning Fund Activities

ISFSI (Reference 3)

SMUD submitted to the NRC on October 4, 1991, a site-specific 10 CFR 72 ISFSI application using the VECTRA HUHOMS-MP187 dual purpose cask design. SMUD signed the contract in 1992 for the design, licensing, and fabrication of a transportable storage system. In 1995, the ISFSI was constructed and fabrication of the cask and associated equipment began. However, in 1996, quality issues throughout the dry storage industry and vendor bankruptcy forced work to be stopped. In 1997, a new supplier resumed the design and license work. The NRC granted the 10 CFR 72 license for the ISFSI on June 30, 2000.

The transportable storage system consists of a transportation cask, 21 dry storage canisters, 22 horizontal storage modules, and a multi-axle trailer. The cask serves for onsite transfer and offsite transportation overpack for the canisters. The canisters hold the spent fuel in a structural array and are then seal-welded. The horizontal storage modules are thick reinforced concrete storage bunkers used to store the canisters. The twenty-second module provides storage for GTCC waste from reactor vessel internals.

Fuel movement began in May of 2001 and was completed in August of 2002. A total of 493 used fuel assemblies were placed in the ISFSI, including 13 damaged assemblies. The canister containing the GTCC waste loaded into the ISFSI on August 22, 2006. All spent fuel and the GTCC waste is currently stored in the ISFSI under a separate Part 72 license.

Asset Recovery (Reference 3)

The electrical generator was sold and removed in 2002. The switchyard remains in operation by the newly constructed Cosumnes Power Plant (CPP) being operated on a nonimpacted portion of the 2,480-acre Rancho Seco site.

Non-Radiological Decommissioning Activities (Reference 3)

Non-radiological decommissioning activities included the removal of temporary buildings such as wooden or metal structures after being cleared by radiation protection. The remaining concrete pads were surveyed as a part of the FSS process. Underground storage tanks for diesel fuel oil were removed and the remaining lines cleaned.

Asbestos was removed from the cooling towers, the roofs of permanent buildings and other miscellaneous locations. The removal of asbestos from piping and components was a major effort. The standard procedure was to survey the item for activity, tent the area and remove the asbestos. It was determined that if the component or pipe could be surveyed and released, the whole pipe section could go to the asbestos disposal site, minimizing the removal effort. This led to the practice of glove-bagging the area of pipe to be cut and surveying the inside after removal, leaving the asbestos on the outside of the pipe. For large-bore pipe, if the pipe was internally contaminated it was moved to a central asbestos tent and remediated in batches. Piping within the Auxiliary Building was glove-bagged in sections so that small-bore piping could be sent to the waste site with the asbestos intact, minimizing the remediation effort (Reference 25). Asbestos abatement, initially estimated to cost $2 million, was projected to cost $5 million by the time it was completed (Reference 26).

Removal of non-essential materials and equipment and general cleanup of the site was also performed.

After obtaining the Phase I site release, low areas are to be filled and graded for drainage. These areas include the cooling tower basins and canal, the spray ponds and the belowgrade portion of the Turbine Building including the circulating water lines. Other grading and landscaping may occur.

4.5.7 Soil and Groundwater Remediation

In accordance with NUREG-1575 (Reference 27) SMUD conducted a Historical Site Assessment (HSA) of Rancho Seco between July 2001 and August 2006 when the report was issued (Reference 28). The objective of the HSA was to (Reference 3):

- Identify known and potential sources of radioactive material and radioactively contaminated areas including systems, structures and environmental media based on the investigation and evaluation of existing information;

- Identify areas of the site with no conceivable or likely potential for radioactive or hazardous materials contamination and assign a preliminary classification of non-impacted while assigning a preliminary classification of Impacted to all remaining portions of the site;

- Evaluate the potential for migration of radiological and hazardous substances beyond the boundaries of the industrial area or SMUD property;

- Develop the records to be utilized during the design of subsequent scoping, characterization, remediation, and the FSS; and

- Provide preliminary information necessary to identify and segregate the site into survey units evaluated against the criteria specified in the MARSSIM guidelines for classification. This classification will designate the need for and level of remedial action required within a particular survey unit as well as the level of survey intensity required during the FSS.

The HSA consisted of a review of historical plant incident records, plant maintenance records, plant modification records, plant radiological survey records, and regulatory reports submitted by SMUD to various government agencies. The HSA also included written questionnaires and oral interviews with current and past facility employees regarding historical incidents that posed potential impacts to the facility. A review of historic site aerial photographs and physical inspections of the facility were performed to verify and validate the results of the historical record reviews.

The HSA identified plant areas that were potentially radiologically impacted by plant operations, including from radiological spills and loss of control of radioactive material events that could have resulted in the potential for contamination spread. Relative to the potential for environmental contamination, the HSA concluded that, based on current and historic sample results from the Rancho Seco Radiological Environmental Monitoring Program (REMP), there was no indication that surface waters on or near the facility or the groundwater off of the site had been affected by operation of Rancho Seco (Reference 28).

Concurrent with the HSA, SMUD performed an initial characterization of the Rancho Seco site between 2001 and 2002 that was the result of reviews and evaluations previously conducted to determine the extent and nature of residual contamination. Areas in the Industrial Area identified as having been radiologically impacted by the operation of the plant included retention basins, tank farm, barrel farm, area adjacent to the RHUT area, storm drains, oily water separator, cooling tower basins, and Turbine Building drains and sumps. Areas outside the industrial area determined to be potentially radiologically impacted included the discharge canal sediment, discharge canal soil, depression area soil (next to “No Name” Creek), and storm drain outfall.

The results of an initial characterization survey (ICS) also identified the following impacted soil regions: plant effluent water course, tank farm, spent fuel pool cooler pad, Spent Fuel Pool Building/Diesel Generator Room gap, and subsoil beneath the Spent Fuel Pool Building footprint. Soil remediation activities were performed for the spent fuel pool cooler pad region, which showed a ^{137}Cs activity of 9.41E+02 pCi/g in the soil, and were concurrent with removal of buried piping in the same region (Reference 27). Soil was remediated in isolated locations to a depth of 2.5 meters with follow-up characterization showing that residual concentrations were below the DCGL.

During the FSS, surface scans were performed for all soil areas based on the three survey unit classifications as described in NUREG 1757 (Reference 27). Soil samples were normally collected from the surface layer (top 15 cm) and, if contamination below 15 cm was suspected, confirmatory investigation and analyses of deeper soil samples of the suspect area were performed (Reference 3). For most survey units, all of the surface scans were less than the DCGL and so no investigation was required. However, several areas were determined to require further investigation and a few of these showed that soil contamination was greater than the DCGL and therefore required some soil remediation. Specific areas requiring soil remediation included the South Retention Basin (structure used for containment and final treatment of liquid effluents prior to their release from the site) and the plant effluent water course (release point for liquid effluents released from the site).

4.5.8 Radioactive Waste Volumes and Activity

This section provides the total volume of LLW generated from the decommissioning of Rancho Seco that was shipped offsite, to either direct disposal or to waste processors, and the total volume of LLW that was shipped directly to disposal. The volume shipped for disposal is compared to the LLW volume assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

LLW Volume and Activity Shipped Offsite

Most waste from Rancho Seco was dispositioned by one of three paths: 1) disposal at a burial facility, 2) offsite processing for free release or volume reduction, or 3) onsite free release. Plant components that never came into direct contact with radioactive systems or which could be easily cleaned by grit blasting were considered candidates for onsite free release. In addition, an extensive final site survey process was used to free release decontaminated structures, most of which are expected to be demolished at a later time under the category of non-radiological decommissioning activities. The total quantity of free released material is not available, although through the year 2003 this quantity was reported to be 8,500,000 pounds (3,855,500 kg) (Reference 30).

The volume and activity of radwaste generated and shipped offsite during the Rancho Seco decommissioning project is provided in Table 4.33. This data was principally derived from the Annual Radioactive Effluent Release Reports for Rancho Seco (References 5 through 14) and the LTP (Reference 3). These reports provide the volume and activity of Class A shipped annually from the Rancho site. As discussed previously Rancho Seco has not shipped any Class B and C waste offsite but is instead storing all such waste onsite in the IOSB. It is estimated that about 93 m^3 (3300 ft^3) of Class B/C waste is stored in the IOSB, which includes 17 CNS 8-120 cask liners containing segmented reactor vessel internals (Reference 16), five high-integrity containers (HICs) containing ion exchange resin, and less than 3 m^3 (100 ft^3) of other generated waste (Reference 15).

Table 4.33. Radwaste Volume and Activity Generated During Rancho Seco Decommissioning[(a)]

Year Shipped	Class A Volume (m^3)	Class A Volume (ft^3)	Class A Activity (Ci)
1998	196	6,922	0.0
1999	481	17,000	1.8
2000	547	19,314	4.7
2001	564	19,921	5.0
2002	1,213	42,840	64.8
2003	845	29,847	16.2
2004	919	32,460	131.1
2005	791	27,921	131.1
2006	563	19,879	167.1
2007	8,172	288,599	79.8
2008	3,491	123,283	30.2
2009	154	5,428	0.3
Total	**17,936**	**633,413**	**632.1**

(a) Information is from Rancho Seco Annual Radioactive Effluent Release Reports (Reference 5 through 14) and the LTP (Reference 3).

Table 4.34 provides the number of shipments required to transport the radwaste reported in Table 4.33. These data are taken principally from the Annual Radioactive Effluent Release Reports (References 5 through 14). As can be seen in the table, shipments were generally by truck to the Clive, Utah, disposal facility.

LLW Volume and Activity Direct-Shipped to a Disposal Facility

Table 4.35 reports the volume and activity of LLW generated from the decommissioning of Rancho Seco and shipped directly to the Energy*Solutions* disposal facility for disposal. This information was obtained from the DOE MIMS, which is a database of LLW information derived from the manifests for waste shipments as reported to the DOE by each of the commercial LLW disposal sites (Reference 29). No LLW was shipped to the Barnwell disposal facility for disposal. The information provided in Table 4.35 is only that LLW shipped directly from the Rancho Seco site to the LLW disposal facility. It does not include LLW shipped from radwaste vendors after processing. The difference between the volumes in Tables 4.33 and 4.35 would ordinarily be expected to be that volume shipped to LLW waste processors, however, the total volume shipped from the site as reported in Table 4.33 is less than the total volume reported to have been disposed of at the Energy*Solutions* disposal facility, as shown in Table 4.35. For most years the Table 4.35 volumes are higher as expected. The major reason for the discrepancy is that the volume for 2008 is reported to be significantly higher in Table 4.35 than

Table 4.33 suggesting that one or the other of these is reported incorrectly in the respective references. It is unknown which volume was reported incorrectly.

Table 4.34. Number of Radwaste Shipments and Mode of Transport[a]

Year Received	Clive, Utah, (Energy*Solutions* Facility)		LLW Processor		Total	
	Truck	Rail	Truck	Rail	Truck	Rail
1997	NA	NA	NA	NA	NA	NA
1998	NA	NA	NA	NA	NA	NA
1999	44	0	0	0	44	0
2000	20	0	0	0	20	0
2001	37	0	0	0	37	0
2002	68	2	1	0	69	2
2003	52	0	11	0	63	0
2004	43	3	10	1	53	4
2005	27	2	5	0	32	2
2006	42	4	8	0	50	4
2007	189	97	0	0	189	97
2008	90	41	3	0	93	41
2009	8	0	2	0	10	0
Total	**620**	**149**	**40**	**1**	**660**	**150**

(a) Information is from Rancho Seco Annual Radioactive Effluent Release Reports.

Table 4.35. Radwaste Volume and Activity Received at the Clive, Utah, Disposal Facility[a]

Year Shipped	Class A Volume (m^3)	Class A Volume (ft^3)	Class A Activity (Ci)
1998	192	6,780	0.1
1999	504	17,799	1.9
2000	541	19,109	4.6
2001	539	19,045	5.0
2002	1,075	37,962	59.4
2003	765	27,031	12.6
2004	835	29,471	97.0
2005	687	24,276	131.3
2006	380	13,428	45.9
2007	7,795	275,272	37.8
2008	6,449	227,759	40.4
2009	124	4,391	0.3
Total	**19,888**	**702,324**	**436.2**

(a) Information is from the DOE Manifest Information Management System (Reference 19).

Based on the information in Tables 4.33 and 4.35, the following observations are made:

- The total volume of LLW disposed of at the Clive, Utah, disposal facility is reported to be 7.0E+05 ft^3 (2.0E+04 m^3). Ignoring the volumes reported for years 1999 and 2008 in which the volume shipped to the Clive, Utah, disposal facility is reported to be greater than the volume shipped from the Rancho Seco site, the total difference in volume for the remaining years implies about 3.6E+04 ft^3 (1.0E+03 m^3) was shipped to radwaste vendors for further processing and disposal. If this processed waste volume is added to the total volume reported to have been disposed of at the Clive, Utah, disposal facility, and to the total volume of Class B/C LLW reported/estimated to be stored onsite, the total volume of LLW generated during the decommissioning of Rancho Seco becomes 7.4E+05 ft^3 (2.1E+04 m^3). The processed waste volume represents about 5% of the total volume reported/estimated as having been generated during decommissioning of Rancho Seco (i.e., Class A LLW shipped from the Rancho Seco site during decommissioning and Class B/C LLW continuing to be stored onsite).

- The total volume of LLW disposed of at the Clive, Utah, disposal facility is reported to be 7.0E+05 ft^3 (2.0E+04 m^3). This represents about 95% of the total volume of 7.4E+05 ft^3 (2.1E+04 m^3) reported/estimated to have been generated during decommissioning of Rancho Seco.

- No Class A LLW was disposed of at the Barnwell disposal facility.

- The total volume of Class B/C LLW disposed of at the Barnwell disposal facility is reported/estimated to be 3.3E+03 ft^3 (93 m^3), representing about 0.4% of the total volume of LLW generated during decommissioning.

The PSDAR does not provide an estimate of the LLW to be generated during decommissioning, therefore a comparison cannot be made to the actual LLW volumes generated during decommissioning. However, the preliminary Decommissioning Plan provided an estimate of 199,000 ft^3 (5,630 m^3) to be generated and disposed during decommissioning, which is a factor of about 3.7 less than the LLW volume actually generated during decommissioning. Insufficient information is available to ascertain the reasons for this difference.

Decommissioning LLW Volume Comparison to Minimum Decommissioning Fund Requirements

The cost basis for the 10 CFR 50(c) minimum decommissioning fund formula includes assumptions with regard to the volume of LLW generated during decommissioning. The cost bases and assumptions for the formula are provided in NUREG/CR-0130 (Reference 17) and subsequent Addendums 3 and 4 to that report (References 18 and 19). The volume of LLW assumed in the formula is provided in Table 4.36, which provides a breakdown of the total LLW volume generated/shipped and the LLW volumes assumed to be shipped to the Barnwell disposal facility, to the Clive, Utah, disposal facility, and to waste processors. Table 4.36 also provides a comparison of the formula LLW volume assumptions to the actual LLW volumes generated during decommissioning of Rancho Seco, as summarized from Table 4.35 and the text above. The following observations are made:

- The total volume reported/estimated to have been generated during decommissioning of Rancho site is about 15% higher than that assumed by the formula.
- The total volume of LLW disposed of at the Barnwell facility is zero, versus the value of 39,375 ft^3 assumed by the formula.

Table 4.36. Comparison of Formula and Actual LLW Volumes

	Formula Volumes		Actual Volumes	
LLW Shipped/Received	m^3	ft^3	m^3	ft^3
Total Volume[(a)]				
Class A	17,964	634,392	20,917	738,687
Class B	214	7,564	93[(a)]	3,300[(a)]
Class C	17	600		
GTCC	133	4,700	85[(b)]	3,000[(b)]
Total	**18,328**	**647,256**	**21,095**	**744,987**
Volume to Barnwell Disposal Facility				
Class A	982	34,675	0	0
Class B	116	4,100	0	0
Class C	17	600	0	0
GTCC	133	4,700	0	0
Total	**1,248**	**44,075**	**0**	**0**
Percentage		6.8%	0%	0%
Volume to Clive, Utah, Disposal Facility				
Class A	16,982	599,717	19,888	702,324
Class B	98	3,464	0	0
Class C	0	0	0	0
GTCC	0	0	0	0
Total	**17,080**	**603,181**	**19,888**	**702,324**
Percentage		93.2%		95%
Volume to Waste Processors				
Class A	0	0	1,030	36,364
Class B	0	0	0	0
Class C	0	0	0	0
GTCC	0	0	0	0
Total	**0**	**0**	**1,030**	**36,364**
Percentage		0.0%		5%

(a) Only the combined volume of Class B and C waste is known. Waste has not been shipped offsite.

(b) Based on the volume of 493 fuel assemblies stored at the ISFSI and the volume of 33,300 pounds of GTCC waste (from the segmentation of irradiated internal reactor components), also stored at the ISFSI.

- The cost basis for the formula assumed that the GTCC waste is disposed of at the Barnwell facility as LLW. GTCC waste is actually being stored at the ISFSI for later disposal. Disposition of GTCC waste is no longer considered a decommissioning cost.

- The actual volume of LLW disposed of at the Clive, Utah, facility is about 16% higher than the amount assumed in the formula. The formula also assumes a small volume of Class B waste goes to the Clive, Utah, facility for processing and disposal, while no Class B wastes were actually sent to this facility from the Rancho Seco decommissioning project. It is recognized that the Clive, Utah, disposal facility cannot dispose of Class B LLW; however, it is assumed that this small volume can be processed/treated and appropriately dispositioned.

- The current cost basis for the formula does not assume any of the LLW is shipped to waste processors for treatment and/or alternate disposal. The actual volume of LLW shipped to waste processors represents less than 5% of the total volume shipped from the Rancho Seco site.

4.5.9 Decommissioning Cost Comparison to Minimum Decommissioning Fund Requirements

This section provides the decommissioning cost estimated by the licensee prior to the start of significant decommissioning activity and the actual decommissioning cost incurred by the licensee to decommission Rancho Seco. The actual decommissioning cost incurred is also compared to the decommissioning cost assumed in the 10 CFR 50.75(c) formula used to determine the minimum decommissioning fund requirement for a nuclear power plant.

Estimated Decommissioning Cost

The initial cost to decommission the Rancho Seco plant and terminate the NRC license was estimated to be $280.8 million (1991$) (Reference 2). However, this estimate assumed that Rancho Seco would be placed into an interim storage condition (SAFSTOR) for monitoring until 2008 after which decommissioning would be initiated. As was discussed earlier, decommissioning activities actually began in 1997 and so the Decommissioning Plan cost estimate does not represent the actual decommissioning strategy pursued.

Amendment 2 to the PSDAR (Reference 33) represents the earliest decommissioning cost estimate that reflects the decision in 1999 to proceed with full decommissioning. The cost to complete decommissioning was estimated to be $433 million (1999$), as shown in Table 4.37. This cost estimate includes the cost of managing the used nuclear fuel (i.e., ISFSI construction and operation), which was not enumerated.

Amendment 4 to the PSDAR subsequently provided an updated decommissioning cost estimate of $518.6 million (2002$), of which $274.7 million had already been expended through 2002 and $243.9 million was the estimated remaining decommissioning cost. These costs included the costs to manage the spent nuclear fuel (e.g., ISFSI construction and operation). No breakdown of these costs into lower-level cost categories was provided in the PSDAR.

Table 4.37. Estimated Cost to Decommissioning Rancho Seco (Reference 33)

Decommissioning Cost Category	Total (Millions of 1999$)
Decontamination	7.460
Removal	46.049
Staffing	212.675
LLW Disposition	
Packaging	5.288
Transportation	3.792
Disposal	38.425
Total	47.505
Other	73.386
Contingency	46.339
Total	**433.414**

The estimated cost to decommission Rancho Seco was once again updated in the LTP to $534.2 million (2005$), of which $371.1 million had already been expended through 2005 and $163.1 million was the estimated remaining decommissioning cost (Reference 3). As with the cost estimate provided in the PSDAR, these costs included the costs to manage the used nuclear fuel (e.g., ISFSI construction and operation) and no breakdown of these costs into lower-level cost categories was provided in the LTP.

Actual Decommissioning Cost

The actual cost to decommission Rancho Seco is provided by year and in total in Table 4.38 (References 20 and 32). These costs also include the costs to manage the spent nuclear fuel (e.g., ISFSI construction and operation) and no breakdown of these costs into lower-level cost categories is available. SMUD estimates that an additional cost of $22.2 million ($2010) will be incurred to transfer GTCC waste to DOE in 2027, provide oversight of the IOSB through 2028, and to terminate the 10 CFR 50 license in 2028 (Reference 20). This estimated additional cost is being retained in the 10 CFR 50 license decommissioning fund.

SMUD estimated the total cost of spent fuel management and other non-radiological decommissioning activities, both actual costs incurred and estimated remaining costs, to be $132.5 million (Reference 20). Subtracting the estimated remaining cost of $22.2 million, the total actual cost reported in Table 4.38 for used fuel management is $110.3 million. Subtracting this cost from the total cost of $482.2 million in Table 4.38 results in the actual cost to-date of $371.9 million to perform the radiological decommissioning of Rancho Seco and release most of the plant site from the 10 CFR 50 license. However, the total cost to complete the radiological decommissioning of Rancho Seco includes the cost to eventually dispose of the Class B/C waste currently in storage at the IOSB, the cost to maintain and decommission the IOSB, and the cost to terminate the 10 CFR 50 license. Adding the estimated cost of $22.2 million to perform these activities to the total decommissioning cost to-date yields the total cost to complete the radiological decommissioning of Rancho Seco of $394.1 million.

Table 4.38. Rancho Seco Actual Decommissioning and Used Fuel Management Costs ($ millions)

Year	Estimated ISFSI and other Non-Radiological Decommissioning Costs	Estimated Cost for Radiological Decommissioning	Annual Cost[(a)]
1994	27.6	7.8	35.3
1995	16.6	7.8	24.4
1996	2.2	15.7	18.0
1997	2.2	16.2	18.4
1998	2.2	19.7	21.9
1999	2.2	32.5	34.7
2000	2.2	43.6	45.8
2001	11.0	25.2	36.2
2002	11.0	29.8	40.9
2003	5.5	18.4	23.9
2004	5.5	25.8	31.4
2005	5.5	28.9	34.4
2006	5.5	26.4	31.9
2007	5.5	39.1	44.6
2008	5.5	31.1	36.6
2009	0	3.9	3.9
Total	**110.3**	**371.9**	**482.2**

(a) Information 1994 through 2008 from the 2011 decommissioning fund status report (References 20). Information for 2009 from 2009 SMUD Annual Financial Report (Reference 32).

Since information was not available on the annual used fuel management costs, a cost spread was assumed, as shown in Table 4.38, in which 40% of the cost was spread over the years 1994 and 1995 when the ISFSI dry storage vault was constructed, an annual cost of $2.2 million from 1996 through 2000 when delays in SNF canister procurement and loading occurred due to bankruptcy of the vendor and resolution of technical issues, a cost of $11 million in 2001 and 2002 during which the SNF was loaded into canisters and moved to the ISFSI, and $5.5 million for the annual operation of the ISFSI from 2003 to 2008, the last year in which the annual cost of the ISFSI was financed from the decommissioning fund. These annual used fuel management costs were then subtracted from the total actual costs reported in Table 4.38 to develop an annual actual cost for radiological decommissioning activities only. These costs were then converted to 2010 dollars using an annual escalation rate of 3.5%. The total actual cost to complete radiological decommissioning of Rancho Seco, including the estimated $22.2 million to dispose of the Class B/C LLW and terminate the 10 CFR 50 license, was determined to be $512.4 million (2010 $).

The minimum decommissioning fund requirement for a nuclear power plant is specified by the formula in 10 CFR 50.75(c). Using the latest revision of NUREG-1307 (Reference 21), the inputs to the formula appropriate for Rancho Seco are as follows:

- thermal power – 2772 MW
- labor factor (L) – 2.29 (for western U.S.)
- energy factor (E) – 2.139 (for PWR)
- burial factor (B) – 12.28 (for direct disposal of Class B and C waste at the Barnwell or Generic disposal facility and with vendor processing/disposal of Class A waste)

Using these inputs, the calculated minimum decommissioning fund requirement in 2010$ is $444.1 million, which is $50 million more than the Rancho Seco estimate. Detailed decommissioning cost breakdowns, like those presented in Tables 4.10 and 4.21 for Haddam Neck and Maine Yankee were not available for this study. This lack of data precludes discussing the reasons for the difference between Rancho Seco's estimate of decommissioning costs and the minimum decommissioning fund amount specified by the formula. However, it should be noted that the formula predicts that about $268.5 million would be spent on waste disposition. If, in fact, Rancho Seco did spend this amount on waste disposal, only $103.3 million would be left for all other decommissioning costs combined—a highly unlikely possibility. Both Maine Yankee and Haddam Neck spent about $120 million on waste disposition (Tables 2.10 and 3.10). It is reasonable to assume that Rancho Seco's LLW disposal cost is less than this amount since all of its Class A LLW was disposed of at the Energy*Solutions* disposal facility and the volume of LLW disposed is much less than that disposed of from the Maine Yankee and Haddam Neck decommissioning projects.

4.5.10 References

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4.6 Summary

This section compares the actual radiological decommissioning costs for four nuclear plants that have completed radiological decommissioning: HNP, MY, TNP, and Rancho Seco. An extensive review and evaluation of each of the four decommissioning projects was performed based on publicly available information and information provided by representatives for each of the four projects. The main purpose of this review and evaluation is to gain sufficient understanding of the decommissioning strategies and processes used and the associated costs so as to perform a comparison with the decommissioning strategy and costs used in the minimum decommissioning fund formula contained in 10 CFR 50.75(c). In general, publicly available information on the decommissioning strategies, methods, and waste volumes was sufficient for the purposes of this study. However, representatives for each of the decommissioning projects were contacted to obtain the more detailed decommissioning cost information than was available publicly. The representatives for HNP and MY provided very detailed, categorized decommissioning costs by year. The cost data provided for Trojan was significantly less detailed but covered the major cost elements. However, only total decommissioning cost data were provided for Rancho Seco, making any detailed comparison with the assumptions in the minimum decommissioning fund formula impossible.

4.6.1 Comparison of Key Attributes for Four Decommissioning Projects

Table 4.39 provides a comparison of key attributes for each of the four decommissioning projects.

Table 4.39. Comparison of Four Decommissioning Projects

Plant Name	Haddam Neck	Maine Yankee	Trojan	Rancho Seco
Reactor Type	PWR	PWR	PWR	PWR
Reactor Model	Westinghouse 4-loop	Combustion Engineering 3-loop	Westinghouse 4-loop	Babcock and Wilcox
Power Rating (MWe/MWt)	590/1825	931/2700	1130/3411	913/2772
Date of Last Operation	December 1996	December 1996	November 1992	June 1989
Date of License Termination or Partial Land Release	November 2007	October 2005	May 2005	September 2009
Decommissioning Strategy	DECON	DECON	DECON	SAFSTOR (8-year SAFSTOR period)
Project Management Strategy	DOC initially, followed by self-perform	DOC initially, followed by self-perform	self-perform	self-perform
License Termination Strategy	Partial Land Release from 10 CFR 50 License (Only ISFSI Remains)	Partial Land Release from 10 CFR 50 License (Only ISFSI Remains)	10 CFR 50 License Terminated – ISFSI Licensed Under 10 CFR 72	Partial Land Release from 10 CFR 50 License (Only Storage Facility for Class B/C LLW Remains) – ISFSI Licensed Under 10 CFR 72
Release Criteria	NRC – 25 mrem/yr + ALARA, and State of Connecticut – 19 mrem/yr + ALARA, EPA – 4 mrem/yr groundwater dose	NRC – 25 mrem/yr + ALARA and State of Maine – 10 mrem/yr + 4 mrem/yr groundwater dose	NRC – 25 mrem/yr + ALARA	NRC – 25 mrem/yr + ALARA
Steam Generator Disposition	Segmented into 2 pieces – steam domes to waste processor, lower half to Barnwell	One piece barged to waste processor	One piece barged to US Ecology	Segmented into 2 pieces – sent to Energy*Solutions*
RPV Internals	Segmented and LLW sent to Barnwell; GTCC stored in ISFSI	Segmented with 70% left inside grouted RPV and sent to Barnwell, 20% containerized and sent to Barnwell; GTCC stored in ISFSI	Left intact inside grouted RPV and sent to US Ecology	Segmented and Class A LLW sent to Energy*Solutions*, Class B/C stored onsite facility, and GTCC stored in ISFSI
RPV	Barged intact to Barnwell	Barged intact to Barnwell with some internals	Barged intact to US Ecology with all internals	Segmented, containerized, and sent to Energy*Solutions*

Table 4.39. (contd)

Plant Name	Haddam Neck		Maine Yankee		Trojan		Rancho Seco	
Environmental Remediation – Volume of Contaminated Soil	1.17E+06 ft^3 (3.3E+05 m^3)		Minimal – 2.5E+04 ft^3 (7.1E+02 m^3)		Minimal		Minimal	
Decommissioning Costs (2010 $ millions)	**Actual**	**Formula[(a)]**	**Actual**	**Formula**	**Actual**	**Formula**	**Actual**	**Formula**
D&D and Miscellaneous[(b)]	420.5	85.4	225.5	92.7	102.1	87.3	Not Available	110.8
Project Management	376.7	50.0	228.0	54.2	161.5	61.0	Not Available	64.8
LLW Packaging, Transportation, and Disposal	121.3	278.6[(c)]	121.7	302.1[(c)]	60.2	222.8[(c)]	Not Available	268.5[(c)]
TOTAL	**918.5**	**414.0**	**575.2**	**449.0**	**323.8**	**371.1**	**512.4**	**444.1**
Waste Allocation by Facility								
Barnwell LLW Facility	0.4%	6.8%	0.4%	6.8%	0%	0%	0%	6.8%
Energy*Solutions* LLW Facility	13.1%	93.2%	71.5%	93.2%	0%	0%	95%	93.2%
US Ecology LLW Facility	0%	0%	0%	0%	100%	100%	0%	0%
Waste Processors	86.6%	0%	28.1%	0%	0%	0%	5%	0%
Total LLW Volume Disposed (m^3)	**240,084**	**15,894**	**135,382**	**17,239**	**12,501**	**18,328**	**20,917**	**17,351**

(a) "Formula" means values obtained from References 3 and 4, and the minimum decommissioning fund formula in 10 CFR 50.75(c).
(b) "Miscellaneous Costs" include regulatory costs, insurance, property taxes, and final status survey.
(c) For Haddam Neck, Maine Yankee, and Rancho Seco, the formula cost for LLW packaging, transportation, and disposal assumes direct disposal of Class B and C waste at the Barnwell or Generic disposal facility with vendor processing/disposal of Class A waste. For Trojan, the formula cost for LLW packaging, transportation, and disposal assumes direct disposal of Class A, B, and C waste at the US Ecology disposal facility.

Prompt decommissioning (DECON) following permanent shutdown was the decommissioning strategy pursued by HNP, MY, and TNP. Rancho Seco initially implemented an extended safe storage (SAFSTOR) strategy but changed strategies after about 8 years of SAFSTOR to decommission the plant. HNP and MY each initially employed a decommissioning operations contractor (DOC) to conduct decommissioning operations; both of these plants subsequently terminated contracts with their DOC part way through the decommissioning period and self-performed the remaining decommissioning. Both TNP and Rancho Seco self-performed the decommissioning throughout the decommissioning project.

Typical decontamination methods were employed at the four plants. Contaminated systems and components were typically removed and sent to an offsite processing facility, sent to an LLW disposal facility, or decontaminated onsite and free released. Other decontamination methods typically included wiping, washing, vacuuming, scabbling, spalling, and abrasive blasting.

Contaminated systems were disassembled as necessary and then cut up as necessary. Disassembly generally means removing fasteners and components in an orderly non-destructive manner (i.e., the reverse of the original assembly). Cutting methods included flame cutting, abrasive cutting, and cold cutting. Abrasive water-jet cutting was generally used to segment the RPV internals.

Each of the four plants took a slightly different approach to the removal and disposal of large components. At HNP and Rancho Seco, the steam generators were cut in half and portions either sent to a licensed radioactive material vendor for processing or directly to an LLW facility for disposal. The primary system parts, including the pressurizer and main coolant pumps, for HNP, MY, and Rancho Seco were sent to the Energy*Solutions* disposal facility. TNP sent its steam generators and pressurizer on a single barge shipment to the US Ecology LLW disposal facility. MY had the most varied approach. The steam generators and pressurizer, serving as their own transport containers, were shipped by barge to a waste vendor in Tennessee for processing. The primary system parts, including reactor coolant pumps, were shipped to the Barnwell facility for disposal. The reactor coolant pump motors were shipped to the Energy*Solutions* facility for disposal.

The HNP RPV internals (the core barrel, baffles, and lower core support plate) were segmented, removed, and stored as GTCC LLW at the ISFSI. The RPV was barged intact, as its own burial package, to Barnwell for disposal. The MY RPV internals were segmented by abrasive water jet and mechanical cutting. About 70% (by weight) of the internals were shipped with the reactor vessel to the Barnwell facility for disposal, 20% of the internals were shipped (also to Barnwell) in casks, and 10%, as GTCC, were stored in the ISFSI. The TNP RPV internals were not segmented, but were left in the pressure vessel, which was barged as its own container to the US Ecology facility for disposal. At Rancho Seco, the reactor vessel internals were segmented by abrasive water jet and the GTCC waste was stored at the ISFSI, the Class B/C waste was stored in an onsite storage facility until a disposal facility for Class B/C waste becomes available, and the Class A waste was shipped to the Energy*Solutions* facility for disposal. The RPV was segmented and shipped to the Energy*Solutions* facility for disposal.

Table 4.39 compares two sets of data for each plant: actual decommissioning costs and waste volumes; and costs and waste volumes derived from the minimum decommissioning fund formula in 10 CFR 50.75(c) and References 3 and 4. Decommissioning costs are divided into three broad categories: D&D and miscellaneous costs, Project Management costs, and LLW Packaging, Transportation, and Disposal costs. The D&D and Miscellaneous category includes other costs, such as regulatory costs, insurance, property taxes, and final status survey. The following observations are made:

- Of the four plants, actual costs and waste volumes for TNP and Rancho Seco come closest to values predicted by the formula. This is not surprising since the TNP and Rancho Seco decommissioning approaches were similar to the cost basis for developing the formula. The decommissioning approaches for HNP and MY were significantly different than that assumed in the formula, as discussed further below.

- The actual costs of D&D and miscellaneous activities are significantly higher than predicted by the formula for HNP and MY, but are about the same for TNP where actual and formula costs are in relatively good agreement. Insufficient information is available to compare the formula and actual costs for Rancho Seco. There are at least two reasons the D&D and miscellaneous costs are higher for HNP and MY than for TNP and the formula:
    - The decommissioning approach for HNP and MY was to demolish all site structures to belowgrade, including radiologically-contaminated buildings such as the containment building and auxiliary building, and ship this demolition debris offsite for either processing or directly to disposal as LLW. The decommissioning approach for TNP and Rancho Seco was to decontaminate structures to below the DCGL, perform a final status survey, release the land/structures from the 10 CFR 50 license, and demolish the released structures later as non-radiological decommissioning activities. The approach used at TNP and Rancho Seco is the same approach assumed in the formula.
    - The decommissioning of HNP required a significant environmental remediation effort. Minimal environmental remediation was required at MY, TNP, and Rancho Seco. The formula also assumes minimal environmental remediation is required. In addition the more stringent cleanup criteria at HNP (i.e., 10 mrem/yr all pathway dose and 4 mrem/yr groundwater dose) resulted in significant additional soil remediation effort than would have been required if using the NRC cleanup criteria (i.e., 25 mrem/yr all pathway dose + ALARA), as discussed further below. It is likely the more stringent cleanup criteria used at MY (i.e., 19 mrem/yr all pathway dose and 4 mrem/yr groundwater dose) also contributed to the significantly higher D&D costs for that project.

- It is apparent that the formula *significantly underestimates* project management costs for HNP, MY, and TNP. Insufficient information is available to compare the formula and actual costs for Rancho Seco. The significantly higher project management costs for HNP and MY are likely due to the same reasons identified above for D&D costs. In addition, the higher project management costs for the HNP and MY projects were likely due to the increased complexities of managing a DOC under fixed price contracts and the resultant schedule delays, and other costs associated with terminating the DOC contracts and ramping up staffing to self-perform the decommissioning. However, even in the case of TNP, which did not have any of the complexities above described complexities associated with the HNP and MY projects, the actual project management costs are more than a factor of two higher than predicted by the formula.

- It is also apparent that the formula *significantly overestimates* LLW disposal costs. The case of HNP is especially noteworthy. HNP generated thirteen times the LLW volume predicted by the formula, yet the cost to disposition this LLW was less than half that predicted by the formula. The MY results are similar; MY generated more than seven times the LLW volume predicted by the formula yet the formula estimates an LLW disposition cost more than two times that actually incurred. It is also noteworthy that the volume of LLW generated at TNP was about 30% less than that predicted by the formula, yet the formula predicted an LLW disposition cost almost four times higher than actually incurred.

  As discussed above, the volume of LLW generated at HNP included a significant quantity of contaminated soil that had to be removed to meet the EPA maximum contaminant levels for the drinking water standards. Both HNP and MY also had a high volume of waste resulting from the demolition of all buildings to an elevation equivalent to three feet or four belowgrade and the subsequent disposition of this demolition debris at an LLW disposal facility, a waste processor, or other appropriate disposal facility. Also contributing to the high waste volume at MY were the enhanced state cleanup standards that established more restrictive cleanup levels than the NRC regulations. HNP was able to achieve a very low cost per unit volume by disposing of 86.6% of its waste through waste vendors. MY disposed of 28.1% of its waste through waste vendors (or other appropriate disposal facility), a much lower percentage than that achieved by HNP. This may explain why HNP could dispose of more waste at less cost than MY.

4.7 References

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5 COMPARISON OF ESTIMATED AND ACTUAL DECOMMISSIONING COSTS

In this section, the low-level waste (LLW) volume and decommissioning cost information provided in Sections 2 through 4 for four plants that have completed decommissioning are compared to one another and to corresponding estimates developed using the 10 CFR 50.75(c) minimum decommissioning fund formula. The comparison is provided by reactor type (i.e., PWR and BWR).

5.1 Background

This section summarizes the results from Sections 2 through 4 of this report. In Section 2, the NUREG/CR-5884 and NUREG/CR-6174 decommissioning cost estimates for the reference PWR nuclear plant (i.e., Trojan Nuclear Plant) and the reference BWR nuclear plant (i.e., Columbia Generating Station) were updated to year 2010 dollars and to incorporate changes to the costing methodology based on nuclear power plant decommissioning experience since the original estimates were developed in the early 1990s. In Section 3, the decommissioning cost estimates for 23 nuclear power reactors that were submitted to the NRC by licensees were reviewed and compared. In Section 4, an in-depth review and assessment of the decommissioning approach and resultant decommissioning costs for four nuclear power plants that had completed decommissioning was performed. In this section, the results from Sections 2 through 4 are compared for those plants in which a cost estimate is available for the DECON decommissioning strategy.

5.2 Comparison Basis

The formula in 10 CFR 50.75(c) that establishes the minimum decommissioning fund requirement for nuclear power plant licensees is based on two studies that were performed by PNNL for the NRC in the late 1970s (References 1 and 2). The Reference 1 study developed a detailed decommissioning cost estimate for a reference PWR, the Trojan Nuclear Power Plant, which has since been decommissioned. Similarly, the Reference 2 study developed a detailed decommissioning cost estimate for a reference BWR, the Columbia Generating Station (formerly WNP-2). Both of these studies developed detailed decommissioning cost estimates for both the immediate dismantlement (DECON) and deferred dismantlement (SAFSTOR) decommissioning strategies. Both studies concluded that, while the SAFSTOR strategy has a higher decommissioning cost on a constant dollar basis, the DECON strategy has a higher decommissioning cost on a discounted dollar or net present value (NPV) basis (assuming a 4% real discount rate). For this reason, the 10 CFR 50.75(c) decommissioning fund formula was developed using the estimated costs for implementing the DECON decommissioning strategy.

Subsequently, in the early 1990s, as discussed in Section 2, PNNL updated the decommissioning cost estimates for the NRC in References 3 and 4 for the Trojan Nuclear Power Plant and the Columbia Generating Station, respectively. Both of these studies developed detailed decommissioning cost estimates for the DECON, SAFSTOR, and entombment (ENTOMB) decommissioning strategies. Since ENTOMB is unlikely to result in license termination within 60 years of permanent cessation of reactor operations as required by 10 CFR 50.82(a)(3), it is not considered a viable decommissioning strategy. Both of the updated studies, with the exception of one ENTOMB scenario, also concluded that implementing the DECON decommissioning strategy has a higher cost on an NPV basis (assuming a 3% real discount rate).

There is no universally accepted method for determining the appropriate discount rate to use when comparing alternatives having different cash flows. However, the U.S. Office of Management and Budget (OMB) has annually published recommended discount rates for use in benefit-cost analyses of federal programs since 1979 (Reference 5). Discount rate recommendations are provided for time horizons ranging from 3 years to 30 years. Since in the SAFSTOR strategy decommissioning is generally assumed to be completed 30 to 60 years after permanent cessation of operations, using a discount rate reflecting a 30-year time horizon is appropriate. The average of the 30-year discount rates reported for the years 1979 through 2011 in Reference 5 is 4.2%, while the average over the 10 years between 2002 and 2011 is 3.1%. Based on this, using a 3%–4% discount rate in the NPV calculation is reasonable and the conclusions from the original and updated PNNL decommissioning cost studies that the DECON strategy has a higher cost on an NPV basis than the SAFSTOR strategy remains valid. For this reason only costs for the DECON strategy are considered further in this study.

5.3 Summary of Comparison Results

Table 5.1 summarizes the decommissioning costs reported in Sections 2 through 4 for those scenarios that assumed the DECON strategy. Plants are first sorted by type of reactor (i.e., PWR and BWR) and then listed alphabetically. For each reactor type, the following is included in the table:

- The “Formula Reference BWR/PWR Station” provides the estimated decommissioning costs in 2010 dollars using the decommissioning fund formula from 10 CFR 50.75I, updated using NUREG-1307, Rev. 14 (Reference 6).

- The “Updated Reference BWR/PWR Station” provides the estimated decommissioning costs in 2010 dollars reported in Section 2.

- The estimated decommissioning costs provided by licensees for individual plants, which have a cost basis of “Estimate,” are summarized from the Section 3 results and are provided in the dollar year of the estimate.

- The decommissioning costs reported for Haddam Neck, Maine Yankee, Rancho Seco, and Trojan, which have a cost basis of “Actual,” are the actual costs to complete the decommissioning of these plants as reported in the Section 4 results.

Table 5.1. Decommissioning Costs and Waste Volumes for DECON of Selected Reactors

Plant Data				License Termination Costs				LLW Volumes (ft^3)			
Plant	Capacity (MWth)	Year[(a)]	Cost Basis[(b)]	D&D and Other	Waste Disposal	Program Management	Total	Class A (LLW Facility)	Class A (Clive)	Class B/C	Processed
BWR Plants											
Formula Reference BWR Station[(c)]	3486	2010	Estimate-SC	87	409	116	612	88,755	564,634	15,046	0
			Estimate-WA	87	199	116	401	653,389	0	15,046	0
Updated Reference BWR Station	3486	2010	Estimate-SC	91	325	101	517	23,227	491,496	19,152	0
			Estimate-WA	91	141	101	333	514,723	0	19,152	0
Cooper	2381	2008	Estimate	142	133	231	506	0	234,031	4,852	319,826
Duane Arnold	1912	2008	Estimate	NA[(d)]	NA	NA	486	0	395,615	4,198	0
LaSalle 1	3546	2009	Estimate	187	124	235	547	0	178,877	6,647	579,346
LaSalle 2	3489	2009	Estimate	200	129	245	573	0	178,877	6,647	579,346
Monticello[(c)]	1775	2005	Estimate	131	108	208	447	0	90,448	8,774	287,833
Oyster Creek	1930	2003	Estimate	155	152	174	480	68,944	227,835	12,451	386,250
Vermont Yankee	1912	2006	Estimate	111	130	228	469	0	327,916	5,146	340,035
PWR Plants											
Formula Reference PWR Station[(c)]	3411	2010	Estimate-SC	65	322	83	469	86,830	547,562	8,163	0
			Estimate-WA	65	190	83	338	634,393	0	8,163	0
Updated Reference PWR Station	3411	2010	Estimate-SC	95	189	77	361	12,021	268,913	9,900	0
			Estimate-WA	95	99	77	271	280,394	0	9,900	0
Braidwood 1	3586	2009	Estimate	149	92	201	442	0	108,978	4,463	191,872
Braidwood 2	3586	2009	Estimate	199	87	243	529	0	108,978	4,463	191,872
Byron 1	3586	2009	Estimate	149	92	208	448	0	111,170	4,463	189,420
Byron 2	3586	2009	Estimate	193	86	242	521	0	111,170	4,463	189,420
Diablo 1	3411	2002	Estimate	113	143	288	545	98,652	0	16,829	0
Diablo 2 & Common	3411	2002	Estimate	132	143	291	566	107,868	0	15,846	0
Haddam Neck	1825	1997-2007	Actual	323	102	295	721	7,581	1,109,243	25,598	7,338,993
Kewaunee	1772	2008	Estimate	NA	NA	NA	381	0	92,949	2,987	12,668

Table 5.1. (contd)

Plant Data				License Termination Costs				LLW Volumes (ft^3)			
Plant	Capacity (MWth)	Year[(a)]	Cost Basis[(b)]	D&D and Other	Waste Disposal	Program Management	Total	Class A (LLW Facility)	Class A (Clive)	Class B/C	Processed
Maine Yankee[(f)]	2700	1997-2005	Actual	153	95	176	424	6,239	3,417,904	14,233	1,342,583
Prairie Island 1	1677	2008	Estimate	128	87	273	488	0	105,572	3,387	132,037
Prairie Island 2	1677	2008	Estimate	151	92	295	538	0	111,901	3,387	156,555
Rancho Seco	2772	1994-2009	Actual	NA	NA	NA	394	0	594,780	3,300	31,711
Salem 1	3459	2002	Estimate	134	121	234	489	67,763	23,405	13,608	72,765
Salem 2	3459	2002	Estimate	150	123	272	545	68,016	30,460	13,626	74,384
Three Mile Island 1	2568	2008	Estimate	154	113	238	504	0	216,729	5,410	179,851
Trojan	3411	1993-2005[(g)]	Actual	58	39	111	208	430,204	0	11,229	NA

(a) Year of original estimate or decommissioning period if plant has completed decommissioning.
(b) Estimate-SC – assumes use of the Barnwell disposal facility; Estimate-WA assumes use of the US Ecology disposal facility.
(c) The original decommissioning studies included disposal of 4,700 ft^3 (PWR) and 1,660 ft^3 (BWR) of GTCC waste in the cost estimate.
(d) NA – not available.
(e) The processed waste volume for Monticello was estimated by dividing the total reported processed volume of 12,088,970 pounds by an assumed average density of 42 pounds/ft^3.
(f) Cost shown here is different than shown in Table 4.20 due to adjustments to account for legal costs and litigation awards.
(g) Although decommissioning occurred between 1993 and 2005, actual costs were provided in 1997 dollars.

Two types of data are presented in the table: license termination costs and waste volumes disposed of during the decommissioning process. License termination costs are composed of 1) D&D costs (which include decontamination and component removal costs, regulatory and insurance costs, property taxes, final status surveys, etc.), 2) project management costs, and 3) waste disposal costs (packaging, shipping, and burial).

As shown in Table 5.1, licensees sent their Class A waste to the Energy*Solutions* facility at Clive, Utah, and/or to an LLW facility (i.e., either the Barnwell or US Ecology disposal facilities). The Trojan Nuclear Plant used the US Ecology LLW facility near Richland, Washington, when it decommissioned. In Section 2 of this report, it was assumed that the Columbia Generating Station would also use this LLW facility when it decommissioned. For all other cases in the table, the LLW facility, if used, is the disposal facility at Barnwell, South Carolina.

Vermont Yankee provided cost estimates for four DECON alternatives and Cooper provided cost estimates for two DECON alternatives; however, there was no difference in the reported license termination cost, on a constant dollar basis, for these alternatives. Many of the licensee-developed cost estimates reported in Section 3 of this report included estimates for a DECON alternative and for a delayed DECON alternative. In all of these cases, the DECON alternative had a higher estimated decommissioning cost on a constant dollar basis and so the cost for the DECON alternative is reported in this summary.

The results presented in Table 5.1 are discussed in more detail in the following sections.

5.4 LLW Volume Results

The decommissioning fund formula assumes that the total LLW volume generated from decommissioning scales linearly with the thermal capacity of the nuclear plant. Figures 5.1 and 5.2 show the relationship of the total LLW volumes reported in Table 5.1 with the corresponding thermal capacities and the decommissioning fund formula for BWRs and PWRs, respectively. The following observations are made from these figures:

- Estimated LLW volumes are generally higher for BWRs than for PWRs as is expected.

- For BWRs, Monticello, Duane Arnold, Oyster Creek, and Vermont Yankee have similar thermal capacities (1700–2000 MWth), but the total volume of LLW generated from decommissioning ranges from about 400,000 ft^3 to about 700,000 ft^3, suggesting that there is no clear relationship between thermal power capacity and total LLW volume. However, the LLW volume for Vermont Yankee includes 135,000 ft^3 of contaminated soil sent directly to the Energy*Solutions* disposal facility for disposal. Not counting this volume, the total LLW volume for Vermont Yankee is about 538,000 ft^3. It is also noted that the LLW volume reported for Oyster Creek also includes "remediation of a significant volume of contaminated soil." How much of the total reported volume is represented by the "significant volume" is not reported. Not including the contaminated soil volume in the Vermont Yankee and Oyster Creek LLW volume totals does suggest a linear relationship between thermal power capacity and total LLW volume, and that the

LLW volume estimates assumed in the decommissioning fund formula are fairly representative of the licensee estimates.

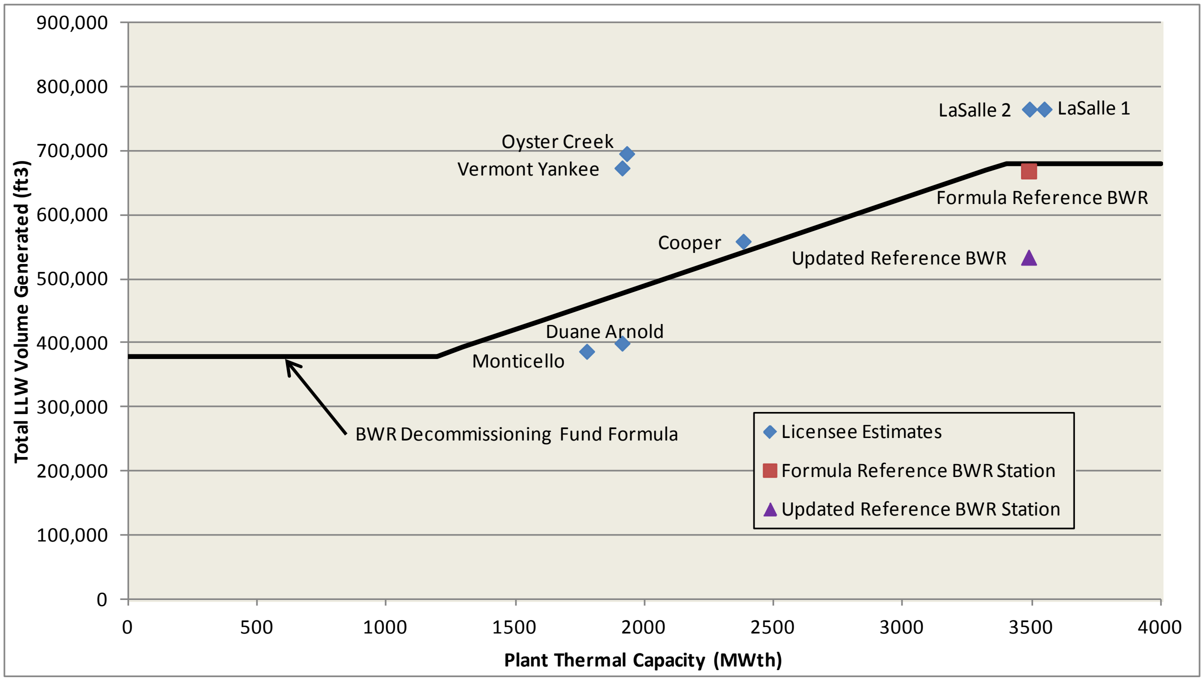

Figure 5.1. BWR LLW Volume vs. Thermal Capacity

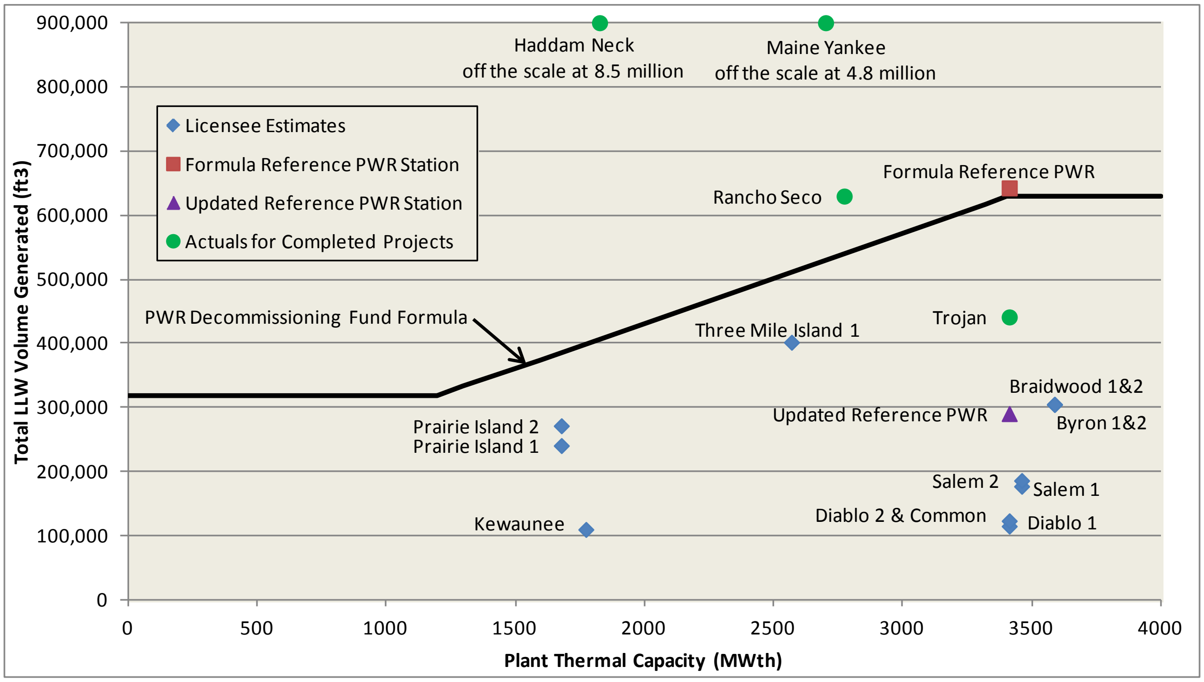

Figure 5.2. PWR LLW Volume vs. Thermal Capacity

- For PWRs, the total LLW volumes for Kewaunee and Prairie Island 1&2, having thermal capacities of 1700–800 MWth, are essentially the same as the estimated volumes for Diablo Canyon 1&2, Salem 1&2, Byron 1&2, and Braidwood 1&2, which have thermal capacities of 3400 to 3600 MWth, implying no clear relationship between thermal power capacity and total LLW volume. The estimated total LLW volume ranges between 100,000 and 300,000 ft^3 for all of these plants. It is noted that the LLW volumes reported for Diablo Canyon 1&2 do not include the volume sent for offsite processing, and so the total volume reported for this plant is low by some unknown amount. Also, all of the licensee estimates were less than the LLW volume estimates assumed in the decommissioning fund formula and, in some cases, by substantial amounts (over 300,000 ft^3).

- However, in every case but one, LLW volumes reported for PWR plants that have completed decommissioning are higher than the both the licensee- and PNNL-estimated volumes, and, in the case of Haddam Neck and Maine Yankee, are significantly higher (about an order of magnitude).
  - Only the LLW volume estimated in the original PNNL study and used in the 10 CFR 50.75(c) formula (Reference 1) was significantly higher than the actual volume reported for Trojan. The original PNNL study volume was also slightly higher than the actual volume reported for Rancho Seco.
  - As discussed in the Section 4 of this report, the significantly higher actual LLW volumes reported for Haddam Neck and Maine Yankee are likely due to the much more restrictive cleanup criteria used at these plants than was used at Rancho Seco and Trojan.
  - Also as discussed in the Section 4 of this report, the higher volume at Haddam Neck was partially due to the significant quantity of contaminated soil that required remediation. None of the other three projects reviewed that have completed decommissioning had any appreciable volume of contaminated soil.
  - It is noted in Table 5.1 that most of the Haddam Neck volume was sent to waste processors. As discussed in Section 4 of this report, much of this volume was ultimately disposed of at controlled landfills in Tennessee because of its very low activity and so should not be classified as LLW.
  - It is also noted in Table 5.1 that while a significant quantity of the LLW volumes for Haddam Neck and Maine Yankee were sent to waste processors, in both of these cases over 1 million ft^3 was sent to an LLW disposal facility. This is significantly higher than any of the estimates by the licensees or in the PNNL studies.

- The actual LLW volume reported for the Trojan decommissioning project falls just about halfway between the original estimate used in the 10 CFR 50.75(c) formula (Reference 1) and the updated PNNL study (Reference 3). The updated study estimated an LLW volume similar to the licensee-developed estimates.

- In general, for PWRs, the licensees' and the updated PNNL study LLW volume estimates appear to substantially underestimate actual LLW volumes that will be generated during decommissioning and are less than the LLW volumes assumed in the decommissioning fund formula. However, the actual LLW volumes reported for three of the four plants that have completed decommissioning are higher than the volumes reported in the formula. For the reasons discussed previously regarding the very restrictive cleanup criteria used in the Haddam Neck and Maine Yankee decommissioning projects, the Rancho Seco and Trojan experiences are believed to be more representative of nuclear plant decommissioning projects implemented to achieve the NRC license termination criteria. The formula LLW volume estimates for these two plants are higher than the Trojan actual volume but less than the Rancho Seco actual volume.

Figures 5.3 and 5.4 show the relationship of the Class B/C LLW volumes reported in Table 5.1 with the corresponding thermal capacities and the decommissioning fund formula for BWRs and PWRs, respectively. There is no clear linear relationship of Class B/C LLW volume to plant thermal capacity. Also, the formula tends to predict a higher Class B/C LLW volume than in the licensee estimates. The few exceptions, namely Oyster Creek (BWR), Diablo Canyon (PWR), and Salem 1 & 2 (PWR), are all notably older estimates developed in the 2002–2003 time frame. The more recent licensee estimates are more consistent with the experience at Rancho Seco. Since there was no available disposal capacity for Class B/C LLW generated from the decommissioning of Rancho Seco, an objective of the RPV internals segmentation project was to minimize the amount of Class B/C material since the Class A material could be disposed of at the Energy*Solutions* disposal facility while the Class B/C LLW continues to be stored at the Rancho Seco site until a disposal facility becomes available. The recent licensee estimates appear to be incorporating this experience as most licensees currently would face a similar situation if they were to decommission their plants today. The actual volume of Class B/C LLW generated at Haddam Neck, Maine Yankee, and Trojan are all higher than predicted by the formula. Each of these sites had available disposal capacity for their Class B/C LLW, providing less incentive to minimize its generation.

At the time the decommissioning cost estimates were developed for the original PWR and BWR studies used in the 10 CFR 50.75(c) formula (References 1 and 2), three full-service LLW disposal facilities were available to all nuclear power plant licensees for the disposal of Class A, B, and C LLW. When the updated decommissioning cost estimates (References 3 and 4) were developed, two full-service LLW disposal facilities were available to all licensees, the US Ecology facility near Richland, Washington, and the Barnwell facility near Barnwell, South Carolina. The Nevada facility closed on December 31, 1992, and the US Ecology facility limited access to only licensees located in the Northwest and Rocky Mountain Compacts effective January 1, 1993. Subsequently, the Barnwell facility began limiting access by steadily reducing the annual volume of LLW that it would accept and eventually limited access to only licensees located in the Atlantic Compact effective July 1, 2008. This decreasing availability of LLW disposal capacity, and corresponding rapidly increasing cost for use of the available capacity, spawned the creation of a niche market for firms specializing in the management and disposal of LLW, referred to as waste processors or vendors. Effective with the 1998 (Revision 8) update of NUREG-1307 (Reference 7), without modifying the decommissioning formula itself, the guidance on how to determine the B_x factor was updated in recognition of this evolving LLW disposition practice. More recently, with the unlimited availability of Class A disposal capacity at the Energy*Solutions* facility, there has been a movement away from using third party waste processors/vendors and sending Class A LLW directly to disposal at the Energy*Solutions* facility.

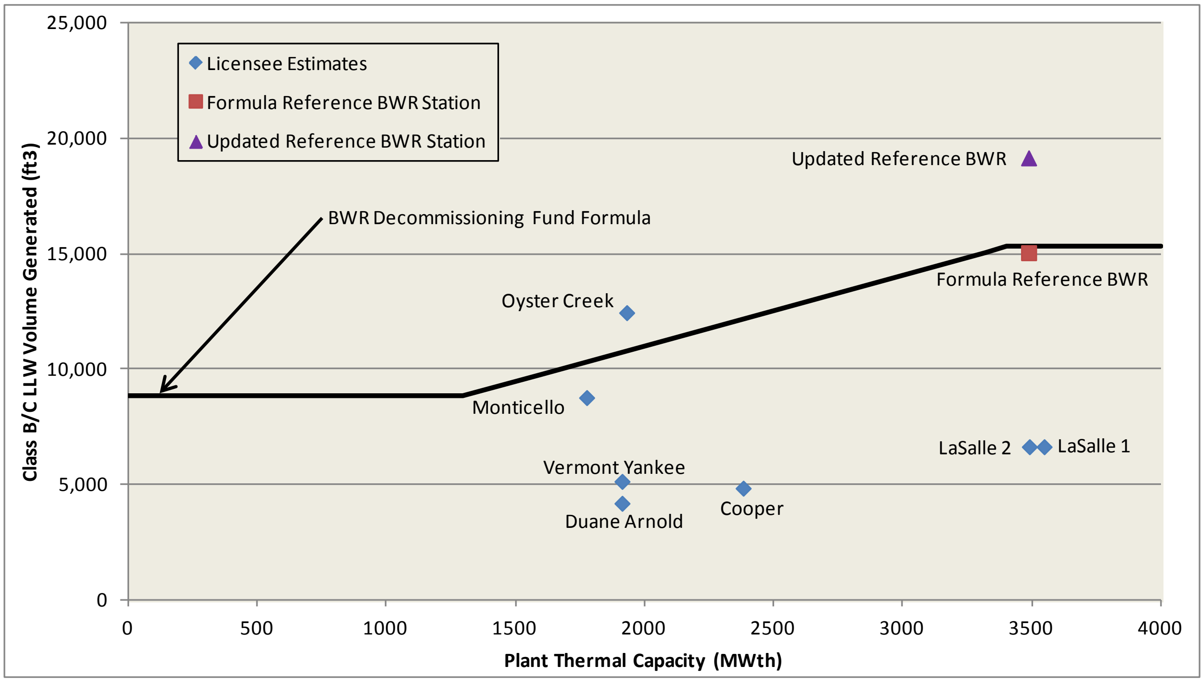

Figure 5.3. BWR Class B/C LLW Volume vs. Thermal Capacity

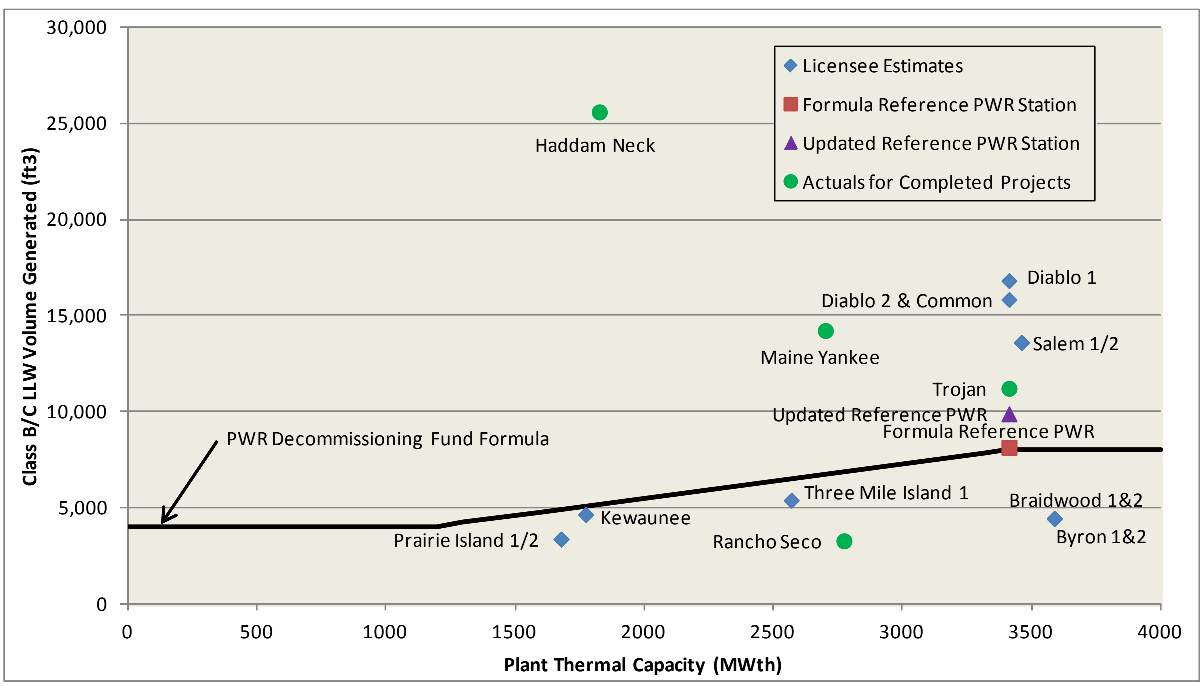

Figure 5.4. PWR Class B/C LLW Volume vs. Thermal Capacity

This evolution in LLW management practice is reflected in Figures 5.5 and 5.6, which show, for the BWR and PWR plants reported in Table 5.1, respectively, how LLW is assumed to be dispositioned or, in the case of the four plants that have completed decommissioning, how the LLW generated during decommissioning was actually dispositioned. The following observations are made:

- The licensee estimates generally assume 40%–70% of the LLW is sent to waste processors/vendors for disposition, with most of the remainder of the LLW, excluding Class B and C LLW, going to the Energy*Solutions* facility for disposal. Some exceptions are noted:
  - o Duane Arnold assumes all of the Class A waste is sent directly to the Energy*Solutions* facility for disposal and none to waste processors/vendors, while Kewaunee assumes 84% of the LLW is sent directly to the Energy*Solutions* facility for disposal and only 11% going to waste processors/vendors. It is interesting that the decommissioning volume and cost estimates for these two plants were performed by Energy*Solutions*, LLC, the owner of the Energy*Solutions* facility, while all of the other estimates were performed by TLG Services, Inc.

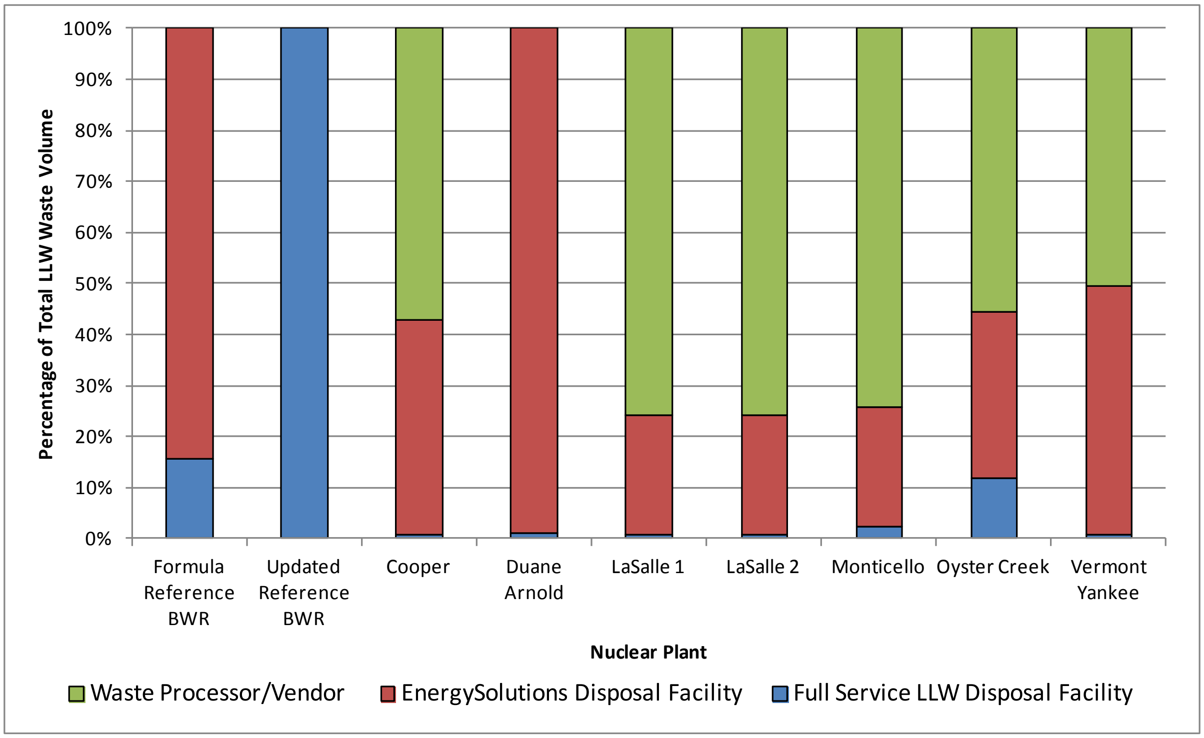

Figure 5.5. Disposition of BWR LLW

  - o The assumption for Diablo Canyon 1&2 is that all of the LLW will be disposed of at a future disposal facility that serves licensees located in the Southwest Compact. The estimates Oyster Creek, and Salem 1&2 also assume some portion of the Class A LLW going to a full-service LLW disposal facility such as the Barnwell facility. It is noted that that the estimates for these three plants are the oldest of the estimates reviewed, with the Diablo Canyon 1&2 and the Salem 1&2 estimates dated 2002 and the Oyster Creek estimate dated 2003. Updated analyses would likely assume that most of this Class A LLW would be shipped to the Energy*Solutions* facility for disposal.

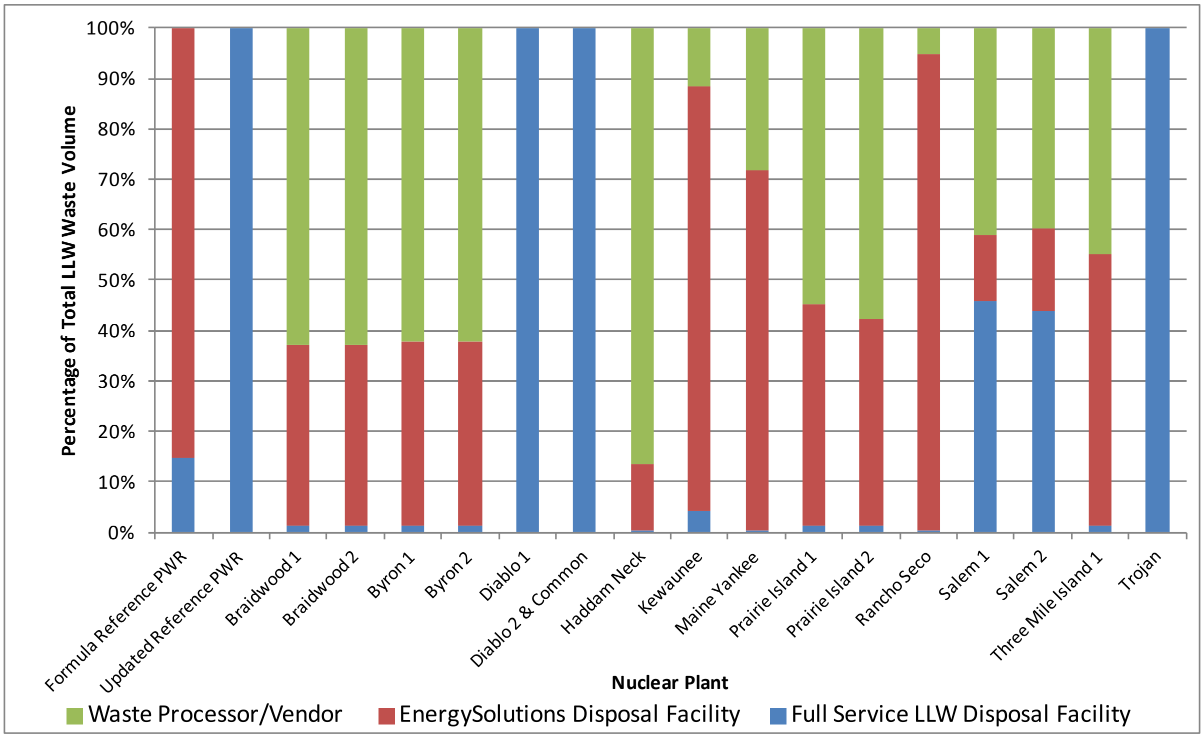

Figure 5.6. Disposition of PWR LLW

- Applying the NUREG-1307, Revision 14 (Reference 6) waste vendor B_x factor to the original cost estimates developed in the PNNL decommissioning studies results in 15% of the LLW being disposed of at a full-service LLW disposal facility, 85% being disposed of at the Energy*Solutions* disposal facility, and no LLW sent to waste processors/ vendors. Applying the B_x factor to the PNNL updated cost estimates results in 8% of the LLW being disposed of at a full-service LLW disposal facility, 92% being disposed of at the Energy*Solutions* disposal facility, and no LLW sent to waste processors/vendors. Both of these studies assume that a small portion of the Class A LLW goes to the full-service LLW disposal facility.

- For the four plants that have completed decommissioning, Trojan sent all LLW to the US Ecology disposal facility. Rancho Seco sent all Class A LLW to the Energy*Solutions* disposal facility and continues to store the Class B and C LLW onsite. Maine Yankee sent 71% of its LLW to the Energy*Solutions* disposal facility, 29% to waste processors/vendors, and 0.3% (Class B and C LLW) to the Barnwell disposal facility. Haddam Neck sent 13% of its LLW to the Energy*Solutions* disposal facility, 87% to waste processors/vendors, and 0.3% (Class B and C LLW) to the Barnwell disposal facility.

These results reflect the fact that currently only nuclear power plant licensees located in the Atlantic and Northwest Compacts have access to full-service LLW disposal facilities, the Barnwell and US Ecology facilities, respectively. All other licensees only have access to a single Class A LLW disposal facility, the Energy*Solutions* facility, and no access to a disposal facility for Class B and C LLW. Licensees that do not have access to a disposal facility for Class B and C LLW must store this waste until a facility becomes available. An example of this is Rancho Seco, which, as discussed in Section 4, has completed decommissioning of the plant but maintains its 10 CFR Part 50 license for approximately 1 acre of the former plant site for a storage facility for Class B and C LLW generated during both plant operations and during decommissioning. However, because of extensive efforts to minimize the amount of Class B and C LLW that is generated during plant operations and stored until a disposal facility becomes available, the amount of operational waste that may be required to be disposed of during decommissioning is expected to be minimal. The decommissioning cost study for Kewaunee estimated the amount of Class B and C LLW generated from plant operations and potentially requiring disposal during decommissioning to be about 1,650 ft^3, which is a negligible contributor to the total decommissioning project LLW volume requiring disposition.

Based on the above discussions, the following conclusions are drawn:

1. There appears to be no strong basis for updating the LLW volume estimates for either PWRs or BWRs used in the decommissioning fund formula.

   The total LLW volume for BWRs assumed in the formula is comparable (within ±20%) to the volumes estimated by the licensees (after accounting for the significant contaminated soil volume included in the estimates for Oyster Creek and Vermont Yankee). This includes the licensee estimate for LaSalle 1&2, which is about 14% higher than the total LLW volume estimated for the reference BWR plant used as the basis for the development of the formula (and both plants have similar thermal capacities). Unfortunately, no large BWR has completed decommissioning so that a comparison to an actual experience can be made. This may change in the near future as the decommissioning of Zion 1&2 is proceeding and is expected to be completed within the next several years.

   While the PWR volume used in the formula is higher than all of the licensee estimates, it falls in the mid-range of the four completed decommissioning projects. While the formula volume is significantly higher than the actual volume reported for Trojan, the Haddam Neck, Maine Yankee, and Rancho Seco experiences more closely represent the decommissioning situations that most of the nuclear plants in the United States would experience if undergoing decommissioning today. The US Ecology disposal facility used by Trojan to dispose of all of its LLW (including Class A, B, and C) is available to only one other nuclear power plant: Columbia Generating Station. In fact, even the Haddam Neck and Maine Yankee experience is out-dated for most nuclear power plants because the Barnwell disposal facility is now only available to plants located in the Atlantic Compact (i.e., Oconee 1/2/3, Summer, Robinson 2, Oyster Creek, Hope Creek, Salem 1/2, Millstone 1/2/3). Only the Rancho Seco experience is typical of what most plants would face today: no disposal facility for Class B/C waste and disposal of Class A waste at the Energy*Solutions* disposal facility in Utah. The total LLW volume used in the decommissioning fund formula (i.e., 643,000 ft^3) is essentially the same as the total LLW volume reported as being generated during the Rancho Seco decommissioning project (i.e., 630,000 ft^3). This is the case even though Rancho Seco has a smaller thermal capacity than the reference PWR (2772 MWth vs. 3486 MWth).

Lastly, the experience with Class B/C LLW generation is mixed. In three of the four cases reviewed, the volume of Class B/C LLW generated was greater than that assumed in the formula. On the other hand, the low volume generated from the decommissioning of Rancho Seco is more reflective of the current situation in which many licensees do not have access to disposal capacity for Class B/C LLW. However, it is unclear that this situation will continue indefinitely into the future. Specifically, the Waste Control Specialists (WCS) full-service LLW disposal facility in Texas is anticipated to open in the near future and to permit LLW from licensees located in out-of-compact states; however, the structure of the disposal rates to be charged are still being negotiated and the final outcome will likely have some impact on the pricing structure for the other LLW disposal facilities. The formula provides a middle ground between the four actual decommissioning experiences reviewed for this study.

2. Consideration should be given to updating the method for calculating the Bx factor to address current LLW management practices. Whether to do so should be based on sensitivity analyses that 1) assumes all Class A LLW is shipped directly to the Energy*Solutions* facility for disposal and 2) assumes that up to 70% of the Class A LLW is sent to waste processors/vendors and the remaining Class A LLW is sent to the Energy*Solutions* facility for disposal.

5.5 License Termination Cost Results

As discussed in the previous section, the decommissioning fund formula assumes that LLW disposal cost, or disposal volume, scales linearly with the thermal capacity of the nuclear plant. Other license termination or decommissioning costs are assumed to be only dependent on the type of reactor (i.e., PWR or BWR) and independent of plant capacity. The results from Section 3 of this report where decommissioning cost estimates developed by the licensees were compared support this assumption. This section therefore compares, by PWR and BWR, the 1) estimated decommissioning costs from the updated PNNL decommissioning studies reported in Section 2, 2) the estimated decommissioning costs developed by licensees reported in Section 3, and 3) the actual decommissioning costs reported in Section 4 for completing the decommissioning of Haddam Neck, Maine Yankee, Rancho Seco, and Trojan.

To perform this comparison, a series of graphs was developed that compares by plant the ratio of the reported cost (both estimated and actual) to the corresponding cost estimated using the minimum decommissioning fund formula. This comparison approach was chosen because it eliminates the need to convert reported decommissioning costs to current-year dollars. Converting the reported decommissioning costs to current-year dollars is inherently difficult because not all cost categories will escalate at the same annual rates and even similar cost categories can escalate at different annual rates depending on factors such as the location of the plant and LLW treatment and disposal assumptions. The formula estimate was developed for each plant using the appropriate labor (L), energy (E), and LLW burial (B) coefficients from the NUREG-1307 reports for the same year in which the estimated decommissioning costs are reported. For the plants that have completed decommissioning, the formula estimate was similarly developed for a peak year of decommissioning.

Table 5.2 provides the comparison of license termination costs by plant and by cost category. The cost categories were chosen based on the availability of cost data to support the comparison and are: 1) project management (PM), which in addition to labor includes costs that cannot be directly allocated to a decommissioning activity (i.e., equipment rental, supplies, etc.), 2) decontamination and removal (D&D) of systems, structures, and components, 3) insurance, to cover nuclear liability and property damage, and regulatory fees (INS), 4) property taxes (PT), 5) energy consumption (Energy), 6) LLW packaging (PKG), 7) LLW transportation (TRN), and 8) LLW disposal (Burial). The results for each of the cost categories are discussed below.

Total Cost of Radiological Decommissioning

Figures 5.7 and 5.8 compare the ratios of the total estimated/actual decommissioning cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.2. The following observations are made from these figures:

- For BWRs, the licensee estimates are between 94%–120% of the formula estimate, with an average that is essentially equivalent to the formula estimate. The estimates for the updated reference BWR station are underestimating the total decommissioning cost by about 20%. In conclusion, on a total decommissioning cost basis, the formula estimate gives similar results to the licensee estimates.

- For PWRs, the licensee estimates are 5%–60% higher than the formula estimate and, on average, about 33% higher than the formula estimate. Actual reported decommissioning costs for three of the four cases reviewed are 10%–25% higher than the formula estimate. The total cost to decommission Haddam Neck appears to be an outlier at a factor of 2.2 greater than the formula and much greater than the factor of 1.6 for the nearest licensee estimate. The estimates for the updated PWR reference station are significantly underestimating relative to both the licensee estimates and the actual experience. In conclusion, on a total decommissioning cost basis, the formula appears to be underestimating by 10%–25%.

Project Management Cost

Figures 5.9 and 5.10 compare the ratios of the project management cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are a factor of 2.05 to 2.3 higher than the formula estimate, with an average that is about a factor of 2.2 higher. The estimates for the updated reference BWR station are significantly underestimating these costs relative to the licensee estimates. In conclusion, the formula estimate appears to be underestimating project management costs by 100%–130%.

Table 5.2. Decommissioning Costs and Formula Estimate for DECON of Selected Reactors

Plant Data			License Termination Costs									
Plant	Capacity (MWth)	Year[(a)]	Cost Basis	PM	D&D	INS	PT	Energy	PKG	TRN	Burial	Total
BWR Plants												
Updated Reference BWR – WA[(b)]	3486	2010	Formula	116	62	4	0	16	19	22	162	401
			Estimate	101	59	23	0	9	8	4	129	333
Updated Reference BWR – SC[(b)]	3486	2010	Formula	116	62	4	0	16	19	22	372	612
			Estimate	101	59	23	0	9	8	20	296	517
Cooper	2381	2008	Formula	105	56	4	0	14	17	32	309	537
			Estimate	231	111	27	0	4	13	9	111	506
Duane Arnold	1912	2008	Formula	102	54	4	0	14	16	31	299	519
			Estimate	NA[(c)]	NA	NA	NA	NA	NA	NA	NA	486
LaSalle 1	3546	2009	Formula	113	60	4	0	15	18	35	333	578
			Estimate	235	164	8	9	6	20	12	92	547
LaSalle 2	3489	2009	Formula	113	60	4	0	15	18	35	333	578
			Estimate	245	179	6	9	6	21	13	95	573
Monticello	1775	2005	Formula	90	48	3	0	11	15	12	234	413
			Estimate	208	101	10	13	7	10	7	91	447
Oyster Creek	1930	2003	Formula	85	45	3	0	10	14	5	237	399
			Estimate	174	132	10	11	2	12	6	134	480
Vermont Yankee	1912	2006	Formula	101	53	4	0	13	16	21	272	481
			Estimate	228	97	12	0	2	12	13	104	469
PWR Plants												
Updated Reference PWR – WA[(b)]	3411	2010	Formula	83	43	4	0	13	26	16	152	338
			Estimate	77	61	25	0	9	5	13	81	271
Updated Reference PWR – SC[(b)]	3411	2010	Formula	83	43	4	0	13	26	16	284	469
			Estimate	77	61	25	0	9	5	34	151	361
Braidwood 1	3586	2009	Formula	81	42	4	0	13	25	25	228	418
			Estimate	201	124	8	12	5	16	11	65	442
Braidwood 2	3586	2009	Formula	81	42	4	0	13	25	25	228	418
			Estimate	243	173	8	13	6	14	9	63	529
Byron 1	3586	2009	Formula	81	42	4	0	13	25	25	228	418
			Estimate	208	120	8	17	4	16	11	65	448

Table 5.2. (contd)

Plant Data				License Termination Costs								
Plant	Capacity (MWth)	Year[(a)]	Cost Basis	PM	D&D	INS	PT	Energy	PKG	TRN	Burial	Total
Byron 2	3586	2009	Formula	81	42	4	0	13	25	25	228	418
			Estimate	242	165	7	16	4	14	9	63	521
Diablo 1	3411	2002	Formula	64	34	3	0	9	20	4	219	353
			Estimate	288	95	11	0	7	13	5	126	545
Diablo 2 & Common	3411	2002	Formula	64	34	3	0	9	20	4	219	353
			Estimate	291	116	10	0	6	13	5	126	566
Haddam Neck	1825	2006	Formula	69	36	4	0	11	21	15	174	330
		1997-2007	Actual	311	290	1	16	NA		102		721
Kewaunee	1772	2008	Formula	70	37	4	0	11	21	21	197	360
			Estimate	NA	NA	NA	NA	NA	NA	NA	NA	381
Maine Yankee	2700	2002	Formula	63	33	3	0	9	20	4	206	338
		1997-2005	Actual[(d)]	176	122	18	12	NA		95		424
Prairie Island 1	1677	2008	Formula	69	36	4	0	11	21	21	195	357
			Estimate	273	92	13	11	12	18	7	62	488
Prairie Island 2	1677	2008	Formula	69	36	4	0	11	21	21	195	357
			Estimate	295	115	12	11	13	18	7	66	538
Rancho Seco	2772	2007	Formula	72	38	4	0	12	22	16	190	354
		1994-2009	Actual	NA	NA	NA	NA	NA	NA	NA	NA	394
Salem 1	3459	2002	Formula	67	35	4	0	9	21	4	219	359
			Estimate	234	115	11	0	8	12	12	98	489
Salem 2	3459	2002	Formula	67	35	4	0	9	21	4	219	359
			Estimate	272	133	9	0	7	12	12	99	545
Three Mile Island 1	2568	2008	Formula	75	39	4	0	12	23	23	212	388
			Estimate	238	134	8	6	6	13	15	84	504
Trojan	3411	1997	Formula	56	29	3	0	9	17	5	72	191
		1993-2005[(e)]	Actual	111	58	NA	NA	NA	14	11	13	208

(a) Year of original estimate or decommissioning period if plant has completed decommissioning.
(b) SC - assumes most Class A LLW disposal at the Barnwell disposal facility and the remainder of LLW disposal at the Energy*Solutions* disposal facility; WA assumes LLW disposal at the US Ecology disposal facility.
(c) NA - not available.
(d) Cost shown here is different than shown in Table 4.20 due to adjustments to account for legal costs and litigation awards.
(e) Although decommissioning occurred between 1993 and 2005, actual costs were provided in 1997 dollars.

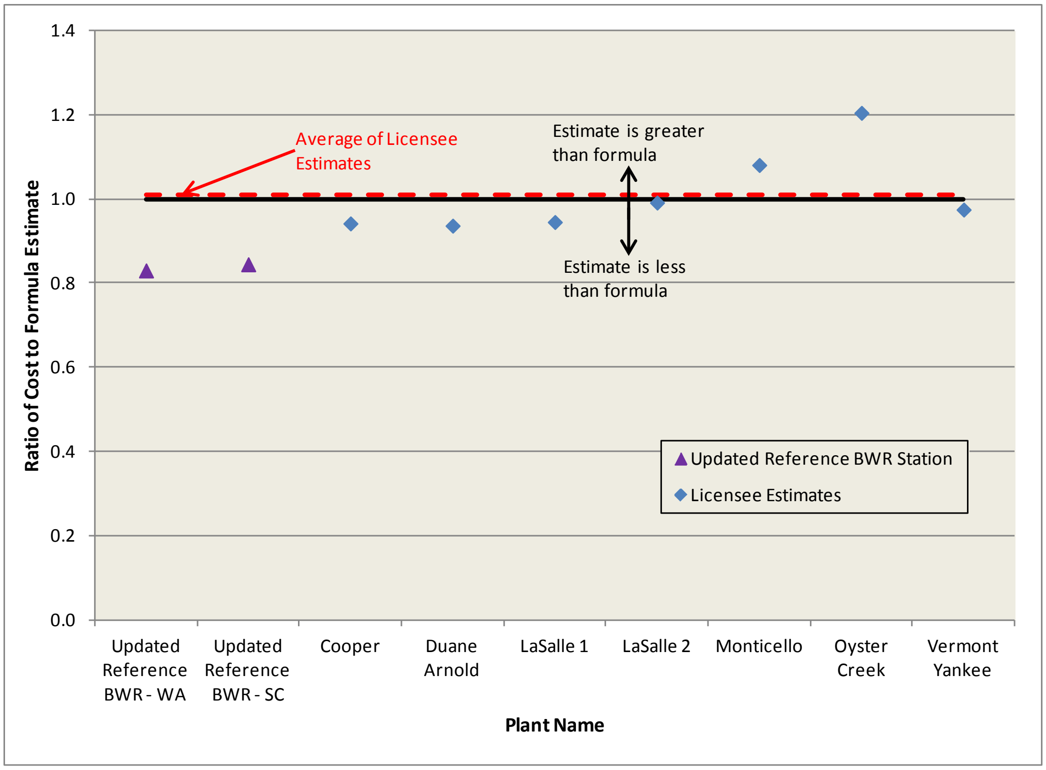

Figure 5.7. Comparison of Total Radiological D&D Cost – BWR

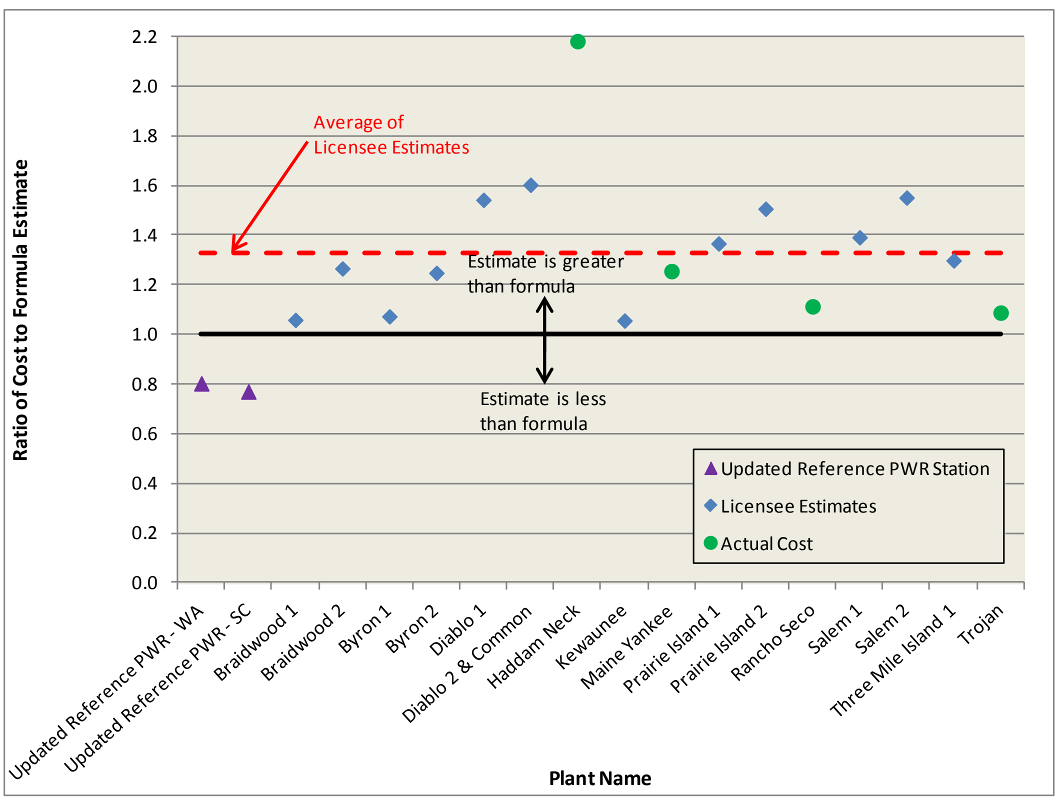

Figure 5.8. Comparison of Total Radiological D&D Cost – PWR

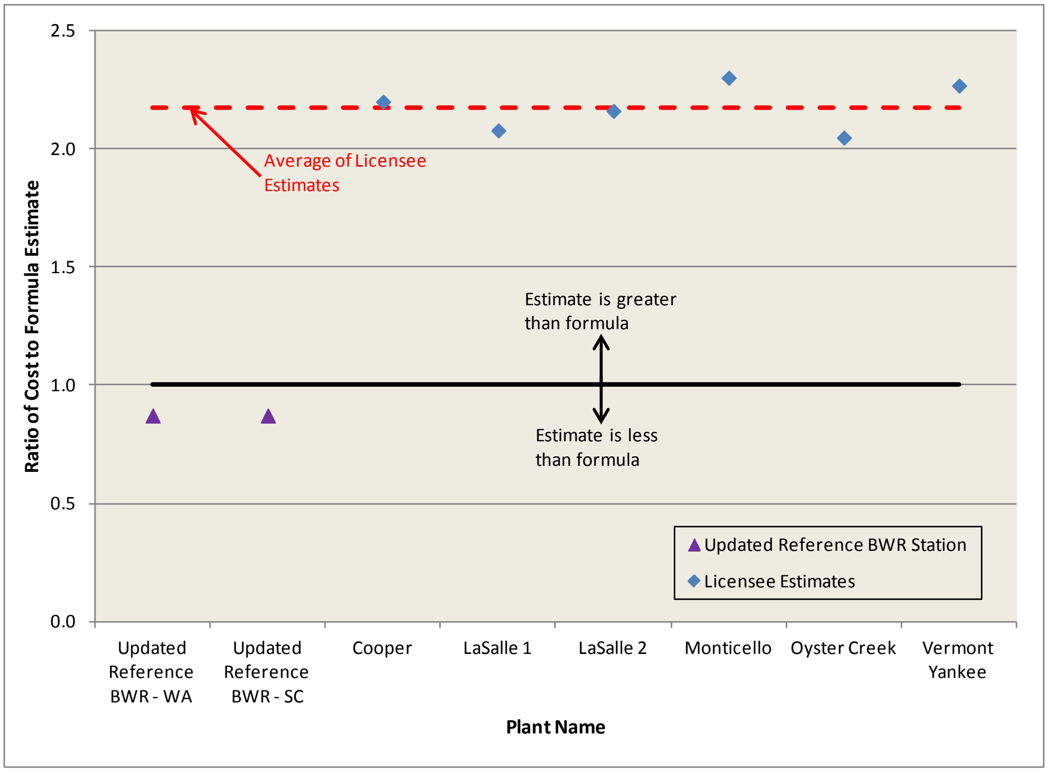

Figure 5.9. Comparison of Project Management Cost – BWR

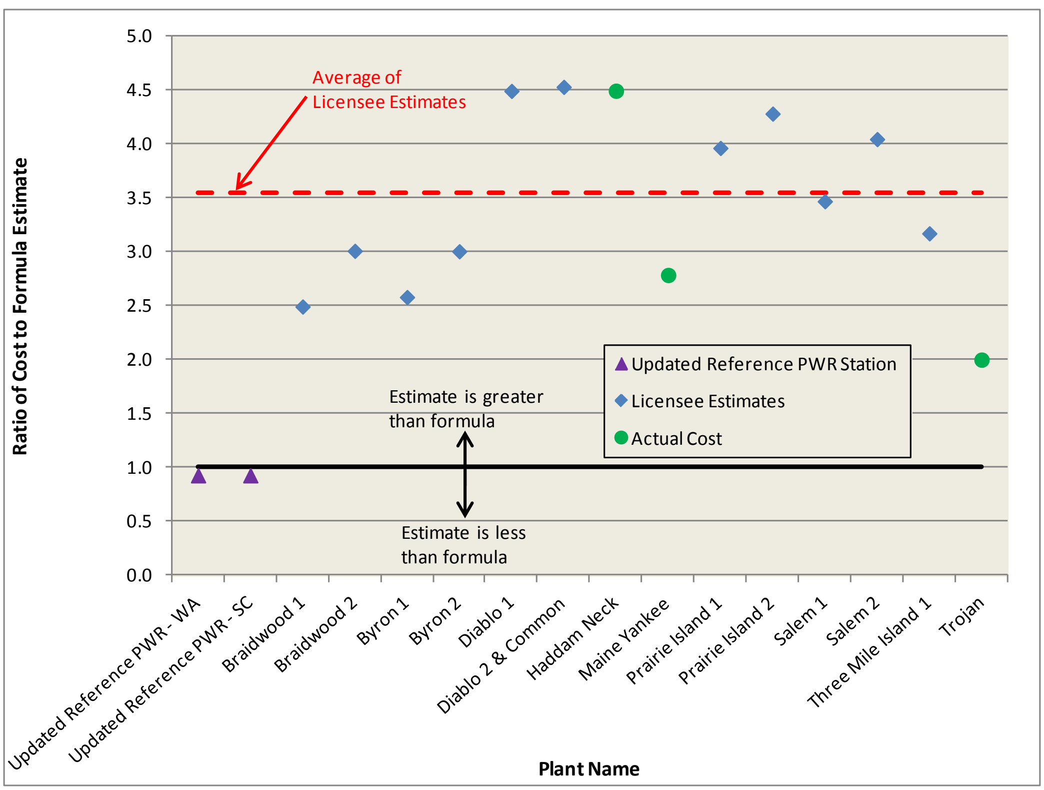

Figure 5.10. Comparison of Project Management Cost – PWR

- For PWRs, the licensee estimates are a factor of 2.5 to 4.5 higher than the formula estimate and the estimates for the updated reference PWR station, with an average that is about a factor of 3.6 higher. Actual reported project management costs for Maine Yankee and Trojan are 100%–175% higher than the formula estimate, at the low end or lower than the licensee estimates. The project management cost reported for Haddam Neck is at the high end of the licensee estimates, or a factor of 4.5 higher than the formula. In conclusion, the formula appears to be underestimating project management costs by 100%–200%.

The cost data available for the completed Rancho Seco decommissioning project, and for the Duane Arnold and Kewaunee licensee estimates, are of insufficient detail to determine the project management cost.

Decontamination and Removal Cost

Figures 5.11 and 5.12 compare the ratios of the radiological decontamination and removal cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are a factor of 1.8 to 3.0 higher than both the formula estimate and the estimates for the updated reference BWR station, with an average that is about a factor of 2.4 higher. In conclusion, the formula estimate is underestimating decontamination and removal costs by 130%–150%.

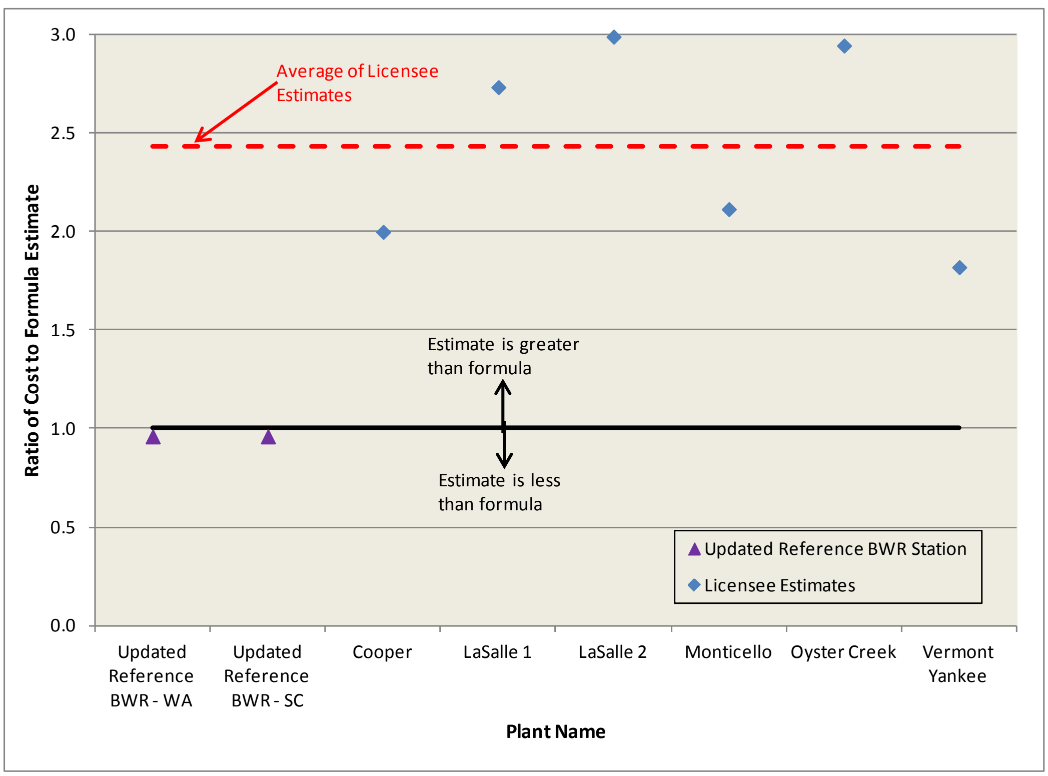

Figure 5.11. Comparison of Decontamination and Removal Cost – BWR

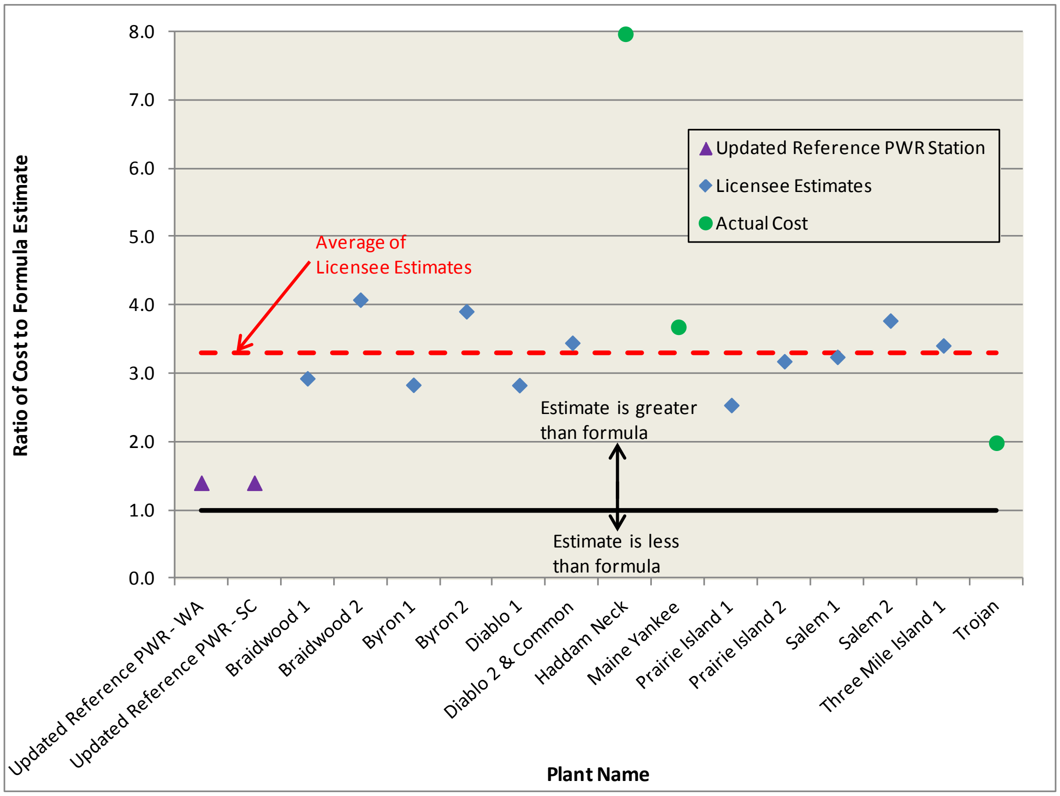

Figure 5.12. Comparison of Decontamination and Removal Cost – PWR

- For PWRs, the licensee estimates are a factor of 2.5 to 4.1 higher than the formula estimate, with an average that is about a factor of 3.3 higher. The estimates for the updated reference PWR station are about 40% higher than the corresponding formula estimate. Actual reported decontamination and removal costs for Trojan are lower than all of the licensee estimates but higher than the formula estimate by a factor of 2. Actual reported costs for Maine Yankee are slightly higher than the average of the licensee estimates, or about a factor of 3.7 higher than the formula estimate. The actual reported cost for Haddam Neck appears to be an outlier at a factor of 8.0 greater than the formula estimate and much greater than the factor of 4.1 for the nearest licensee estimate. In conclusion, the formula appears to be underestimating decontamination and removal costs by 100%–250%.

The cost data available for the completed Rancho Seco decommissioning project, and for the Duane Arnold and Kewaunee licensee estimates, are of insufficient detail to determine the cost of decontamination and removal.

Cost of Insurance and Regulatory Fees

Figures 5.13 and 5.14 compare the ratios of the radiological decontamination and removal cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are a factor of 1.5 to 6.8 higher than both the formula estimate, with an average that is about a factor of 3.2 higher. The licensee estimate for Cooper appears to be an outlier at a factor of 6.8 higher than the formula estimate and is significantly higher than the next nearest licensee estimate at a factor of 3.1 higher (it is unclear from the available information why Cooper is so much higher than the other estimates). Removing Cooper results in the average of the licensee estimates being a factor of about 2.5 higher than the formula estimate. The estimates for the updated reference BWR station are about a factor of 5.25 higher than the corresponding formula estimate and are significantly higher than most of the licensee estimates. In conclusion, the formula estimate is underestimating the costs of insurance and regulatory fees by 100%–150%.

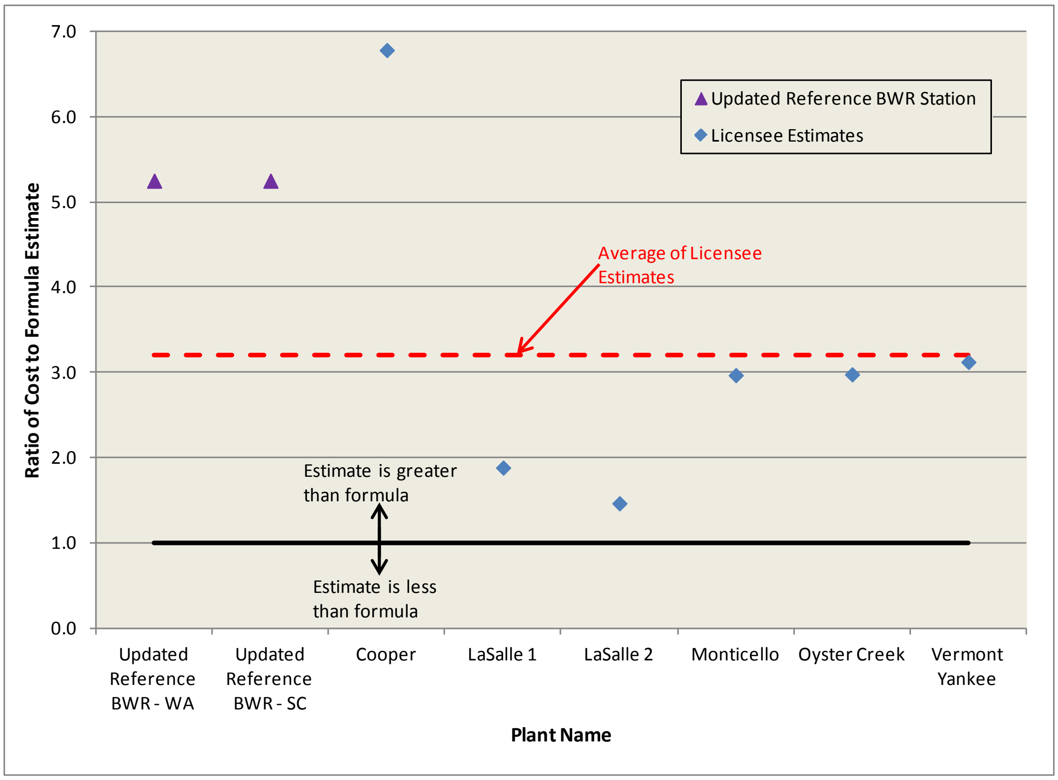

Figure 5.13. Comparison of Cost for Insurance and Regulatory Fees – BWR

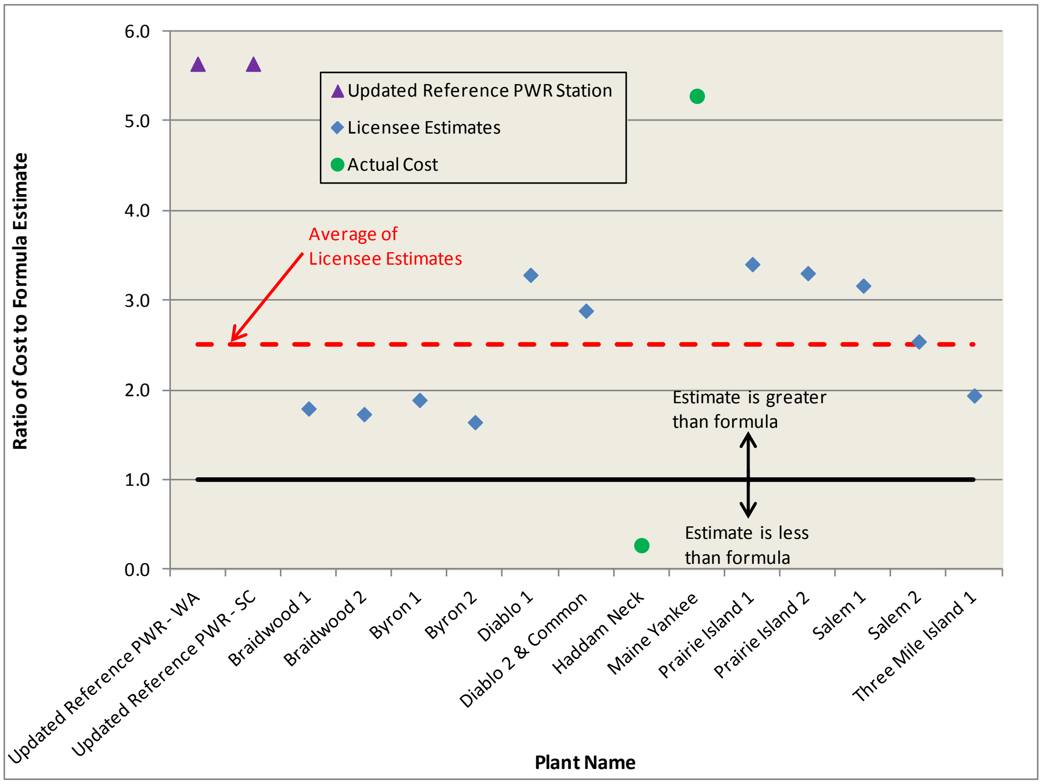

Figure 5.14. Comparison of Cost for Insurance and Regulatory Fees – PWR

- For PWRs, the licensee estimates are a factor of 1.6 to 3.4 higher than the formula estimate, with an average that is about a factor of 2.5 higher. The estimates for the updated reference PWR station are about a factor of 5.6 higher than the corresponding formula estimate. Actual reported costs for Maine Yankee are a factor of 5.3 higher than the formula estimate while the actual reported cost for Haddam Neck is a factor of 3.7 less than the formula estimate, with an average of about a factor of 2.8 greater than the formula. The low cost of insurance and regulatory fees for Haddam Neck appears to be an outlier because it is the result of a substantial refund that the licensee received from its nuclear insurer. In conclusion, the formula appears to be underestimating the cost of insurance and regulatory fees by 100%–200%.

The cost data available for the completed Rancho Seco and Trojan decommissioning projects, and for the Duane Arnold and Kewaunee licensee estimates, are of insufficient detail to determine the cost of insurance and regulatory fees.

Property Tax

Neither the formula or the updated cost estimates for the reference BWR and PWR stations assume that property tax is included as a license termination cost. This assumption was made since the value of the land on which the permanently shutdown plant resides is unrelated to the decommissioning activity (especially since the plant theoretically has zero residual value, thus the reason for it being decommissioned). However, some licensees do include property tax in their decommissioning estimates. Also, two of the completed decommissioning projects, Haddam Neck and Maine Yankee, included property taxes in their decommissioning cost (the cost data available for Rancho Seco and Trojan are of insufficient detail to determine if property taxes were included in the cost of decommissioning). Figures 5.15 and 5.16 provide the property tax for the licensee estimates and completed decommissioning projects. As the figures show, about two-thirds of the licensee estimates do include a property tax in their estimated decommissioning costs while about one-third do not. Since many licensees do not include property taxes in their estimated decommissioning costs, and for the reasons previously described, it is recommended that the revised formula continue to not include an estimate for property taxes.

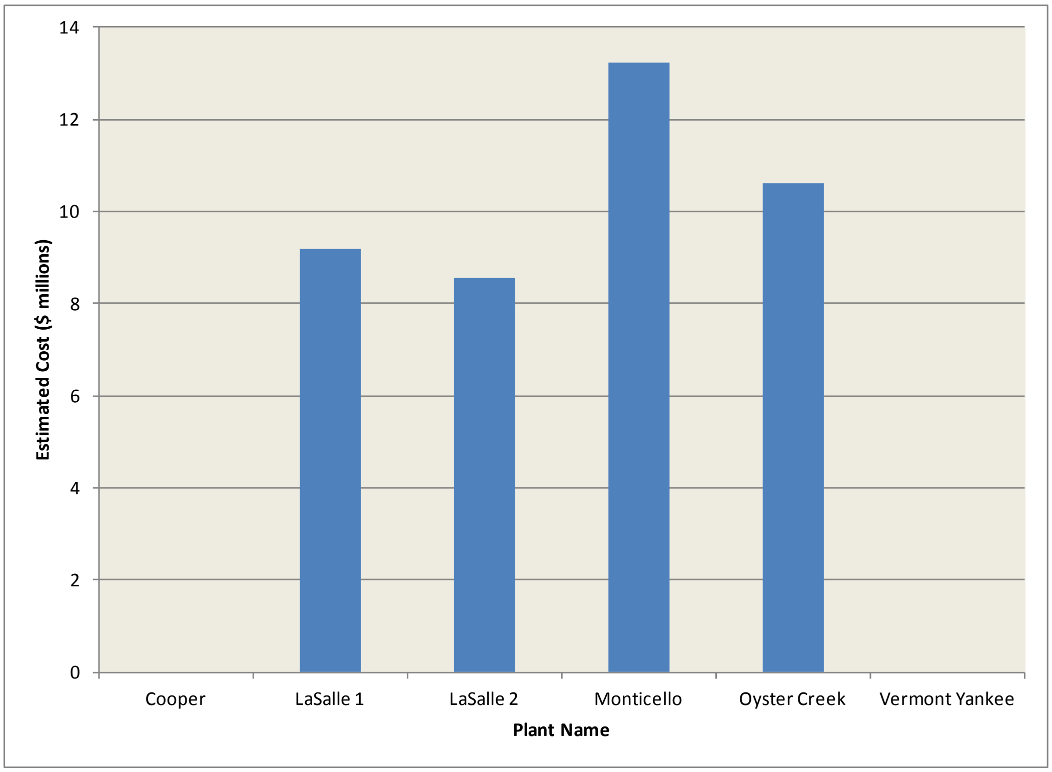

Figure 5.15. Property Taxes Included in License Termination Costs – BWR

Energy Cost

Figures 5.17 and 5.18 compare the ratios of the energy cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are 16%–58% of the formula estimate, and are an average of 33% of the formula estimate. The estimated energy cost for the updated reference BWR station is also lower than the formula at about 54% of the formula estimate but generally somewhat higher than the licensee estimates. In conclusion, the formula estimate is overestimating energy costs by about 70%.

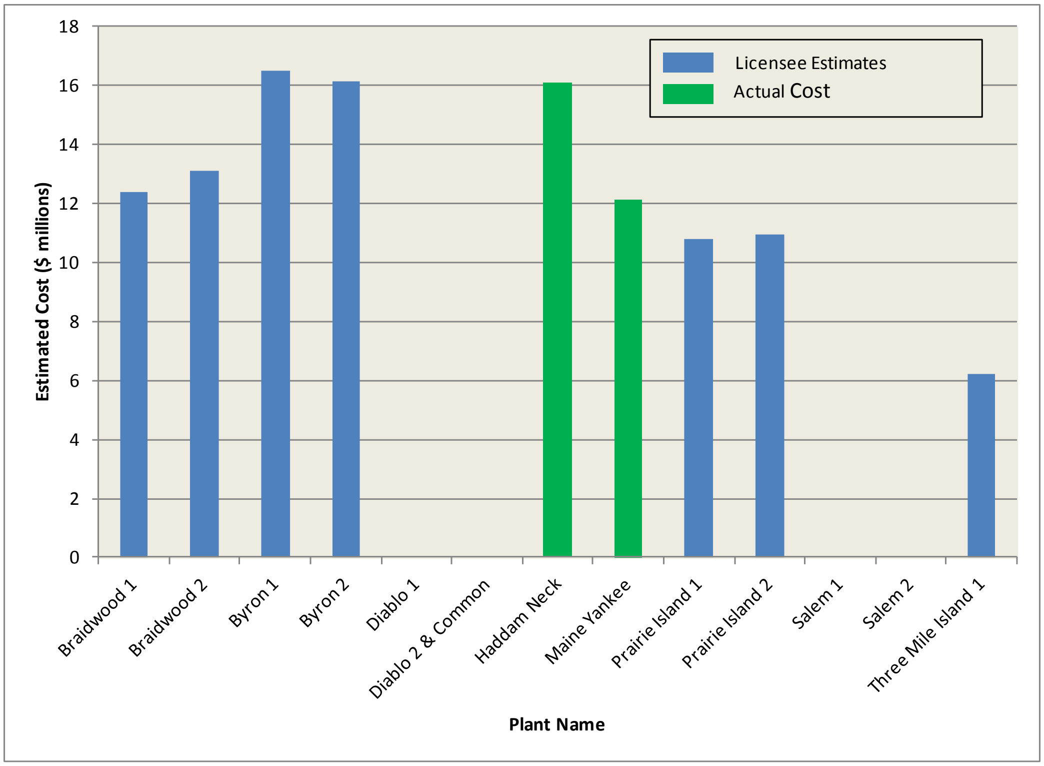

Figure 5.16. Property Taxes Included in License Termination Costs – PWR

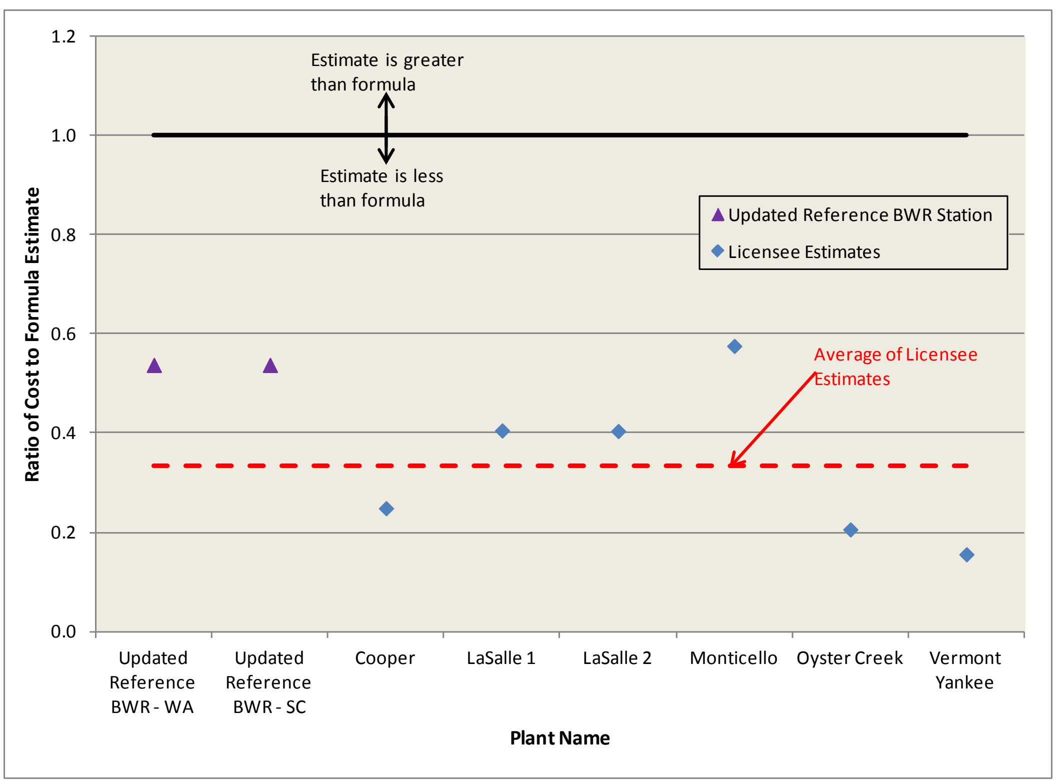

Figure 5.17. Comparison of Energy Cost – BWR

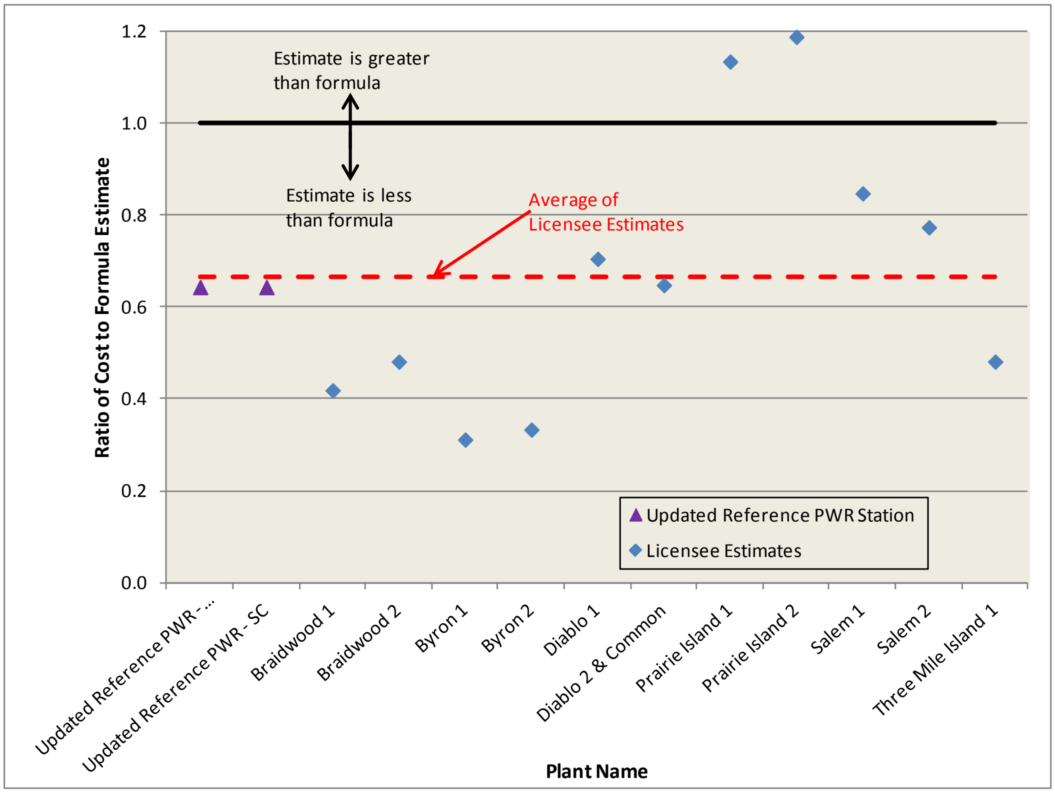

Figure 5.18. Comparison of Energy Cost – PWR

- For PWRs, the licensee estimates are 31%–119% of the formula estimate, with an average that is about 67% of the formula estimate. The estimates for the updated reference PWR station are about 64% of the formula estimate and about the same as the average of the licensee estimates. In conclusion, the formula appears to be overestimating energy costs by 30%–40%.

The cost data available for the Duane Arnold and Kewaunee licensee estimates are of insufficient detail to determine the cost of energy. In addition, none of the actual costs reported for the completed decommissioning projects were of sufficient detail to determine the cost of energy.

LLW Packaging Cost

LLW packaging cost is a function of both the volume of LLW and the material cost of the LLW containers. The previous section compared LLW volumes for the various decommissioning estimates and completed decommissioning projects. In order to compare LLW packaging cost, the total LLW packaging cost is divided by the total LLW volume and this “unit packaging cost” is compared. Figures 5.19 and 5.20 compare the ratios of the unit LLW packaging cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are generally lower than the formula estimate, ranging from 52%–102% of the formula estimate, and are an average of 79% of the formula estimate. The estimated packaging cost for the updated reference BWR station is also lower than the formula at about 53% of the formula estimate, and is also generally lower than the licensee estimates. In conclusion, the formula estimate is overestimating packaging costs by about 20%.

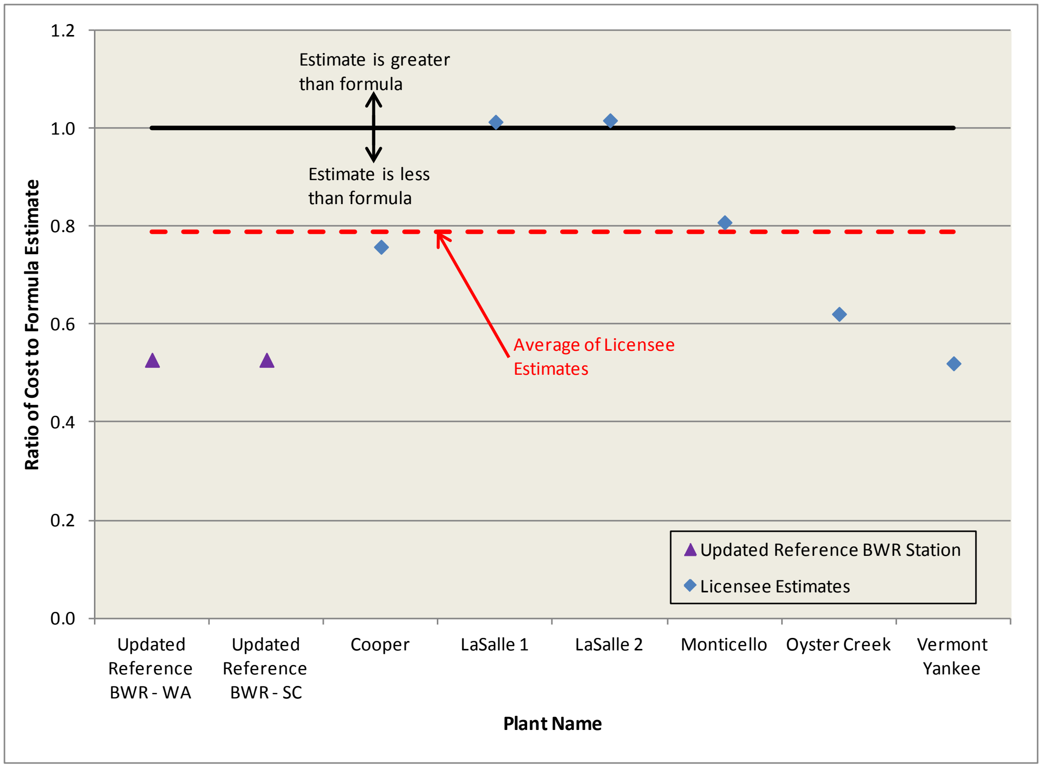

Figure 5.19. Comparison of Unit LLW Packaging Cost – BWR

- For PWRs, the licensee estimates are 72%–355% of the formula estimate, with an average that is about 173% of the formula estimate. The unit costs for Diablo Canyon are significantly higher than for the other estimates. This appears to be due to the relatively low volume of presumably containerized LLW assumed to be shipped for disposal at a future high-cost, full-service disposal facility. It is also assumed that an extensive program is implemented to minimize the amount of material requiring disposal as LLW. Not including the licensee estimates for Diablo Canyon results in an average for the licensee estimates of about 135% of the formula estimate. The other estimates, with the exception of Salem, assume disposal of all Class A LLW at the Energy*Solutions* facility, where a significant portion of the material can be disposed of as bulk waste. The unit cost for Salem is somewhat higher than these other estimates, presumably because a smaller fraction of the material is assumed to be disposed of as bulk waste. The estimated unit packaging cost for the updated reference PWR station is lower than the formula at about 43% of the formula estimate, and is also significantly lower than the licensee estimates. Actual reported costs for Trojan are 120% of the formula estimate, all waste for which was presumably disposed of as containerized material. In conclusion, the formula appears to be underestimating unit packaging costs by 20%–35%.

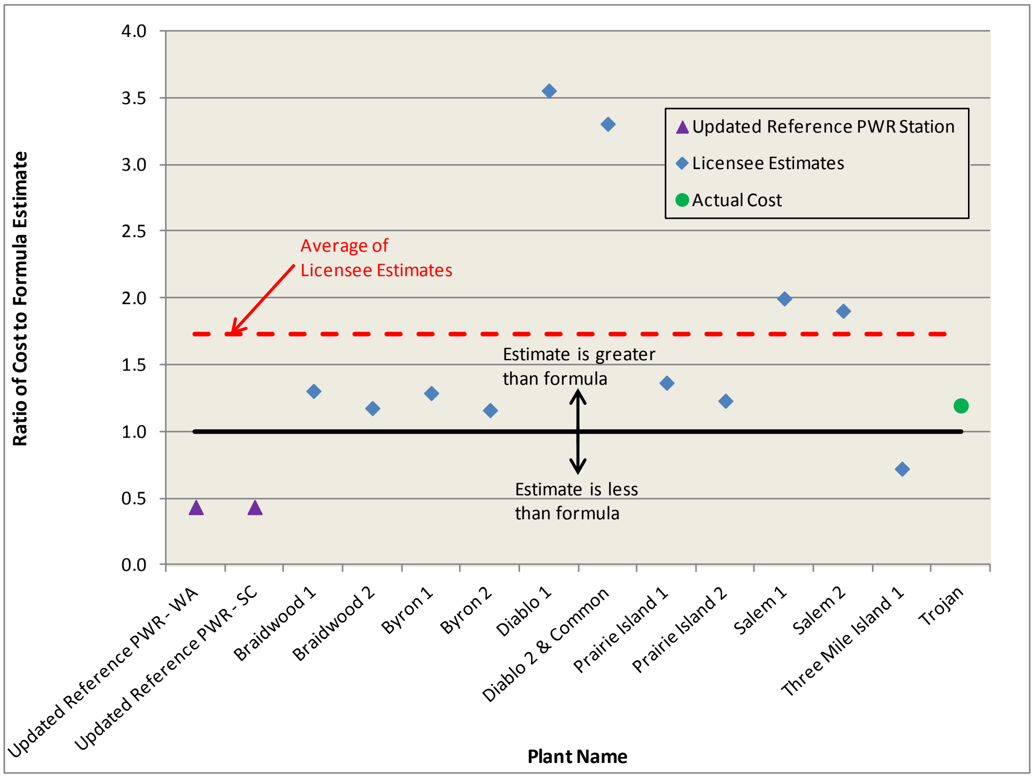

Figure 5.20. Comparison of Unit LLW Packaging Cost – PWR

The cost data available for the Duane Arnold and Kewaunee licensee estimates are of insufficient detail to determine the cost of LLW packaging. In addition, the actual costs reported for the Haddam Neck, Maine Yankee, and Rancho Seco completed decommissioning projects were of insufficient detail to determine the packaging cost.

LLW Transportation Cost

LLW transportation cost is a function of the volume or weight of LLW, the mode of transportation (i.e., truck, rail, and/or barge), the distance from the plant to the LLW disposal and/or processing facility, and fuel cost. Neither the licensee estimates nor the cost information provided for the completed decommissioning projects provide sufficiently detailed information to determine the relative contribution of each of these components to the total LLW transportation cost, with the exception of LLW volume. The previous section compared LLW volumes for the various decommissioning estimates and completed decommissioning projects. In order to compare LLW transportation cost, the total LLW transportation cost is divided by the total LLW volume and this “unit transportation cost” is compared. Figures 5.21 and 5.22 compare the ratios of the unit LLW transportation cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are 26%–76% of the formula estimate, and are an average of 46% of the formula estimate. With the exception of Oyster Creek, each of the estimates assumes 98-99% of the LLW is shipped either to the Energy*Solutions* disposal facility or a waste processor. Shipping distance appears to be the reason for the clustering of mid-west plants (i.e., Cooper and LaSalle 1&2) at the lower end of the cost and the other east/northeast plants having a higher cost. The estimated transportation cost for the updated reference BWR station ranges widely between 23%–115% of the formula estimate, reflecting the extremes in transportation distances between the “Updated Reference BWR-WA” case, where the disposal facility is located near the plant, and the “Updated Reference BWR-SC” case, where the disposal facility is located a long distance (i.e., greater than 1000 miles) from the plant. These two cases bound the licensee estimates. In conclusion, the formula estimate appears to be overestimating unit LLW transportation costs by 60%–80% for west/mid-west plants and by 20%–60% for plants located in the east/northeast/southeast.

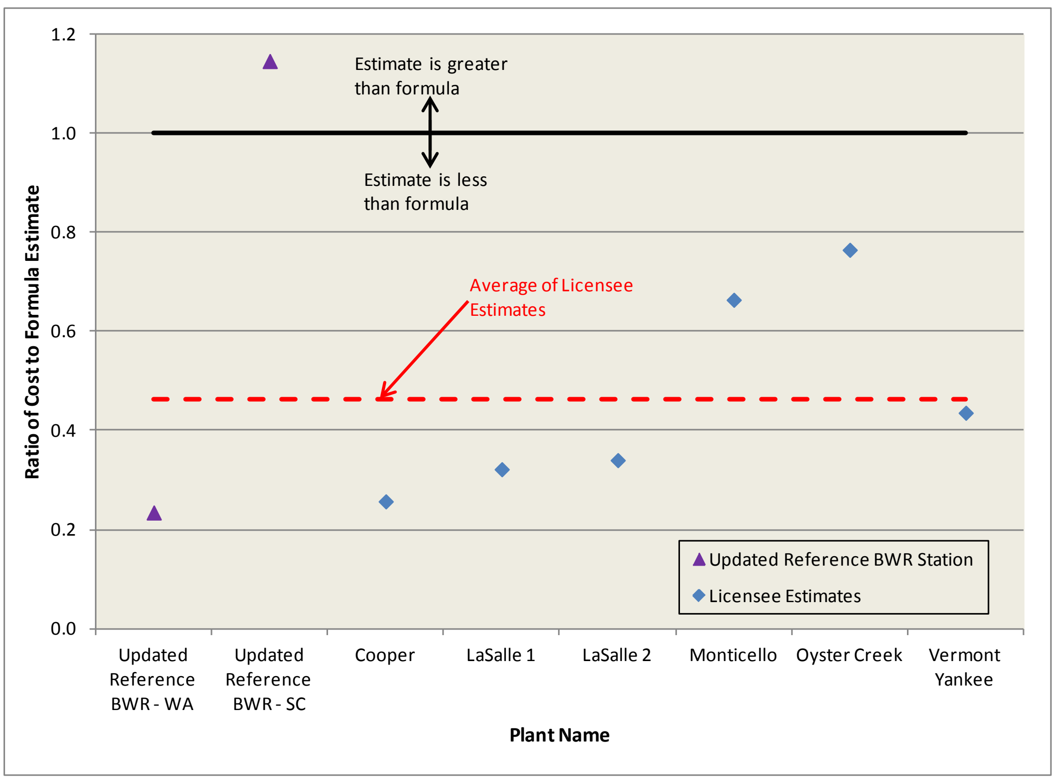

Figure 5.21. Comparison of Unit LLW Transportation Cost – BWR

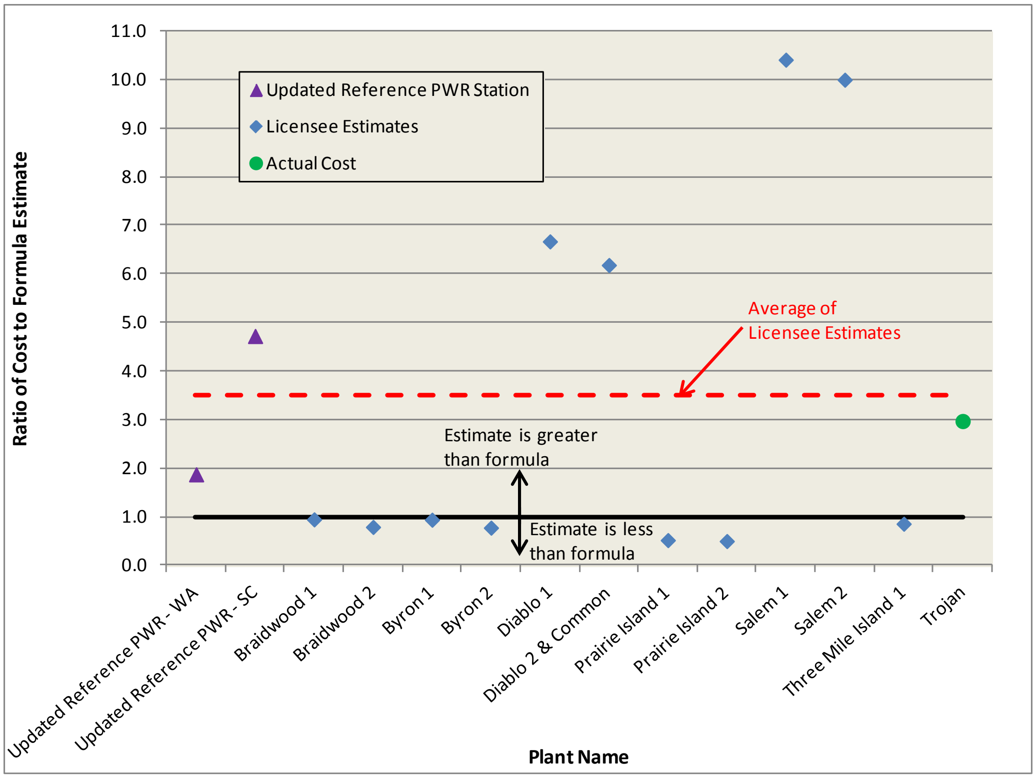

Figure 5.22. Comparison of Unit LLW Transportation Cost – PWR

- For PWRs, the licensee estimates range widely from 50% of the formula estimate to greater than a factor of 10 higher than the formula estimate. Relative to the other licensee estimates, the estimates for Salem 1&2 and Diablo Canyon 1&2 are significantly higher than the corresponding formula estimates, which appears to be at least partially, but not completely, related to the assumption that a significant percentage of the LLW volumes (45%–100%) are shipped to a full-service LLW disposal facility (perhaps implying that shipments are predominantly by truck, which has a higher unit cost than rail). All of the other licensee estimates assume 99% of the LLW is shipped either to the Energy*Solutions* disposal facility or a waste processor, which would largely be bulk shipments by rail and therefore having the much lower unit transportation costs shown in the figure. Excluding Salem 1&2 and Diablo Canyon 1&2, since the assumptions for these are not consistent with today's LLW management practices, results in an average licensee estimate that is 76% of the formula estimate. There is no apparent correlation of shipping distance to unit transportation distance as there was with the BWR plants described above, but each would appear to be assuming lower cost bulk rail shipments.

  The estimated transportation cost for the updated reference PWR station ranges widely between a factor of 1.9 to 4.7 higher than the formula estimate. Actual reported costs for Trojan are a factor of 3.0 higher than the formula estimate and about twice the cost for the "Updated Reference PWR – WA" estimate, which assumed a shipment distance and shipment mode (truck/barge) that was the same as actually experienced in the Trojan decommissioning project. In conclusion, the formula appears to be overestimating unit LLW transportation costs by 10%–25% for predominantly bulk rail shipments and underestimating unit LLW transportation costs by about a factor of 3 for predominantly short distance truck/barge shipments (e.g., less than 500 miles). There is no recommended change to the unit transportation cost for long distance truck/barge shipments (e.g., greater than 500 miles).

The cost data available for the Duane Arnold and Kewaunee licensee estimates are of insufficient detail to determine the cost of LLW transportation. In addition, the actual costs reported for the Haddam Neck, Maine Yankee, and Rancho Seco completed decommissioning projects were of insufficient detail to determine the transportation cost.

LLW Disposal Cost

LLW disposal cost is a function of both the volume of LLW and the rates charged for disposal and processing. Neither the licensee estimates nor the cost information provided for the completed decommissioning projects provide sufficiently detailed information to determine the relative contribution of each of these components to the total LLW disposal cost, with the exception of LLW volume. The previous section compared LLW volumes for the various decommissioning estimates and completed decommissioning projects. In order to compare LLW disposal cost, the total LLW disposal cost is divided by the total LLW volume and this "unit disposal cost" is compared. Figures 5.23 and 5.24 compare the ratios of the LLW disposal cost to the corresponding formula estimate for BWRs and PWRs, respectively, for the values shown in Table 5.1. The following observations are made from these figures:

- For BWRs, the licensee estimates are significantly lower than the formula estimate, ranging in a fairly narrow band from 25%–46% of the formula estimate, and are an average of 33% of the formula estimate. All of these estimates assume that a substantial portion of the LLW (generally 98%–99%) is shipped to the Energy*Solutions* facility for disposal or to waste processor facilities. The estimated disposal cost for the updated reference BWR station is essentially the same as the formula and, therefore, also substantially higher than the licensee estimates. In conclusion, the formula appears to be overestimating unit disposal costs by 60%–80% for scenarios in which most all of the LLW (greater than 90%) is shipped to the Energy*Solutions* facility for disposal or to waste processor facilities for disposition.

- For PWRs, the licensee estimates are generally lower than the formula estimate, ranging widely from 48%–312% of the formula estimate, with an average that is about 118% of the formula estimate. The high costs of the Diablo Canyon 1&2 estimates are outliers in that these estimates assumed all LLW was disposed of at a future full-service disposal facility located in California. The costs for Salem 1&2 are higher than other licensee estimates because a substantial quantity of the LLW (about 50%) is assumed to be disposal of at a full-service disposal facility having disposal rates similar to that of the Barnwell disposal facility. The estimated costs for the remainder of the licensee estimates are at about 50% of the formula estimate and each of these assume that 99% of the LLW is shipped to either the Energy*Solutions* facility for disposal or to a waste processing facility. The estimated disposal cost for the updated reference PWR station is higher than the formula by about 17%, and so is also generally higher than the licensee estimates. Actual reported costs for Trojan are 26% of the formula estimate reflecting the very low disposal rate for the US Ecology facility. In conclusion, the formula appears to be overestimating unit disposal costs at the US Ecology facility by about 75% and overestimating by about 50% disposal rates for scenarios in which most all of the LLW (greater than 90%) is shipped to the Energy*Solutions* facility for disposal or to waste processor facilities for disposition. Based on the higher cost estimates for Salem and Diablo Canyon, it is recommended that no changes be made to the formula for the full-service Barnwell facility, or Generic LLW disposal facility.

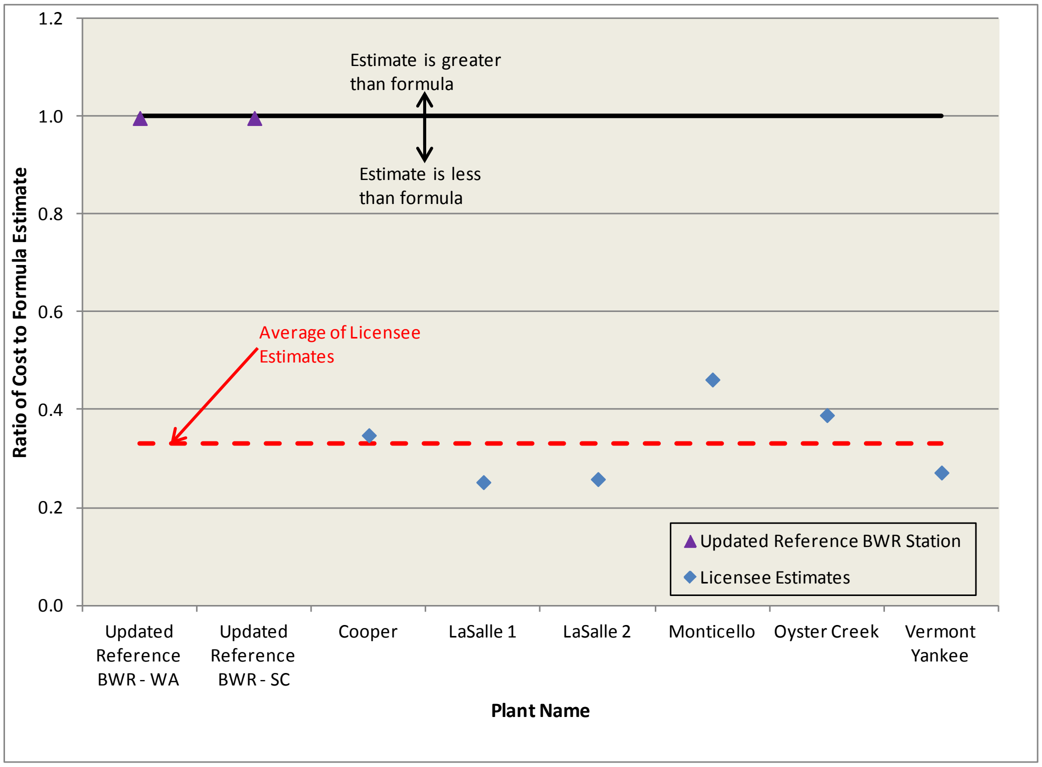

Figure 5.23. Comparison of Unit LLW Disposal Cost – BWR

The cost data available for the Duane Arnold and Kewaunee licensee estimates are of insufficient detail to determine the cost of LLW disposal. In addition, the actual costs reported for the Haddam Neck, Maine Yankee, and Rancho Seco completed decommissioning projects were of insufficient detail to determine the disposal cost.

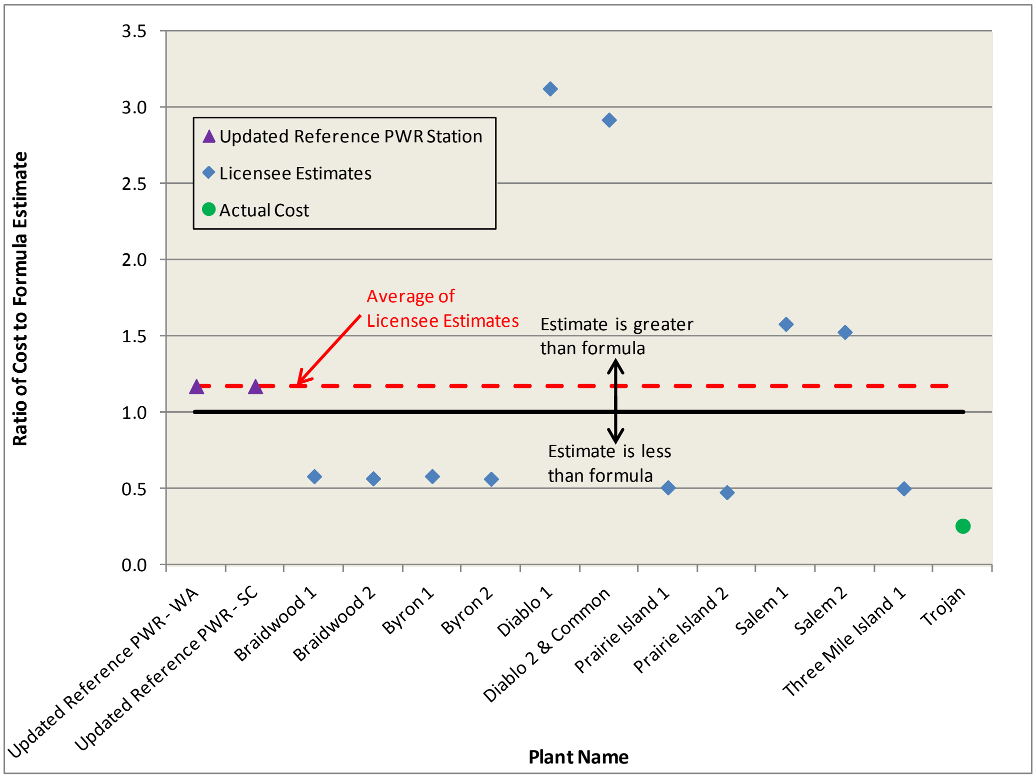

Figure 5.24. Comparison of Unit LLW Disposal Cost – PWR

PWR LLW Packaging/Transportation/Disposal Cost

The LLW packaging, transportation, and disposal costs comparison discussed above did not include reported costs for Haddam Neck and Maine Yankee because of insufficient detail in the cost data provided. However, the cost data provided for these two completed decommissioning projects do include a combined LLW packaging, transportation, and disposal cost. In order to include this cost information for consideration in revising the formula, Figure 5.25 compares the ratios of the combined LLW packaging/transportation/disposal cost to the corresponding formula estimate for PWRs for the values shown in Table 5.1. The following observations are made from this figure:

- The licensee estimates are significantly lower than the formula estimate, ranging from 31%–59% of the formula estimate, with an average that is about 42% of the formula estimate. The estimated packaging/transportation/disposal cost for the updated reference PWR station is also lower than the formula at 41%–49% of the formula estimate, but is generally higher than the licensee estimates and the actual reported costs. Actual reported costs for Haddam Neck, Maine Yankee, and Trojan are 41%–49% of the formula estimate. These results are similar to those discussed previously for LLW disposal since LLW disposal dominates the combined packaging/ transportation/disposal cost. In light of the conclusion in Section 4 of this report that

LLW volume estimates should not be changed at this time, it is concluded here that the formula appears to be overestimating LLW packaging/transportation/disposal costs by 50%–60%.

The cost data available for the Kewaunee licensee estimate are of insufficient detail to determine the cost of LLW packaging/transportation/disposal. In addition, the actual costs reported for the Rancho Seco completed decommissioning project was of insufficient detail to determine the packaging/transportation/disposal cost.

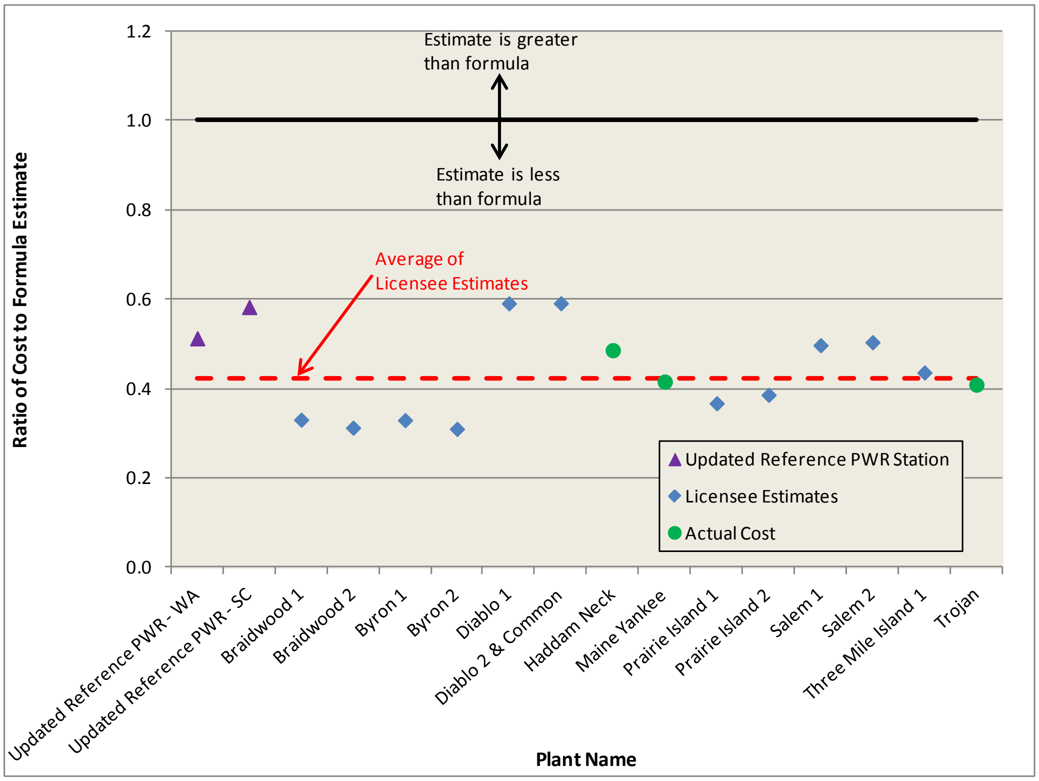

Figure 5.25. Comparison of LLW Packaging/Transportation/Disposal Cost – PWR

5.6 Conclusions

The following conclusions are drawn from the results discussed in the above sections.

7. There appears to be no strong basis for updating the LLW volume estimates for either PWRs or BWRs used in the decommissioning fund formula.

8. Consideration should be given to updating the method for calculating the Bx factor to address current LLW management practices. Whether to do so should be based on sensitivity analyses that 1) assumes all Class A LLW is shipped directly to the Energy*Solutions* facility for disposal and 2) assumes that up to 70% of the Class A LLW is sent to waste processors/vendors and the remaining Class A LLW is sent to the Energy*Solutions* facility for disposal.

9. On a total license termination cost basis, the formula estimate gives similar results to the licensee estimates for BWRs and appears to be underestimating by 10%–25% the cost for PWRs.

10. The formula estimate is underestimating project management costs by 100%–130% for BWRs and by 100%–200% for PWRs.

11. The formula estimate is underestimating decontamination and removal costs by 130%–150% for BWRs and by 100%–250% for PWRs.

12. The formula estimate is underestimating the costs of insurance and regulatory fees by 100%–150% for BWRs and by 100%–200% for PWRs.

13. The formula should continue to not include an estimate for property taxes.

14. The formula estimate is overestimating energy costs by about 70% for BWRs and by 30%–40% for PWRs.

15. The formula estimate is overestimating unit packaging costs by 10-20% for BWRs and by 20%–35% for PWRs.

16. The formula estimate appears to be overestimating unit LLW transportation costs by about 60%–80% for west/mid-west BWR plants and by 20%–60% for BWR plants located in the east/northeast/southeast. In addition, the formula appears to be overestimating unit LLW transportation costs for PWRs by 10%–25% for predominantly bulk rail shipments and underestimating unit LLW transportation costs by about a factor of 3 for predominantly short distance truck/barge shipments (e.g., less than 500 miles).

17. The formula estimate is overestimating unit LLW disposal costs by about 60% for BWRs. The formula is also overestimating unit disposal costs for PWRs by about 75% for plants in the Northwest Compact and by about 50% for plants using the Energy*Solutions* facility for disposal of most of their Class A LLW.

18. The formula appears to be overestimating combined LLW packaging/transportation/disposal costs by 50%–60% for PWRs.

5.7 References

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6 PROPOSED UPDATED MINIMUM DECOMMISSIONING FUND FORMULA

In this section, the results of the decommissioning cost and LLW volume comparisons in Section 5 are used to develop a proposed update to the 10 CFR 50.75(c) minimum decommissioning fund formula. The first step in this process is to develop an updated cost for the reference PWR and BWR plants that incorporates the Section 5 results. The reference PWR plant is the Trojan Nuclear Plant for which the original license termination cost estimate was developed in NUREG/CR-0130 (Reference 1), and associated addendums, and subsequently updated in NUREG/CR-5884 (Reference 2). The reference BWR plant is the Columbia Generating Station for which the original license termination cost estimate was developed in NUREG/CR-0672 (Reference 2), and associated addendums, and subsequently updated in NUREG/CR-6174 (Reference 4). The minimum decommissioning fund formula is based on the original cost estimates for these reference plants. The subsequent updated estimates for the reference plants were further updated to 2010 dollars in Section 2 of this report. Section 6.1 revises the cost estimates for the reference PWR and BWR based on the results of Section 5 of this report. These results are then used to derive an updated minimum decommissioning fund formula in Section 6.2.

6.1 Revised Cost Estimates for the Reference PWR and BWR Plants

The general approach taken to revise the cost estimates for the reference plants is to scale the updated cost estimates from Section 2 of this report using scaling factors developed from the Section 5 results. The updated cost estimates from Section 2 are used as the starting point for this scaling rather than the original cost estimates used in the 10 CFR 50.75(c) formula development because the updated estimates more accurately reflect the decommissioning processes and methods utilized/experienced at the completed nuclear power plant decommissioning projects that have been reviewed to date. For example, the updated studies assumed a decommissioning period of about 8.6 years for the PWR and 6.3 years for the BWR from permanent plant shutdown to license termination, whereas the original studies assumed a decommissioning periods of 3.5–4 years. The additional time was provided in the updated estimates to allow for cooling of spent fuel in the spent fuel pool prior to loading into dry storage casks for long-term interim storage. The decommissioning period for the nuclear plant projects reviewed in this study that have completed decommissioning, all of which were PWRs, have ranged from 8.8 years for Maine Yankee to about 12.5 years from Trojan (note that while the time period from permanent plant shutdown to nominal license termination was almost 20 years for Rancho Seco, as the plant was in safe storage for a period of about eight years prior to the commencement of decommissioning activities). While these time periods are somewhat longer than those assumed for the reference plants in the updated cost estimates, the actual experience to date reflects plants that have permanently shutdown prematurely and did not benefit from decommissioning planning and preparation activities that could normally be performed prior to permanent shutdown. The cost estimates for the reference plants assume decommissioning planning and preparation activities for about 2.5 years prior to permanent plant shutdown.

The updated decommissioning cost estimates from Section 2, in 2010 dollars, are provided in Table 6.1 for both PWRs and BWRs and for the same cost categories as used in Section 5 of this report. The costs are also provided for the six scenarios reported in NUREG-1307, Revision 14 (Reference 5), which are as follows:

1. Disposal of all LLW at the full-service US Ecology facility in the state of Washington. This disposal scenario is currently only available to plants located in the Northwest and Rocky Mountain Compacts, which currently only includes the Columbia Generating Station. This is also currently the only option available to the Columbia Generating Station.

2. Disposal of all waste at the Energy*Solutions* Barnwell facility in South Carolina. This disposal scenario is currently only available to plants located in the Atlantic Compact, which currently only includes the Millstone Nuclear Power Station (Units 1, 2, and 3), Oyster Creek Nuclear Generating Station, Salem Nuclear Power Plant (Units 1 and 2), Hope Creek Nuclear Generating Station, H. B. Robinson Nuclear Generating Station, Oconee Nuclear Station (Units 1, 2, and 3), Catawba Nuclear Station (Units 1 and 2), and Virgil C. Summer Nuclear Generating Station.

3. Disposal of all waste at a Generic facility (which is assumed to have the same disposal rates as the Barnwell facility). This disposal scenario is available to all plants not previously identified in Scenarios 1 and 2 above.

4. Disposal of 85% of LLW (all Class A) at the Energy*Solutions* facility in Utah and the remainder at the US Ecology facility. The disposal scenario is currently not available to any plant.

5. Disposal of 85% of LLW (all Class A) at the Energy*Solutions* facility in Utah and the remainder at the Barnwell facility. This disposal scenario is currently only available to plants located in the Atlantic Compact, as identified in Scenario 2 above.

6. Disposal of 85% of LLW (all Class A) at the Energy*Solutions* facility in Utah and the remainder at a Generic facility (which is assumed to have the same disposal rates as the Barnwell facility). This disposal scenario is available to the same plants as described for Scenario 3 above or, in other words, those not previously identified in Scenarios 1 and 2.

Since Scenario 3 is assumed to have the same disposal cost as Scenario 2, these are combined under one scenario in Table 6.1. Scenarios 5 and 6 are also combined under one scenario in Table 6.1 for the same reason.

The one element of the original decommissioning cost estimates used in the 10 CFR 50.75(c) formula development that is carried forward into the revised cost estimates developed in this section for the reference plants is the LLW volumes and classifications. The updated studies for the reference plants had substantially decreased the volume of LLW expected to be disposed of at LLW disposal facilities from the volumes assumed in the original cost studies. This was done because the rapidly increasing cost of LLW disposal was expected to result in the rigorous use of volume reduction/minimization methods to reduce the volume shipped for disposal. However, as discussed in Section 5.4, the higher LLW volumes from the original studies are reasonably representative of the volumes reported for the completed PWR decommissioning projects and for the licensee estimates for BWR decommissioning. The availability of the Energy*Solutions* facility for cost-effective bulk and containerized disposal of Class A LLW has significantly reduced the incentive for the use of rigorous volume reduction and minimization techniques.

Table 6.1. Updated Cost Estimates for the Reference Plants ($ millions 2010)

	Full-Service Disposal Facility		Separate Class A and Class B/C Disposal Facilities	
Cost Category	US Ecology	Energy*Solutions* Barnwell or Generic	Energy*Solutions* Utah – US Ecology	Energy*Solutions* Utah – Energy*Solutions* Barnwell or Generic
PWR				
Project Management	76.86	76.86	76.86	76.86
Decontamination and Removal	60.86	60.86	60.86	60.86
Regulatory and Insurance	25.11	25.11	25.11	25.11
Property Taxes	0.43	0.43	0.43	0.43
Energy	8.63	8.63	8.63	8.63
LLW Packaging	5.03	5.03	5.03	5.03
LLW Transportation	13.39	30.92	13.39	30.92
LLW Burial	98.58	334.86	80.83	150.67
TOTAL	**288.90**	**542.69**	**271.14**	**358.51**
BWR				
Project Management	101.32	101.32	101.32	101.32
Decontamination and Removal	59.11	59.11	59.11	59.11
Regulatory and Insurance	23.44	23.44	23.44	23.44
Property Taxes	0.00	0.00	0.00	0.00
Energy	8.62	8.62	8.62	8.62
LLW Packaging	7.93	7.93	7.93	7.93
LLW Transportation	4.17	25.45	4.17	25.45
LLW Burial	175.49	575.80	129.03	296.46
TOTAL	**380.08**	**801.67**	**333.63**	**522.33**

Using the LLW volume estimates from the original PWR and BWR studies and the Section 5.5 results of the comparison of the formula and updated cost estimates for the reference plants to the actual costs for completed decommissioning projects and licensee estimates, revised cost estimates for the reference PWR and BWR are developed. In general, the approach was to develop scaling factors, based on the Section 5.5 results, for each cost category reported in Table 6.1 that would result in a revised cost estimate for the reference plants that were in the low end-to-below average of the estimated/actual costs reviewed in this study, with a greater emphasis placed on actual reported costs when available. The revised results are then compared to the actual reported costs and licensee-developed costs, updated to 2010 dollars, from Sections 3 and 4 of this report. The results for each cost category are provided below. The discussion for each cost category describes the scaling factor used and the basis for its selection. Figures are also provided showing the comparison of the revised cost estimate for the reference plant to the actual costs and licensee-estimated decommissioning costs. [Note: All of the figures provided for each cost category show all of the plants included in developing the scaling factors. In some cases, no data were available for certain of the plants to use in the development of the scaling factor; however, the plants are included in the figure anyway so that the figures are consistent for each cost category.]

Project Management

For PWRs, a scaling factor of 3.25 is used to increase the Table 6.1 project management costs to approximately that reported for the decommissioning of Maine Yankee. As shown in Figure 6.1, applying this factor results in a revised project management cost for the reference PWR that is about the same as that reported for the decommissioning of Maine Yankee (which is higher than that for Trojan but less than that reported for Haddam Neck) and is at the lower end of the estimates reported by licensees.

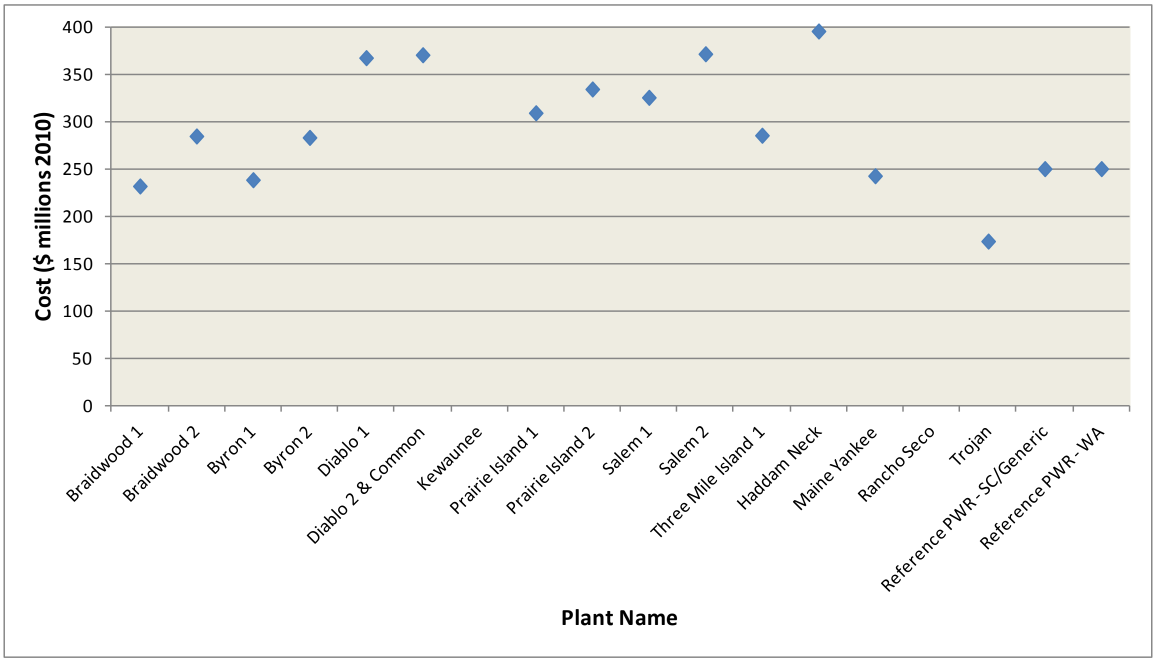

Figure 6.1. Project Management Cost – PWR

For BWRs, a scaling factor of 2.5 is used to increase the Table 6.1 project management costs to the lower end of the licensee estimates. This result is shown in Figure 6.2.

Decontamination and Removal

For PWRs, a scaling factor of 2.1 is used to increase the Table 6.1 decontamination and removal costs to about the average of the licensee estimates. As shown in Figure 6.3, applying this factor results in a revised decontamination and removal cost for the reference PWR that is about the average of the costs reported for Trojan and Maine Yankee and also about the average of the licensee estimates.

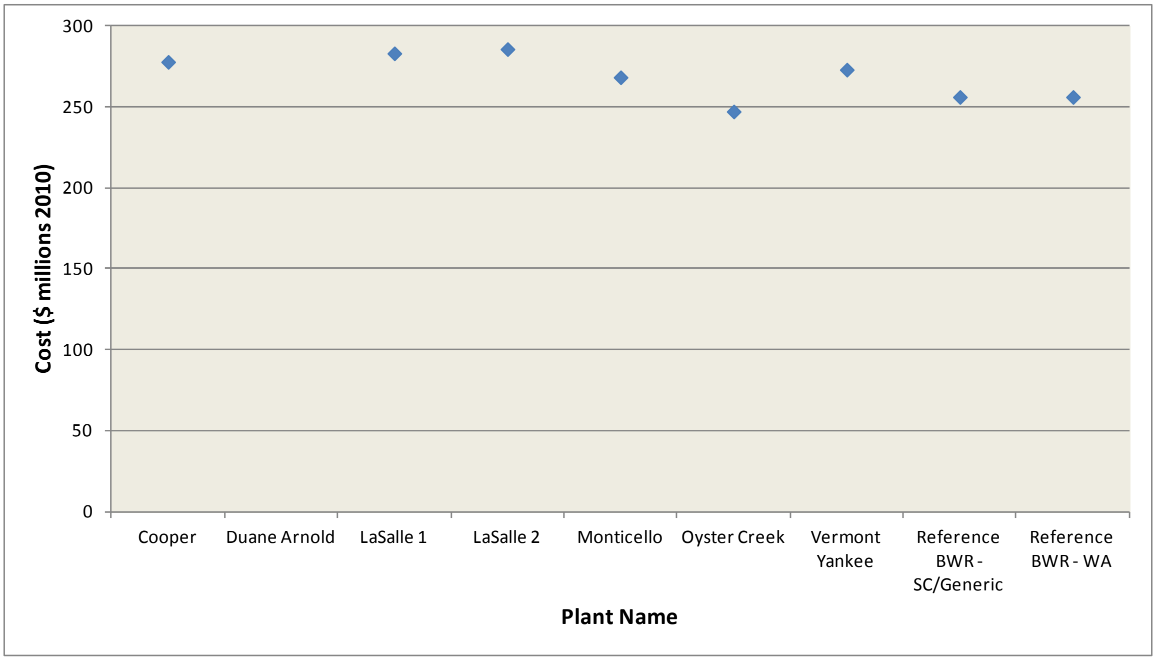

Figure 6.2. Project Management Cost – BWR

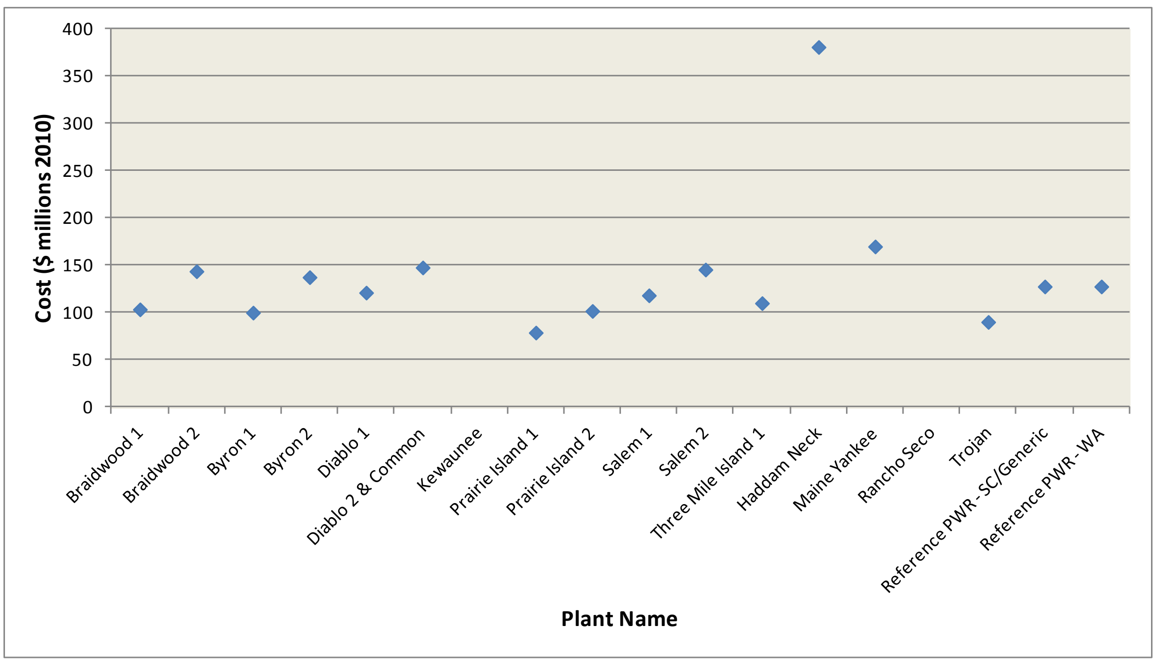

Figure 6.3. Decontamination and Removal Cost – PWR

For BWRs, a scaling factor of 2.1 is also used to increase the Table 6.1 decontamination and removal costs to about the average of the licensee estimates. This result is shown in Figure 6.4.

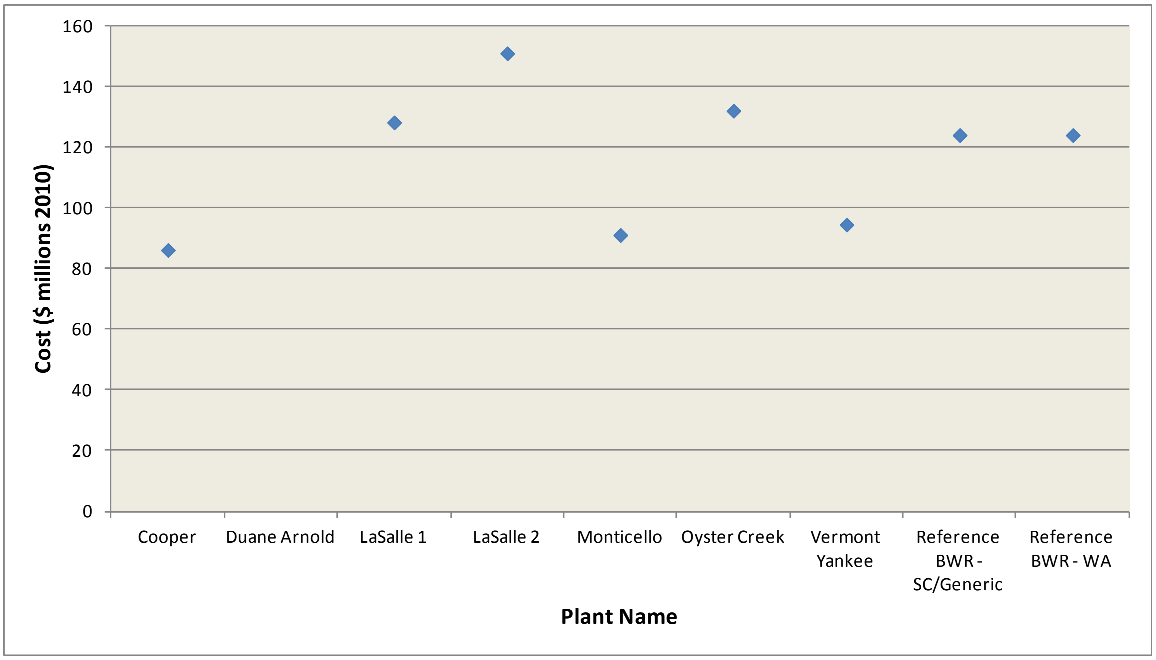

Figure 6.4. Decontamination and Removal Cost – BWR

Regulatory and Insurance

For PWRs, a scaling factor of 0.36 is used to decrease the Table 6.1 regulatory and insurance and removal costs to the lower end of the licensee estimates. This result is shown in Figure 6.5.

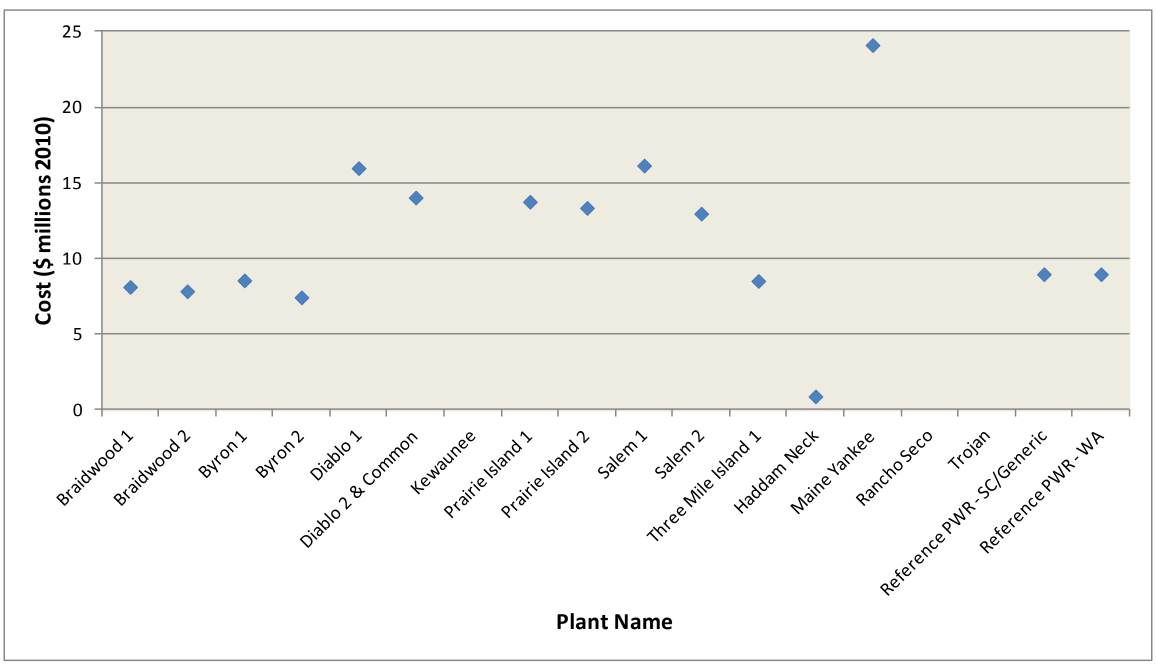

Figure 6.5. Regulatory and Insurance Cost – PWR

For BWRs, a scaling factor of 0.38 is used to decrease the Table 6.1 regulatory and insurance and removal costs to the lower end of the licensee estimates. This result is shown in Figure 6.6.

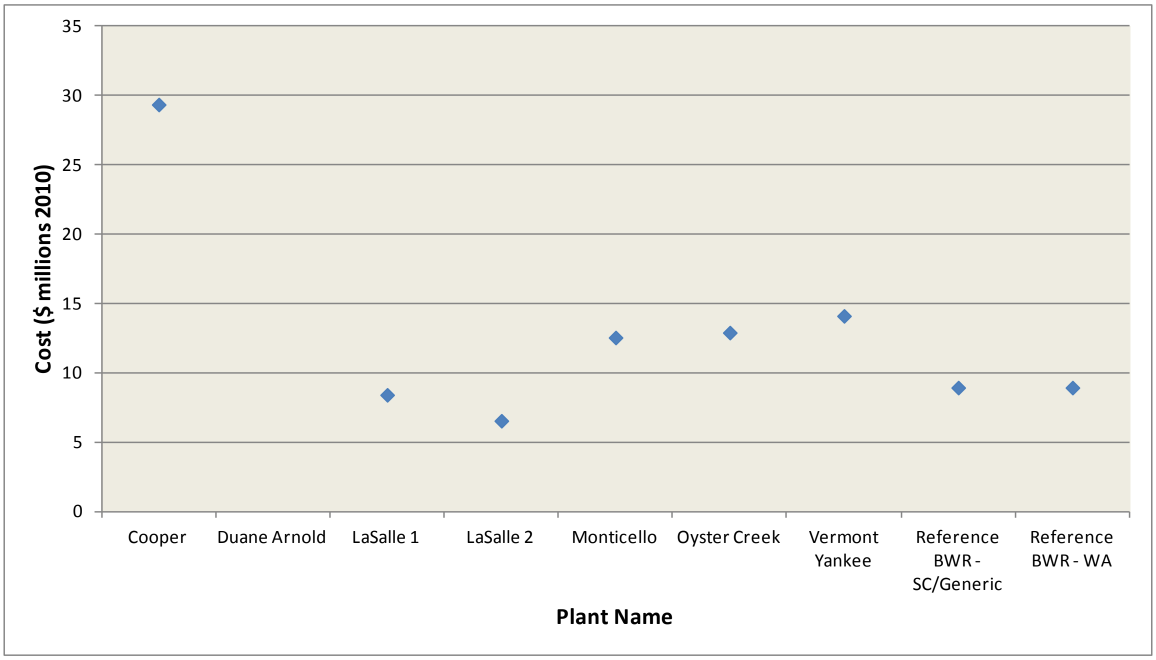

Figure 6.6. Regulatory and Insurance Cost – BWR

Property Taxes

No estimate of property taxes is included in the revised license termination cost estimates for the reference PWR and BWR since property taxes are not considered by the authors to be a decommissioning cost.

Energy

The updated cost estimates for energy provided in Table 6.1 are used as-is for the revised cost estimates for the reference PWR and BWR (i.e., these costs are not assumed to be scaled). No scaling was assumed because these costs: 1) are already fairly representative of the licensee estimates (energy costs were not reported for the completed decommissioning projects), 2) can change dramatically from year to year due to fluctuations in fuel oil prices, and 3) represent a small fraction of the total license termination cost (i.e., less than 2%). The results are compared with the actual reported costs and licensee-developed costs in Figures 6.7 and 6.8 for PWRs and BWRs, respectively.

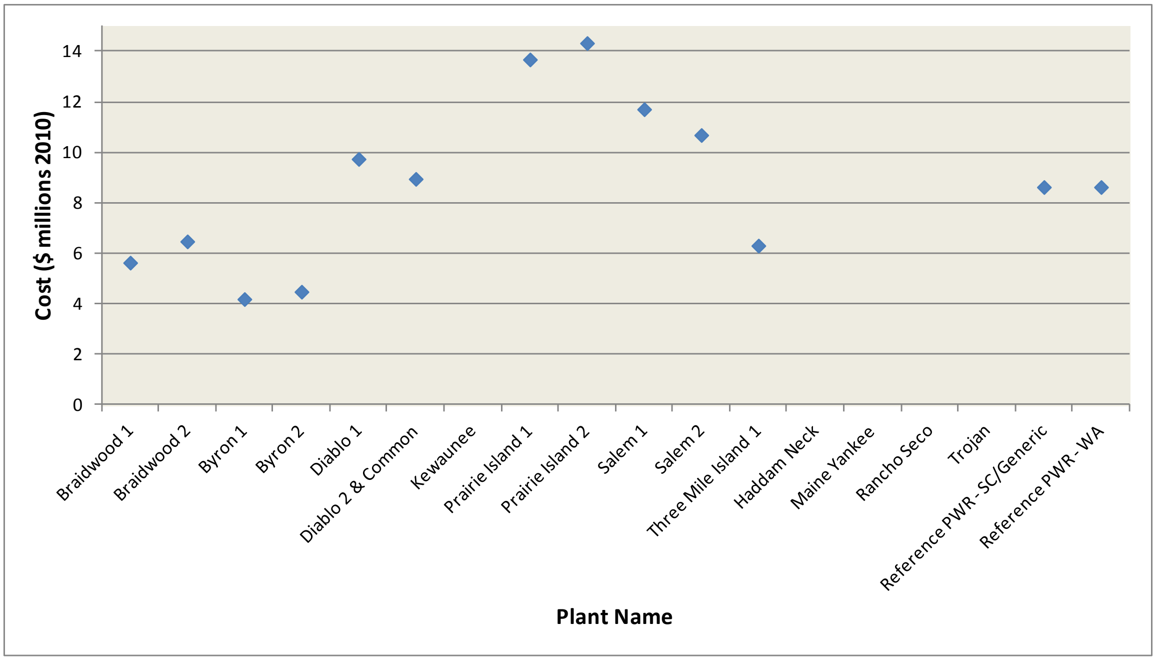

Figure 6.7. Energy Cost – PWR

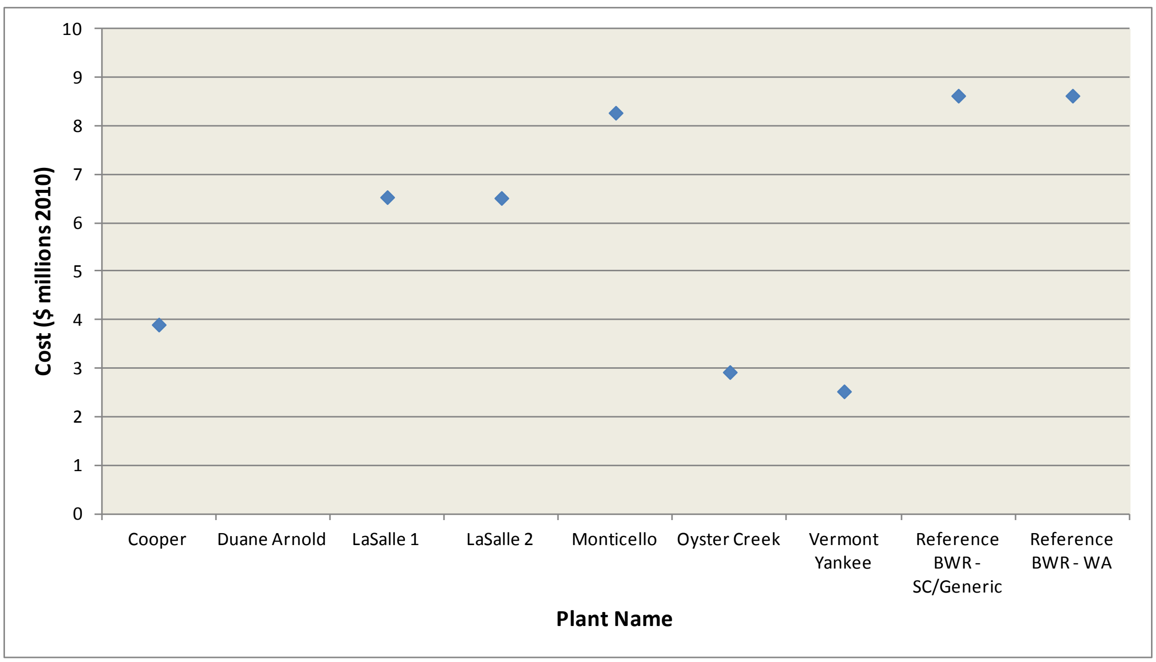

Figure 6.8. Energy Cost – BWR

LLW Packaging

Based on the results of Section 5.5 of this report, unit LLW packaging costs ($/ft^3) are higher for containerized LLW destined for disposal at full-service disposal facilities than for bulk LLW destined for disposal at the Energy*Solutions* facility or for processing at an offsite processor facility. Furthermore, the data show that as the volume of low-activity bulk LLW increases, the weighted-average unit LLW packaging cost decreases. Therefore, two scaling factors are developed for each of the reference plants: 1) a scaling factor for situations in which the majority of the LLW is shipped as bulk waste for disposal/processing and 2) a scaling factor for situations in which all of the LLW is shipped as containerized waste for disposal at a high-cost, full-service disposal facility. For the former, the BWR packaging cost from Table 6.1 of \$7.93 million is divided by the assumed volume of 533,875 ft^3 from NUREG/CR-6174 (Reference 4) to obtain the unit packaging cost of \$14.85/ft^3. Based on the results of Section 5.5, this unit cost is increased by a factor of 1.5 to \$22.42/ft^3, the average of the licensee estimates. Multiplying this unit cost by the original LLW volume of 668,435 ft^3 from NUREG/CR-0672 (Reference 3) results in a revised total LLW packaging cost of \$14.98 million for the reference BWR plant for the scenario in which the majority of the LLW is shipped as bulk waste for disposal/processing.

Unfortunately, the packaging cost is not available for the three PWR plants (Haddam Neck, Maine Yankee, and Rancho Seco) that have completed decommissioning, and which are representative of the scenario in which the majority of the LLW is shipped as bulk waste for disposal/processing. For this reason, and since the original LLW volume of 642,556 ft^3 for the reference PWR plant from NUREG/CR-0130 (Reference 1) is very close to that for the original LLW volume for the reference BWR plant, the unit packaging cost determined previously for BWRs is used for the reference PWR plant. Multiplying this unit cost by the original LLW volume results in a revised total LLW packaging cost of \$14.40 million for the reference PWR plant for the scenario in which the majority of the LLW is shipped as bulk waste for disposal/processing.

As shown in Figures 6.9 and 6.10, the revised total LLW packaging cost for the reference PWR and BWR, for scenario – SC/Generic, is at the lower end of the licensee estimates for PWRs and BWRs, respectively. As discussed in Section 5.5, the unit LLW packaging cost reported for the completed Trojan decommissioning project is about the same as the low end of the PWR licensee estimates. For this reason, the same unit and total packaging costs are used for the case in which all or a large fraction of the PWR and BWR LLW is disposed of at the full-service disposal facility located in Washington. This result is shown in Figures 6.9 and 6.10 (scenario – WA) for the reference PWR and BWR, respectively.

For the second scenario, all or a significant fraction of the LLW is assumed to be shipped as containerized LLW for disposal to a generic full-service disposal facility or the South Carolina (i.e., Barnwell) facility. Because of the relatively high cost of the full-service disposal facility, volume reduction and minimization techniques will reduce the LLW volume to be disposed relative to that assumed above for the bulk waste disposal scenario. Based on the licensee-estimated total LLW volumes for the Diablo Canyon and Salem PWR plants reported in Section 5.4 of this report, the total LLW volumes for these plants are about a factor of four less than the original LLW volume for the reference PWR plant of 642,556 ft^3 (Reference 1). Dividing the reference PWR plant LLW volume by four results in a total LLW volume for this scenario of 160,639 ft^3. The PWR packaging cost from Table 6.1 of \$5.03 million is divided by the assumed volume of 290,834 ft^3 from NUREG/CR-5884 (Reference 2) to obtain the unit packaging cost of \$17.30/ft^3. Based on the results of Section 5.5, this unit cost is increased by a factor of 4 to \$69.19/ft^3, about the same as for the licensee estimate for Salem. This unit cost is multiplied by the LLW volume of 160,639 ft^3 for the reference PWR plant for this scenario to obtain the revised total LLW packaging cost of $11.11 million for the reference PWR plant for the scenario in which the majority of the LLW is shipped to a high-cost full-service disposal facility for disposal.

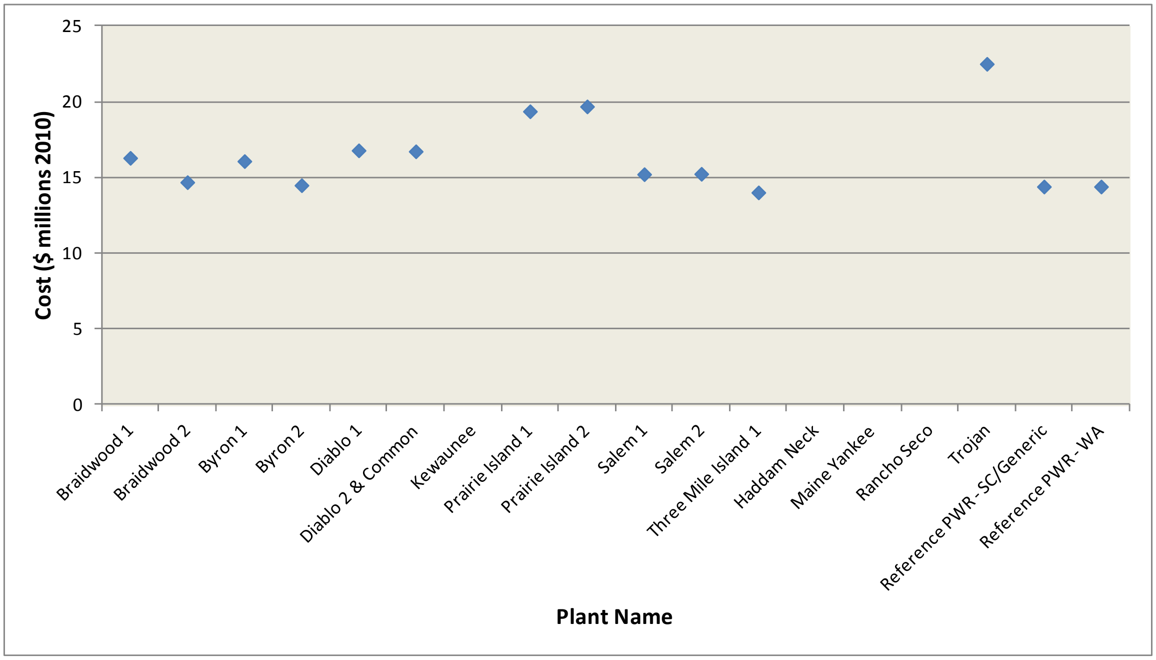

Figure 6.9. LLW Packaging Cost – PWR

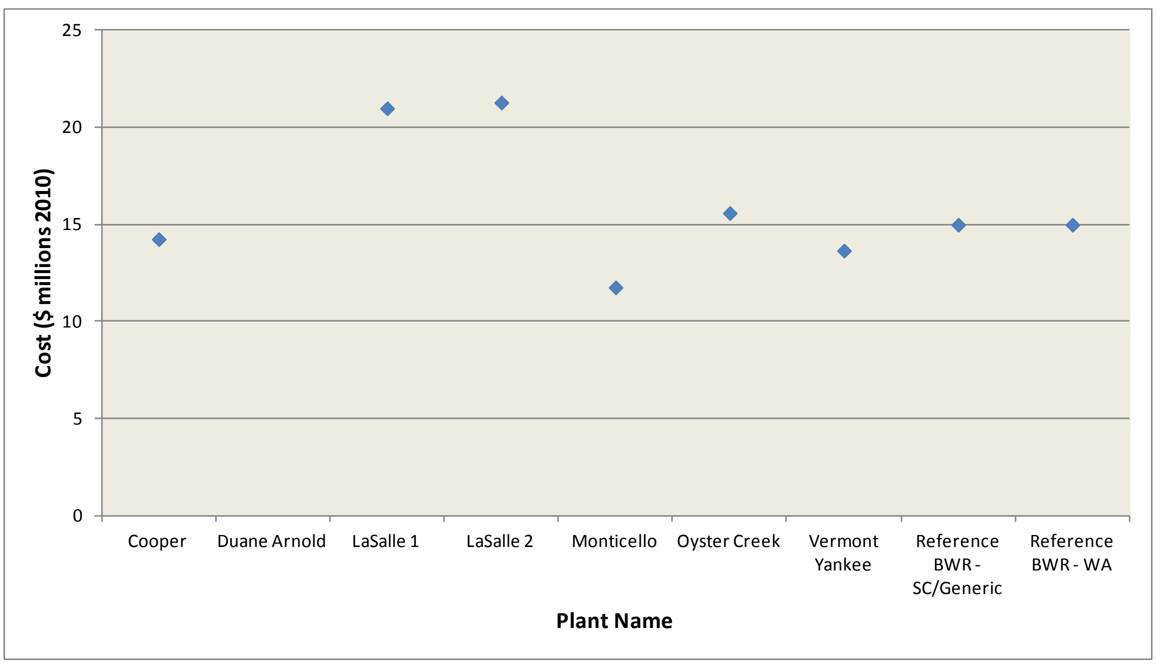

Figure 6.10. LLW Packaging Cost – BWR

None of the BWR licensee estimates is for a scenario in which all or a significant fraction of the LLW is assumed to be shipped as containerized LLW for disposal at a full-service disposal facility. For this reason, the unit packaging cost and volume reduction/minimization factor determined previously for PWRs is used for the reference BWR plant. Dividing the reference BWR plant LLW volume by four results in a total LLW volume for this scenario of 167,109 ft^3. Multiplying this volume by the unit LLW packaging cost results in a revised total LLW packaging cost of $11.56 million for the reference BWR plant for the scenario in which the majority of the LLW is shipped to a high-cost full-service disposal facility for disposal.

LLW Transportation

As noted in Section 5.5 and Table 6.1, the updated LLW transportation cost estimates for the reference plants included separate estimates for shipment of LLW to the two full-service disposal facilities located in Washington and South Carolina. For the reference PWR plant (i.e., Trojan), the transportation distance was assumed to be 297 miles to the Washington facility and 2,799 miles to the South Carolina facility. For the reference BWR plant (i.e., Columbia), the transportation distance was assumed to be 15 miles to the Washington facility and 2,674 miles to the South Carolina facility.

Based on the results of Section 5.5 of this report, unit LLW transportation costs ($/mile/$ft^3$) are a function of the distance to the disposal/processor facility, decreasing as the shipping distance increases. Three different scenarios are considered here: 1) shipment of the majority of the LLW as bulk waste to a waste processer or the Energy*Solutions* facility in Utah, which is assumed to be 1,000 miles, 2) shipment of the majority of the LLW as containerized waste to the disposal facility in Washington (shipping distances assumed to be 297 miles for the reference PWR plant and 15 miles for the reference BWR plant), and 3) shipment of the majority of the LLW as containerized waste to a generic high-cost full-service disposal facility or the South Carolina facility).

For the first scenario in which the majority of the LLW is assumed to be shipped as bulk waste, the PWR transportation cost from Table 6.1 of $30.92 million (i.e., for the generic site) is divided by the assumed volume of 290,834 ft^3 (Reference 2) and then further divided by 2,799 miles to obtain the unit transportation cost of $0.038/mile/$ft^3$. Based on the results of Section 5.5, this unit cost is decreased by a factor of 2.8 to $0.014/mile/$ft^3$, the average of the licensee estimates for the same bulk waste shipping scenario. Assuming a typical shipping distance of 1,000 miles, this unit cost is multiplied by the original LLW volume of 642,556 ft^3 from NUREG/CR-0130 (Reference 1) and by 1,000 miles, which results in a revised total LLW transportation cost of $8.72 million for the reference PWR plant for the scenario in which the majority of the LLW is shipped as bulk waste for disposal/processing.

Similarly, the BWR transportation cost from Table 6.1 of $25.45 million (i.e., for the generic site) is divided by the assumed volume of 533,874 ft^3 (Reference 4) and then further divided by 2,674 miles to obtain the unit transportation cost of $0.018/mile/$ft^3$. Based on the results of Section 5.5, this unit cost is decreased by a factor of 1.2 to $0.015/mile/$ft^3$, the average of the licensee estimates for the same bulk waste shipping scenario. Assuming a typical shipping distance of 1,000 miles, this unit cost is multiplied by the original LLW volume of 668,435 ft^3 from NUREG/CR-0672 (Reference 3) and by 1,000 miles, which results in a revised total LLW transportation cost of $9.83 million for the reference BWR plant for the scenario in which the majority of the LLW is shipped as bulk waste for disposal/processing.

As shown in Figures 6.11 and 6.12, the revised total LLW transportation cost for the reference PWR and BWR, for scenario – SC/Generic, is at the lower end of the licensee estimates for a similar scenario for PWRs and BWRs, respectively.

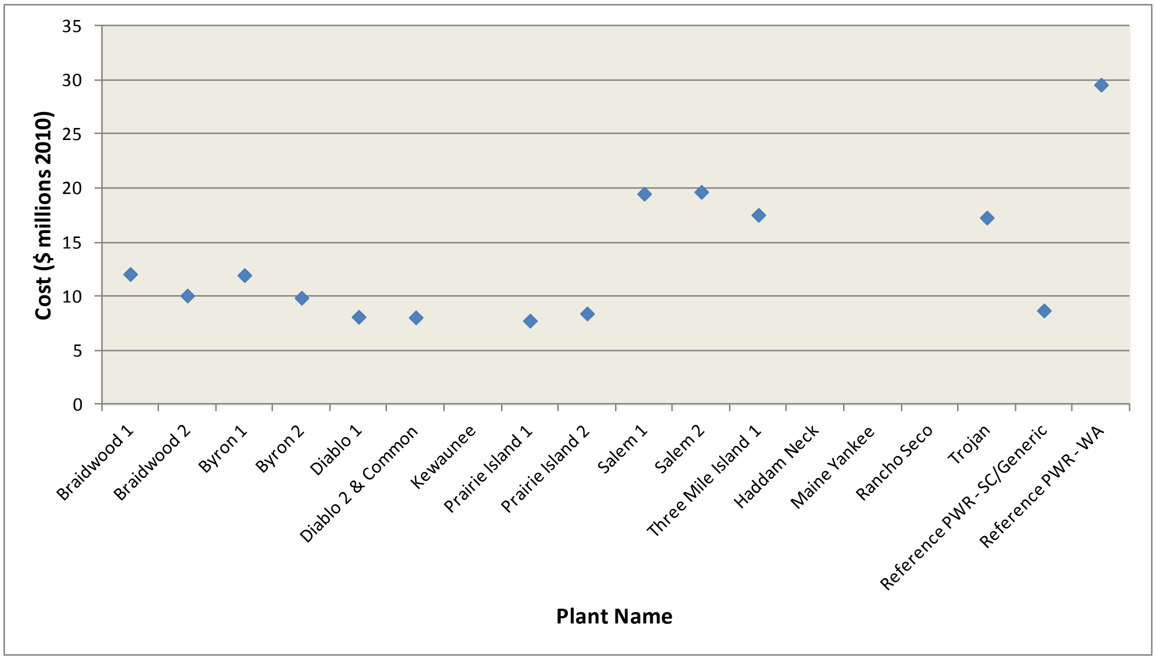

Figure 6.11. LLW Transportation Cost – PWR

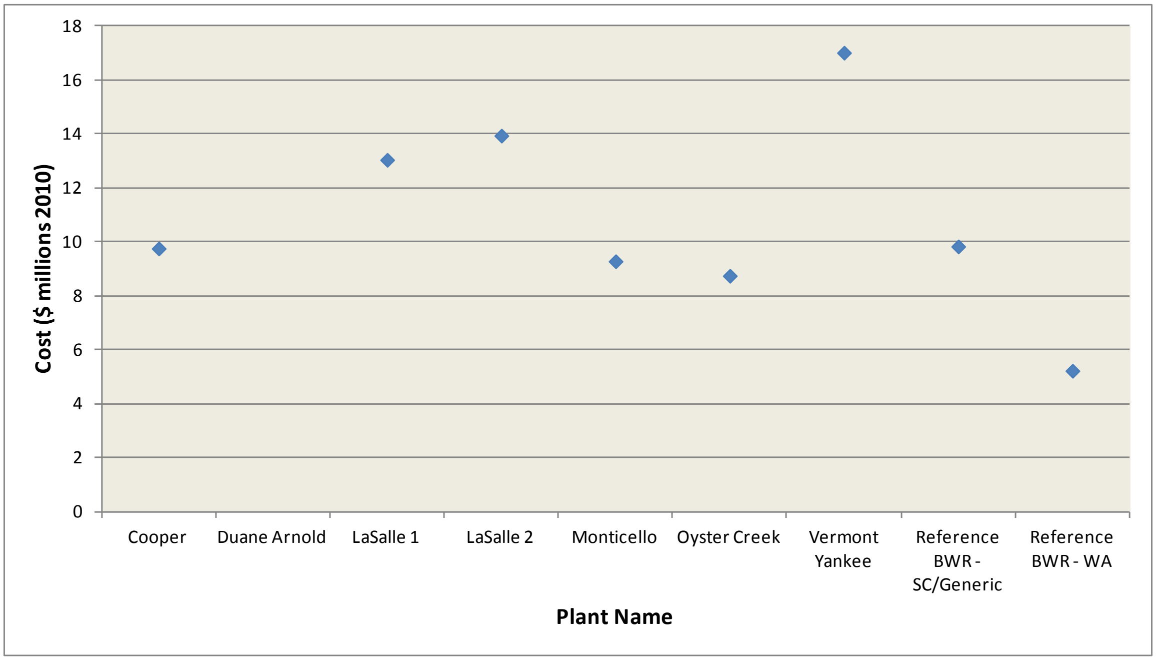

Figure 6.12. LLW Transportation Cost – BWR

For the second scenario in which the majority of the LLW is shipped as containerized waste to the disposal facility in Washington, the PWR transportation cost from Table 6.1 of $13.39 million is divided by the assumed volume of 290,834 ft^3 (Reference 2) and then further divided by 297 miles to obtain the unit transportation cost of $0.155/mile/$ft^3$. Based on the results of Section 5.5, this unit cost is used as-is (i.e., not scaled). A shipping distance of 297 miles is assumed since this is the distance from the Trojan plant to the disposal facility, the only PWR located in the Northwest and Rocky Mountain Compacts. The unit cost is multiplied by the original LLW volume of 642,556 ft^3 from NUREG/CR-0130 (Reference 1) and by 297 miles, which results in a revised total LLW transportation cost of $29.59 million for the reference PWR plant for the scenario in which the majority of the LLW is shipped as containerized waste for disposal at the Washington facility.

Similarly, the BWR transportation cost from Table 6.1 of $4.17 million is divided by the assumed volume of 533,874 ft^3 (Reference 4) and then further divided by 15 miles to obtain the unit transportation cost of $0.52/mile/$ft^3$. Based on the results of Section 5.5, this unit cost is used as-is (i.e., not scaled). A shipping distance of 15 miles is assumed since this is the distance from the Columbia plant to the disposal facility, the only BWR located in the Northwest and Rocky Mountain Compacts. The unit cost is multiplied by the original LLW volume of 668,435 ft^3 from NUREG/CR-0672 (Reference 3) and by 15 miles, which results in a revised total LLW transportation cost of $5.22 million for the reference BWR plant for the scenario in which the majority of the LLW is shipped as containerized waste for disposal at the Washington facility.

These results for the reference PWR and BWR plants are shown in Figures 6.11 and 6.12, respectively, as the "Reference PWR or BWR – WA" plant. The revised cost for the reference PWR plant is significantly higher than the equivalent-distant Trojan plant principally because the reference plant is assumed to ship about 50% more LLW than was reported to be shipped during the Trojan decommissioning project. The revised cost for the reference BWR plant is significantly lower than any of the licensee estimates due to the shipping distance of only 15 miles, which is significantly less than the shipping distances for the licensee's plants.

For the third scenario in which the majority of the LLW is shipped as containerized waste to the high-cost generic disposal facility or the South Carolina facility, the revised estimate for both the reference PWR and BWR plants is calculated in a similar manner to that used for containerized shipments to the Washington disposal facility. The same unit transportation costs are used for this calculation. However, for this scenario the shipping distance is assumed to be 1,000 miles and, as described previously for estimating the revised LLW packaging cost, the LLW volume shipped is assumed to be reduced by a factor of four due to volume reduction/minimization activities. The resulting transportation cost is $24.90 million and $25.91 million for the reference PWR and BWR plants, respectively.

LLW Disposal

As discussed previously, the LLW volumes developed in the original decommissioning studies for the reference PWR and BWR plants are being used to develop the revised decommissioning costs for the reference plants. For this reason, the methodology described in NUREG-1307 for bi-annually updating the LLW disposal costs, or the B_x factor in the 10 CFR 50.75(c) formula, for the reference plants is also used here to develop the revised LLW disposal cost estimates for these plants. The NUREG-1307 methodology uses the published disposal rates for the Washington and South Carolina disposal facilities, price quotes provided for disposal of LLW at the Energy*Solutions* facility in Utah, and price quotes provided by vendors providing LLW processing services. The most recent cost data are provided in NUREG-1307, Revision 14 (Reference 5). This revision of NUREG-1307, which provides costs in 2010 dollars, is used in this study to develop the revised cost estimates for LLW disposal for the reference PWR and BWR plants.

The NUREG-1307 methodology was used to develop LLW disposal cost estimates for the following scenarios:

- disposal of all of the LLW at the Washington facility,

- disposal of all of the LLW at the Generic or South Carolina facility,

- disposal of 100% of the Class A LLW at the Energy*Solutions* Utah facility and all of the Class B and C LLW at a) the Washington facility and b) the Generic or South Carolina facility,

- disposal of 75% of the Class A LLW at the Energy*Solutions* Utah facility, processing of the remaining 25% of the Class A LLW at processor facilities, and disposal of all of the Class B and C LLW at a) the Washington facility and b) the Generic or South Carolina facility,

- disposal of 50% of the Class A LLW at the Energy*Solutions* Utah facility, processing of the remaining 50% of the Class A LLW at processor facilities, and disposal of all of the Class B and C LLW at a) the Washington facility and b) the Generic or South Carolina facility, and

- disposal of 25% of the Class A LLW at the Energy*Solutions* Utahy, processing of the remaining 75% of the Class A LLW at processor facilities, and disposal of all of the Class B and C LLW at a) the Washington facility and b) the Generic or South Carolina facility.

The estimated disposal cost for each of these scenarios is provided in Table 6.2 for the reference plants.

In developing the revised cost estimates for the reference plants, the results in Table 6.2 for the "Full-Service" scenarios and for the "75% Utah/25% Processors" scenario are used. The "75% Utah/25% Processors" scenario was used for this study principally because it represents the Maine Yankee decommissioning experience (i.e., 71%/28% Energy*Solutions*/Processors split), which holds the middle ground between the extremes of the Haddam Neck decommissioning experience (i.e., 13%/87% Energy*Solutions*/Processors split) and the Rancho Seco experience (i.e., 94%/5% Energy*Solutions*/Processors split). The Trojan decommissioning experience is not considered since 100% of its LLW was disposed of at the US Ecology facility in Washington. See Section 5.2 of this report for a discussion of these results.

Table 6.2. Cost Estimates for LLW Disposal Scenarios ($ millions 2010)

Scenario	Washington Facility	Generic or South Carolina Facility
Reference PWR		
Full-Service (Class A/B/C)	147.20	495.67
100% Utah	115.74	163.52
75% Utah/25% Processors	106.28	154.07
50% Utah/50% Processors	96.82	144.61
25% Utah/75% Processors	87.37	135.15
Reference BWR		
Full-Service (Class A/B/C)	178.16	557.74
100% Utah	133.49	248.70
75% Utah/25% Processors	128.81	244.03
50% Utah/50% Processors	124.14	239.35
25% Utah/75% Processors	119.46	234.68

However, the results in Section 5.5 of this report determined that the NUREG-1307 methodology, or decommissioning fund formula, substantially over-predicts LLW disposal costs. Based on these results, the Table 6.2 estimated cost for Energy*Solutions*/Processor scenario are reduced by a factor of two for the reference PWR plant and by a factor of 3 for the reference BWR plant. Applying these factors for the reference PWR plant results in revised LLW disposal costs of $53.14 million for the scenario in which the Class B/C LLW is disposed of at the Washington facility and $77.03 million for the scenario in which the Class B/C LLW is disposed of at the Generic or South Carolina facility. Similarly, applying these factors for the reference BWR plant results in revised LLW disposal costs of $42.51 million for the scenario in which the Class B/C LLW is disposed of at the Washington facility and $97.83 million for the scenario in which the Class B/C LLW is disposed of at the Generic or South Carolina facility.

As shown in Figures 6.13 and 6.14, the revised total LLW disposal cost for the reference PWR and BWR, for scenario – SC/Generic, is at the lower end of the licensee estimates.

For the scenario in which all LLW is disposed of at the Washington facility, the Section 5.5 results for Trojan indicate that the Table 6.2 cost estimate for the reference PWR plant should be reduced by a factor of four. Since no corresponding data are available for disposal of BWR LLW at the Washington facility, the factor of four reduction is assumed for the reference BWR plant. Applying this factor yields a revised LLW disposal cost of $38.80 million for the reference PWR plant and $44.54 million for the reference BWR plant. These results are shown in Figures 6.13 and 6.14 (i.e., scenario – WA). As shown in Figure 6.13, the revised total LLW disposal cost for the reference PWR is very low but still higher than the disposal cost reported for the completed Trojan decommissioning project.

As discussed previously for LLW packaging, for the scenario in which all LLW is disposed of at the high-cost Generic or South Carolina facility, the LLW volume is reduced by a factor of four due to volume reduction/minimization activities. Therefore, reducing the Table 6.2 values by a factor of four yields a revised LLW disposal cost of $123.92 million for the reference PWR plant and $139.44 million for the reference BWR plant.

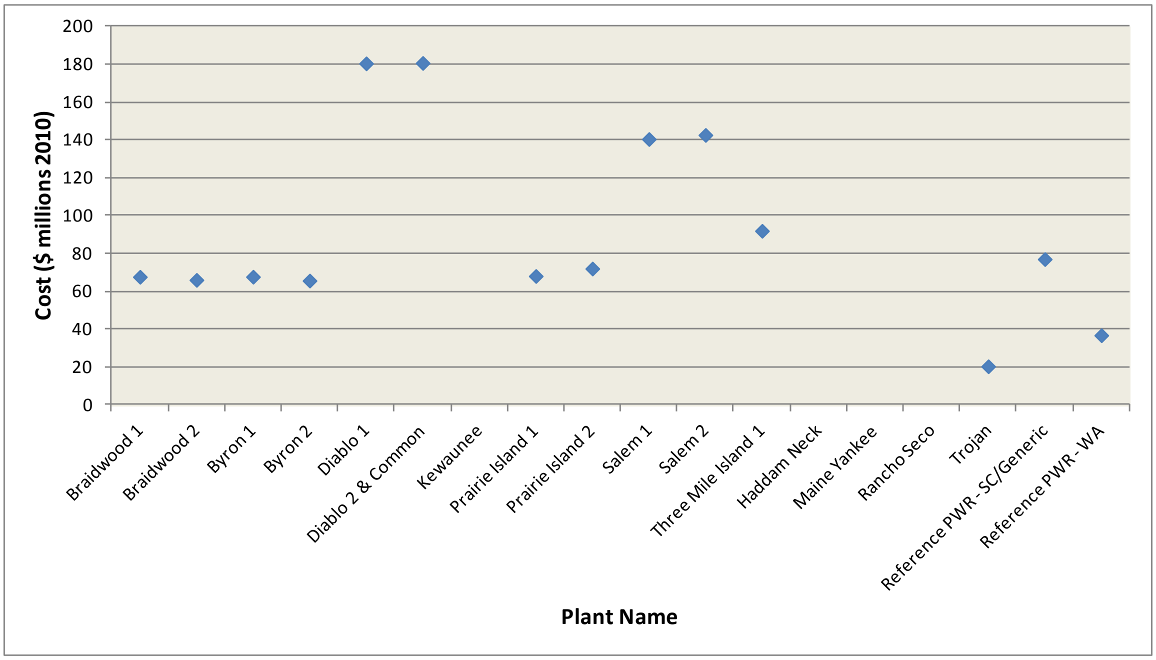

Figure 6.13. LLW Disposal Cost – PWR

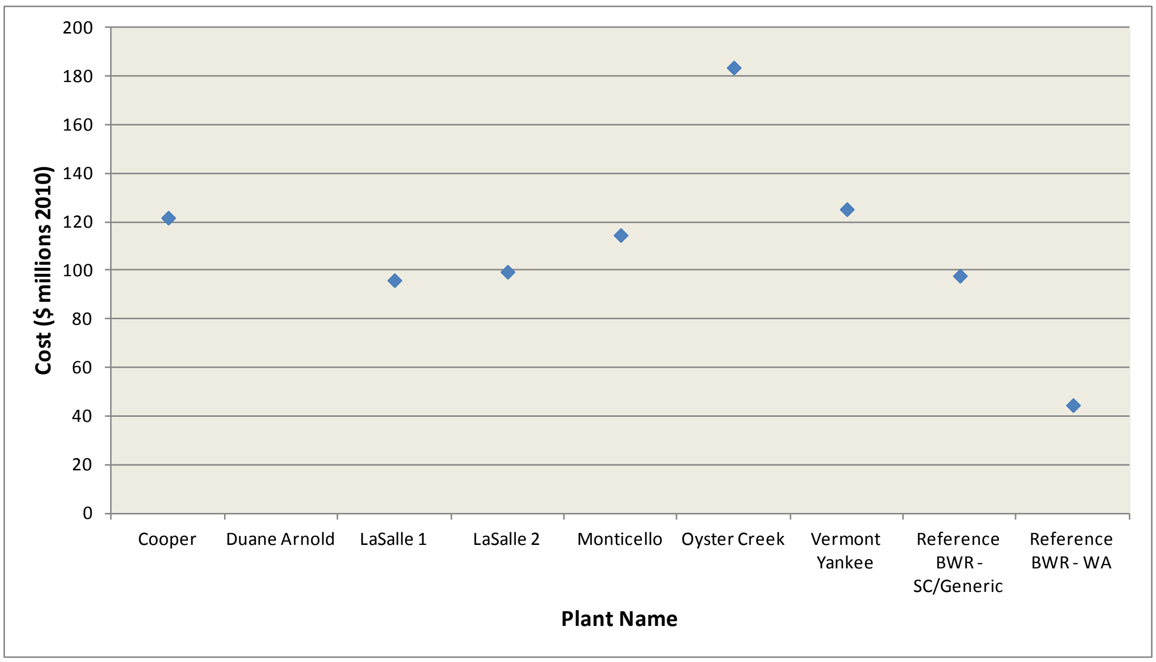

Figure 6.14. LLW Disposal Cost – BWR

PWR LLW Packaging/Transportation/Disposal Cost

The LLW packaging, transportation, and disposal costs comparison discussed above did not include reported costs for Haddam Neck and Maine Yankee because of insufficient detail in the cost data provided. However, the cost data provided for these two completed decommissioning projects does include a combined LLW packaging, transportation, and disposal cost. In order to include this cost information for comparison to the revised cost estimate for the reference PWR plant, Figure 6.15 compares the combined LLW packaging/transportation/disposal cost for the completed projects and licensee estimates to the corresponding revised cost estimate for the reference PWR plant. The revised estimate for scenario "SC/Generic" is somewhat lower than the actual costs experienced at Haddam Neck and Maine Yankee, but somewhat higher than the licensee estimates for similar scenarios (i.e., scenarios in which a large fraction of the LLW is shipped to the Energy*Solutions* Utah facility for disposal or to processors).

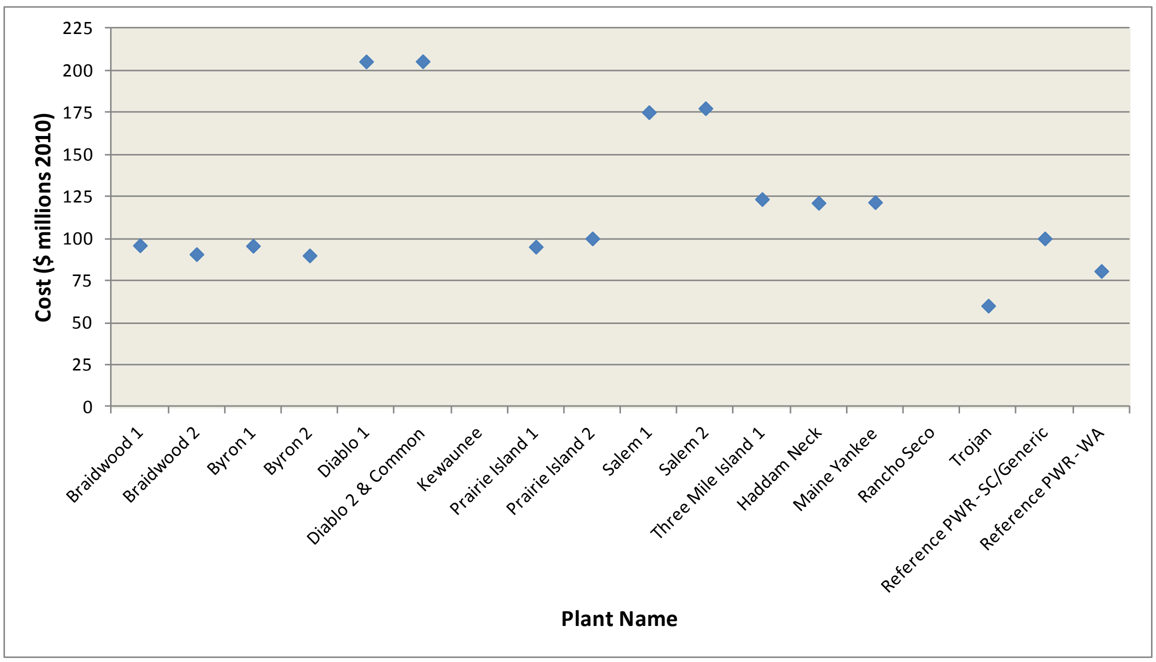

Figure 6.15. LLW Packaging/Transportation/Disposal Cost – PWR

Total License Termination Cost

The revised cost estimates for the reference PWR and BWR plants are summarized in Table 6.3 by cost category. The revised total license termination cost estimate for the reference PWR plant and reference BWR plant are compared in Figure 6.16 and Figure 6.17, respectively, to the license termination costs for the completed projects and licensee-developed estimates. The revised cost estimates are at the lower end of the licensee-developed estimates and the revised cost estimate for the reference PWR plant is comparable to the reported cost to complete the decommissioning of the Rancho Seco plant and somewhat higher than the cost to complete the decommissioning of the Trojan plant.

Table 6.3. Revised Cost Estimates for the Reference Plants ($ millions 2010)

Cost Category	Full-Service Disposal Facility: US Ecology	Full-Service Disposal Facility: Energy*Solutions* Barnwell or Generic	Separate Class A and Class B/C Disposal Facilities: US Ecology – Energy*Solutions* Utah	Separate Class A and Class B/C Disposal Facilities: Energy*Solutions* Barnwell or Generic – Energy*Solutions* Utah
PWR				
Project Management	249.79	249.79	249.79	249.79
Decontamination and Removal	127.80	127.80	127.80	127.80
Regulatory and Insurance	8.97	8.97	8.97	8.97
Property Taxes	0.00	0.00	0.00	0.00
Energy	8.63	8.63	8.63	8.63
LLW Packaging	14.40	11.11	14.40	14.40
LLW Transportation	29.59	24.90	8.72	8.72
LLW Burial	36.80	123.92	53.14	77.03
TOTAL	**475.97**	**555.12**	**471.44**	**495.34**
BWR				
Project Management	256.20	256.20	256.20	256.20
Decontamination and Removal	124.14	124.14	124.14	124.14
Regulatory and Insurance	8.93	8.93	8.93	8.93
Property Taxes	0.00	0.00	0.00	0.00
Energy	8.62	8.62	8.62	8.62
LLW Packaging	14.98	11.56	14.98	14.98
LLW Transportation	5.22	25.91	9.83	9.83
LLW Burial	44.54	139.44	42.51	97.83
TOTAL	**462.64**	**574.80**	**465.21**	**520.54**

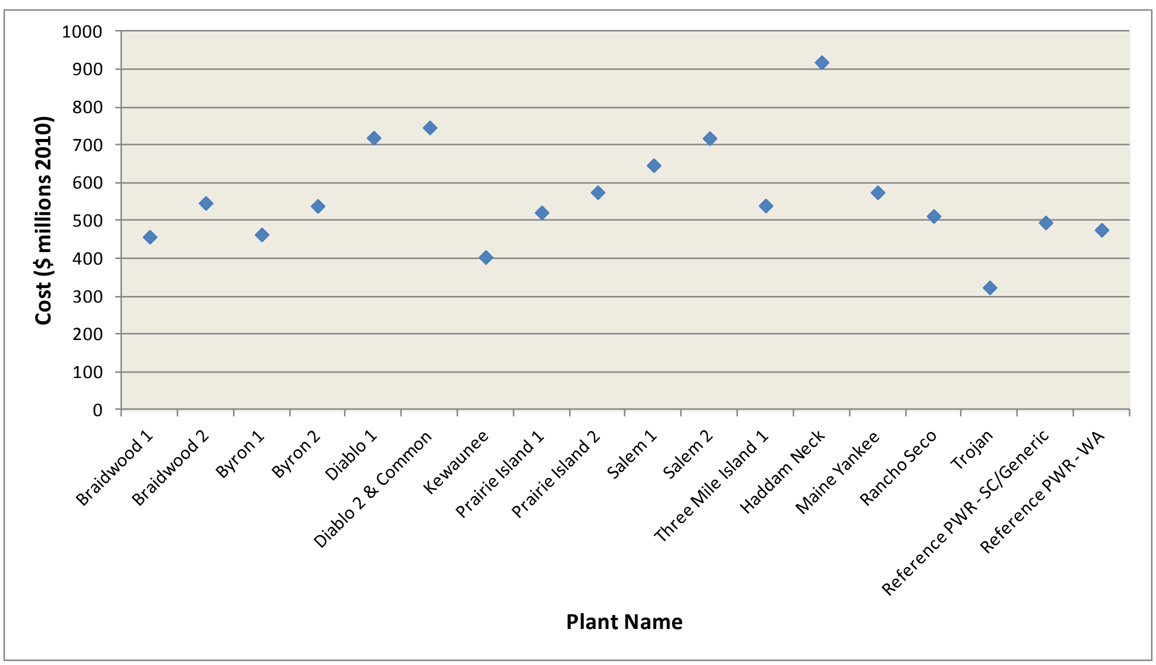

Figure 6.16. License Termination Cost – PWR

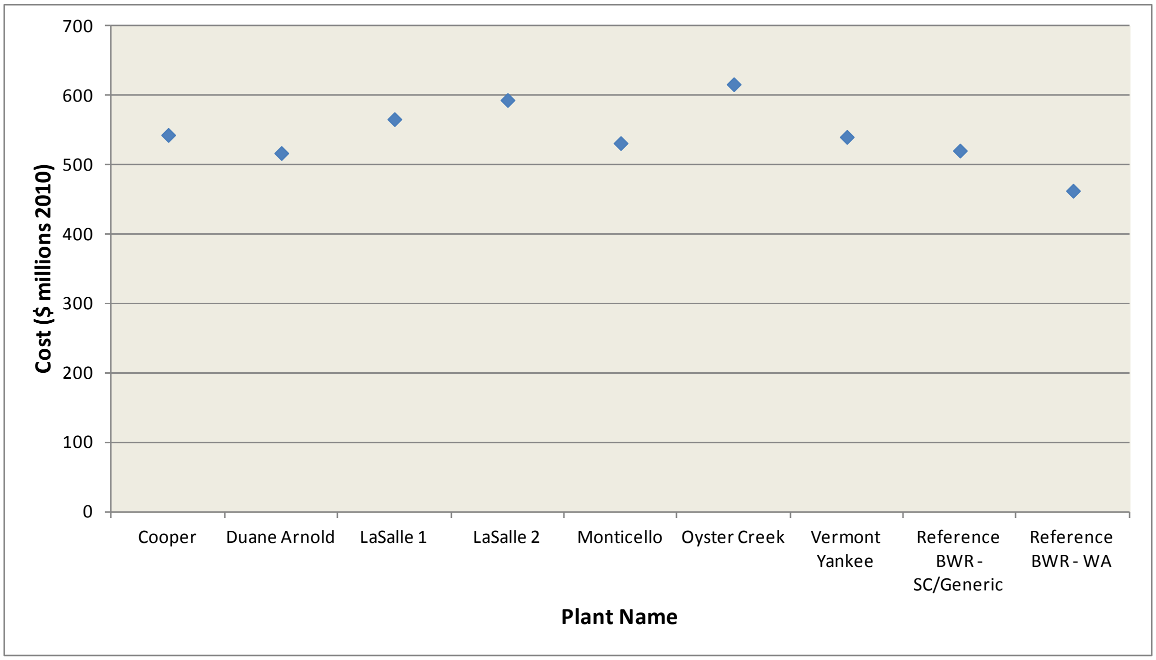

Figure 6.17. License Termination Cost – BWR

6.2 Revised Cost Escalation Formula

For purposes of developing a revised cost escalation formula, license termination costs are divided into the following three general areas:

1. labor, materials, and services,
2. energy, LLW packaging, and LLW transportation, and
3. radioactive waste burial/disposition.

With the exception of LLW packaging, this division is the same as used in the 10 CFR 50.75(c) formula, thus resulting in the same basic cost escalation equation:

$$\text{Escalated Cost (Year X)} = [2010\ \$\ \text{Cost}]\times(A\times Lx + B\times Ex + C\times Bx)$$

where
Estimated Cost (Year X) = estimated decommissioning costs in Year X dollars,
[2010 $ Cost] = estimated decommissioning costs in 2010 dollars,
A = fraction of the [2010 $ Cost] attributable to labor, materials, and services
B = fraction of the [2010 $ Cost] attributable to energy, LLW packaging, and LLW transportation
C = fraction of the [2010 $ Cost] attributable to waste burial
L_x = labor, materials, and services cost adjustment, January of 2010 to latest month of Year X for which data are available

E_x = energy, LLW packaging, and LLW transportation cost adjustment, January of 2010 to latest month of Year X for which data are available

B_x = LLW burial/disposition cost adjustment, January of 2010 to January of Year X (i.e., burial/ disposition cost in nominally January of Year X, divided by the burial cost in January of 2010)

$$= (R_x + \Sigma S_x) / (R_{2010} + \Sigma S_{2010})$$

where R_x = radioactive waste burial/disposition costs (excluding surcharges) in Year X dollars

ΣS_x = summation of surcharges in Year X dollars

R_{2010} = radioactive waste burial costs (excluding surcharges) in 2010 dollars

ΣS_{2010} = summation of surcharges in 2010 dollars.

However, while the basic equation remains unchanged, the values of the coefficients A, B, and C do change.

Table 6.3 provides the revised license termination cost estimates for four different LLW disposition scenarios considered in this study. However, the scenario in which all Class A LLW is shipped to the Energy*Solutions* Utah facility for disposal or to a waste processor and the Class B/C LLW is shipped to the Generic or South Carolina facility for disposal is representative of the situation for all but one currently operating nuclear power plant. The one exception is the Columbia Generating Station, which must ship its LLW to the Washington facility for disposal. The scenario in which all LLW is shipped to the Generic or South Carolina full-service disposal facility, while feasible, is not a very realistic option currently given the availability of the lower cost facility in Utah for disposal of Class A LLW. Also, the scenario in which all Class A LLW is shipped to the Energy*Solutions* Utah facility for disposal or to a waste processor and the Class B/C LLW is shipped to the Washington facility for disposal is not a viable option for any currently operating nuclear power plant. Thus, the scenario in which all Class A LLW is shipped to the Energy*Solutions* Utah facility for disposal or to a waste processor and the Class B/C LLW is shipped to the Generic or South Carolina facility for disposal is that which will be used as the basis for revising the cost escalation equation coefficients.

The major elements of the three components of the license termination cost estimates for both the reference PWR and BWR are provided in Table 6.4. Considering the uncertainties and approximations included in these numbers, and considering that the values of the coefficients for the PWR and the BWR are so similar, a single best estimate value for both PWR and BWR for each coefficient is calculated as their averages:

$$A_{ave} = 0.77 \qquad B_{ave} = 0.06 \qquad C_{ave} = 0.17$$

The adjustment factor for labor, materials and services is derived from employment cost indexes (ECI) provided by the Bureau of Labor Statistics (BLS). The value of L_x for a particular region is the value of the ECI for that region for the current year divided by the value of the same ECI for the reference year (2010).

Table 6.4. Evaluation of Coefficients A, B, and C

Cost Category	Reference PWR 2010 $ (millions)	Reference PWR Coefficient	Reference BWR 2010 $ (millions)	Reference BWR Coefficient
Project Management	249.79		256.20	
Decontamination and Removal	127.80		124.14	
Regulatory and Insurance	8.97		8.93	
Subtotal	**386.55**	**A = 0.78**	**389.27**	**A = 0.75**
Energy	8.63		8.62	
LLW Packaging	14.40		14.98	
LLW Transportation	8.72		9.83	
Subtotal	**31.75**	**B = 0.06**	**33.44**	**B = 0.06**
Burial	77.03	C = 0.16	97.83	C = 0.19
Total	**495.34**		**520.54**	

E_x is made up of three components: industrial electric power (P_x), metal and metal products (M_x), and light fuel oil (F_x). The value for E_x is a weighted average of three producer price indexes (PPIs): industrial electrical power (WPU0543), metals and metal products (WPU10), and light fuel oils (WPU0573). Considering that the values of the weighting factors for the PWR and the BWR are so similar, a single best estimate value for both PWR and BWR for each weighting factor is calculated as their averages:

$$E_x = [0.27P_x + 0.45M_x + 0.28F_x]$$

The value of E_x is the weighted summation of the value of WP0543 for the current year divided by the value for WPU0543 for the reference year (2010), the value of WPU10 for the current year divided by the value for WPU10 for the reference year (2010), and the value of WPU0573 for the current year divided by the value for WPU0573 for the reference year (2010).

The adjustment factor for waste burial/disposition, B_x, is taken directly from biannual updates to NUREG-1307.

6.3 Scaling License Termination Cost for Plant Size

The current 10 CFR 50.75(c) decommissioning fund formula includes factors for scaling the total decommissioning cost for different PWR and BWR plant sizes. This was based on a determination in the original decommissioning studies, and associated addendums, that LLW burial volume and hence disposal cost was a function of the thermal capacity of the plant. The results in Section 5.2 of this report showed that, for the license-developed cost estimates for BWR plants, total LLW volume did indeed increase with increasing plant thermal capacity. However, the result was not conclusive for PWRs.

In this section the cost of LLW burial/disposition is graphed as a function of the plant thermal capacity for those plants implementing the DECON strategy and for which the majority of LLW is shipped to the Energy*Solutions* facility for disposal or to offsite processor facilities. Data for both licensee-developed estimates and completed decommissioning projects are included in this assessment. Figure 6.18 provides this graph for both PWRs and BWRs. No clear correlation exists between plant thermal capacity and LLW burial/disposition cost.

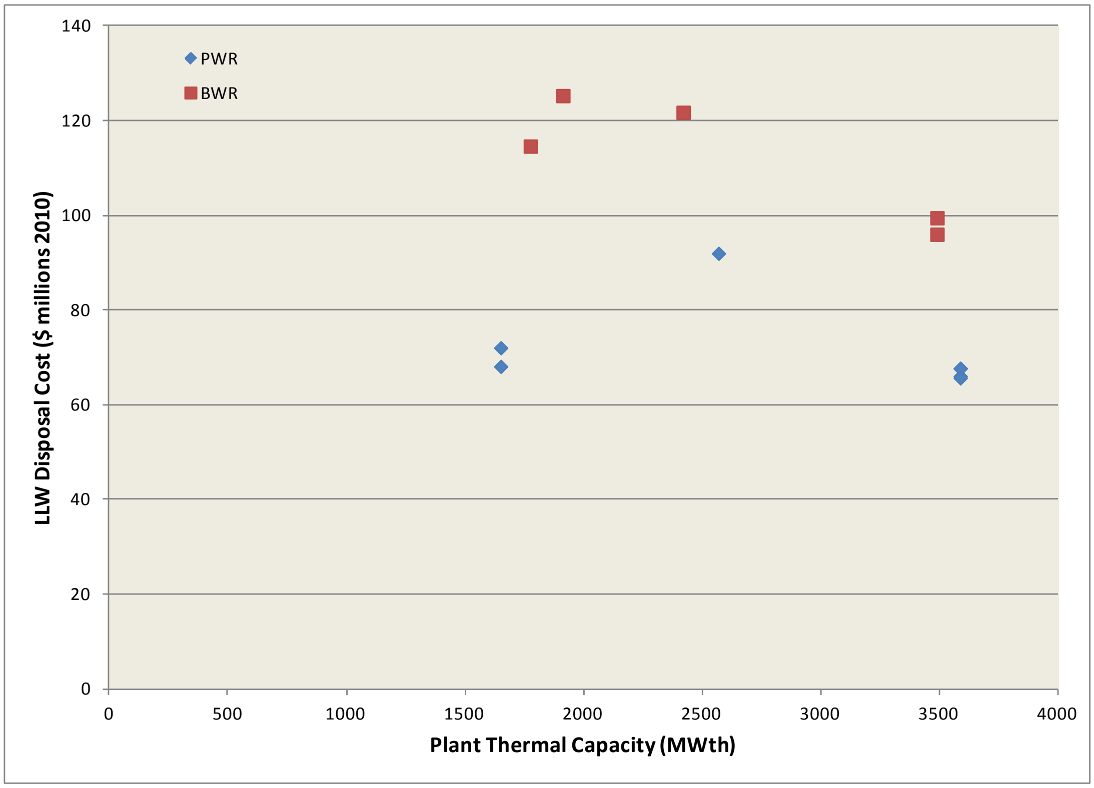

Figure 6.18. LLW Disposal Cost vs. Plant Thermal Capacity

The revised cost estimates developed in Section 6.1 assumed that the cost of LLW packaging, LLW transportation, and LLW disposal were all a function of the total LLW volume. Figure 6.19 graphs the total of these three cost categories as a function of plant thermal capacity. Again, no clear correlation exists.

The implication from these two graphs is that site-specific factors mask any potential correlation between plant thermal capacity and LLW disposition cost. One potential source of masking is negotiated LLW processing/disposal volume discounts that can vary significantly from plant-to-plant and, even more importantly, from fleet-to-fleet. These negotiated discounts are not publicly available information and were not available to the authors of this study.

While the available data are insufficient to determine how LLW disposition costs change with plant thermal capacity, these costs are expected to increase with increasing thermal capacity when all other factors are unchanged. Therefore, for this study, it is assumed that the plant size scaling factors developed in the original studies are still applicable. The derived scaling factors are 0.518 for the reference PWR (Reference 1) and 0.648 (Reference 3) for the reference BWR based on plants that had capacities of 1300 MWth and 1593 MWth, respectively.

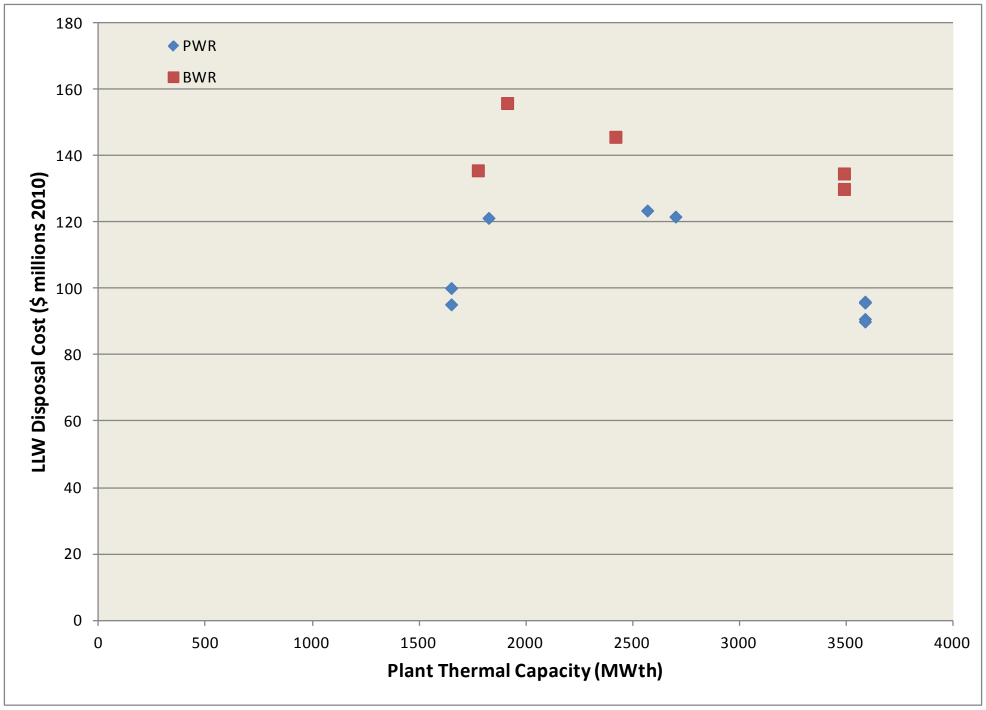

Figure 6.19. LLW Packaging/Transportation/Disposal Cost vs. Plant Thermal Capacity

The scaling factors were multiplied by the respective total LLW volume estimates for the reference plants to derive an estimated LLW volume of 332,844 ft^3 for the 1300-MWth PWR plant and 433,146 ft^3 for the 1593-MWth BWR plant. These LLW volumes were then used to develop costs for LLW packaging, LLW transportation, and LLW disposal per the methodology described in Section 6.1. The total of these three cost categories is $51.23 million for the 1300-MWth PWR plant and $79.62 million for the 1593 MWth-BWR plant. This compares to $100.15 million and $122.64 million for the reference PWR (3411 MWth) and BWR (3320 MWth) plants, respectively.

To develop the revised scaling equation, these cost estimates for each reactor type were formulated into two linear equations having two unknown coefficients and the equations were solved for the unknown coefficients. For PWRs, the linear equations and results are as follows:

$$A + B(3411\ \text{MWth}) = \$100.15\ \text{million},\ A + B(1300\ \text{MWth}) = \$51.23\ \text{million}$$

where B is 0.023 million $/MWth and A is 21.10 million.

Adding the other fixed license termination costs (i.e., project management, decontamination and removal, regulatory and insurance, and energy) of $395.18 million to the result for "A" of $21.10 million results in fixed costs of $416.28 million. Thus, the PWR scaling equation for license termination costs is:

$$\text{Total Cost (millions 2010\$)} = (416\ \text{million} + 0.023 \times P)$$

where P is the plant thermal capacity.

The cost for plants smaller than 1200 MWth is set equal to the cost for a 1200-MWth plant, and the cost for plants larger than 3400 MWth is set equal to the cost for a 3400-MWth plant.

Similarly, for BWRs, the linear equations and results are as follows:

$$A + B(3320 \text{ MWth}) = \$122.64 \text{ million}, \quad A + B(1593 \text{ MWth}) = \$79.62 \text{ million}$$

where B is 0.025 million $/MWth and A is 39.94 million.

Adding the other fixed license termination costs (i.e., project management, decontamination and removal, regulatory and insurance, and energy) of $397.89 million to the result for "A" of $39.94 million results in fixed costs of $437.83 million. Thus, the BWR scaling equation for license termination costs is:

$$\text{Total Cost (millions 2010\$)} = (438 \text{ million} + 0.025 \times P)$$

where P is the plant thermal capacity.

The cost for plants smaller than 1200 MWth is set equal to the cost for a 1200-MWth plant, and the cost for plants larger than 3400 MWth is set equal to the cost for a 3400-MWth plant.

These equations are believed to represent an adequate approach to estimating the amount of funds needed to provide reasonable assurance that decommissioning of PWR and BWR stations can be completed after permanent plant shutdown. These equations are based on immediate dismantlement (DECON) following permanent plant shutdown. Since DECON is generally the higher cost decommissioning strategy on a discounted cost basis, the minimum decommissioning funding requirement specified by these equations provides reasonable assurance that adequate funds will be available to implement other decommissioning strategies.

6.4 References

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