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

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

Appendices

Draft Report for Comment

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

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

With the issuance of the final Decommissioning Rule (July 27, 1988), owners and operators of licensed nuclear power plants are required to prepare, and submit to the U.S. Nuclear Regulatory Commission (NRC) for review, decommissioning plans and cost estimates. The NRC staff is in need of bases documentation that will assist them in assessing the adequacy of the licensee submittals, from the viewpoint of both the planned actions, including occupational radiation exposure, and the probable costs. The purpose of this reevaluation study is to provide some of the needed bases documentation.

This report presents the results of a review and reevaluation of the PNL 1978 decommissioning study of the Trojan nuclear power plant, including all identifiable factors and cost assumptions which contribute significantly to the total cost of decommissioning the nuclear power plant for the DECON, SAFSTOR, and ENTOMB decommissioning alternatives. These alternatives now include an initial 5-7 year period during which the spent fuel is stored in the spent fuel pool, prior to beginning major disassembly or extended safe storage of the plant.

This report also includes consideration of the NRC requirement that decontamination and decommissioning activities leading to termination of the nuclear license be completed within 60 years of final reactor shutdown, consideration of packaging and disposal requirements for materials whose radionuclide concentrations exceeded the limits for Class C low-level waste (i.e., Greater-Than-Class C), and reflects 1993 costs for labor, materials, transport, and disposal activities. Sensitivity of the total license termination cost to the disposal costs at different low-level radioactive waste disposal sites, and to different depths of contaminated concrete surface removal within the facilities are also examined.

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APPENDIX A

STUDY CONTACTS

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

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

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APPENDIX B

COST ESTIMATING BASIS

APPENDIX B

COST ESTIMATING BASES

The cost information developed in this reevaluation study is based on unit cost data presented in this appendix. Categories for which basic unit cost data are given include: salaries, waste packaging, cask rental, transport, waste disposal, special equipment, and services and supplies. Reactor-specific cost data also are provided concerning taxes, insurance, and license termination survey costs. In addition, the impact on decommissioning costs resulting from cascading costs and contingency allowance is discussed. The bases for the estimated decommissioning costs for specialized decommissioning tasks such as removal of the pressurizer, the reactor pressure vessel, the steam generators, and systems chemical decontamination are contained in Chapter 3, Appendices E, F, and G, respectively, and are not repeated here. The cost data presented in this appendix are all early-1993 costs.

A decommissioning cost estimating computer program (CECP) developed at Pacific Northwest Laboratory (PNL) for the U.S. Nuclear Regulatory Commission (NRC) was utilized in this pressurized water reactor (PWR) reevaluation study. The CECP, designed for use on an IBM personal computer or equivalent, was developed for estimating the cost of decommissioning light-water reactor power stations to the point of license termination. Such costs include component, piping and equipment removal costs; packaging costs; decontamination costs; transportation costs; burial volumes and costs; and manpower staffing costs. Using equipment and consumables costs, inventory data, and labor rates supplied by the user, the CECP calculates unit cost factors and then combines these factors with transportation and burial cost algorithms to produce a complete report of decommissioning costs. In addition to costs, the CECP also calculates person-hours, crew-hours, radiation exposure person-hours, and cumulative radiation dose associated with decommissioning. Inventories of process system components, piping, and valves for the Trojan plant (the reference PWR plant) were used to develop and test the CECP. The CECP, the inventories, and the base unit cost factors developed for use in this study are described in greater detail in Appendix C.

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

B.1 BASES AND ASSUMPTIONS

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

- The cost estimates in this reevaluation study, just as in NUREG/CR-0130,[1] take into consideration only those costs for decommissioning that affect the public health and safety - i.e., costs to reduce the residual radioactivity in a facility to a level that permits the facility to be released for unrestricted use and the NRC license to be terminated. Hence, the cost estimates in this study do not include such items as the cost to remove clean materials and equipment nor to restore the land to a "green field," which would require additional demolition and site restoration activities. Although these additional costs for site restoration may be needed from the viewpoint of public relations or site resale value, they are not related to health and safety and therefore were considered to be outside of NRC's area of responsibility.

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

- Labor rates for each craft and salaried worker representative of the Trojan location are used in this development of a site-specific decommissioning cost estimate. Portland General Electric Company, the majority owner and the operator of the Trojan plant, provided typical craft labor rates and salary data for utility personnel from utility records.

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

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

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

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

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

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

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

- This study does not address the removal or disposal of mixed waste from the site. The costs for such activities are assumed to be

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

operational costs covered by an active (and continued in force) Resource Conservation and Recovery Act (RCRA) permit for the facility. However, the study does include consideration of the constraints that the presence of mixed waste onsite may impose on decommissioning alternatives and on schedules.

- The study presumes the installation of spent fuel dry storage modules such that decommissioning operations can proceed with minimum impact (i.e., all fuel is transferred to the dry storage compound by approximately 7 years after shutdown). Separate, distinct funding for post-shutdown activities associated with the spent nuclear fuel (SNF) are delineated in 10 CFR Part 50.54(bb), "Conditions of Licenses." All such costs associated with the SNF are considered to be operational costs in this reevaluation study, not decommissioning costs. Therefore, neither the disposition of the SNF nor the cost of the dry storage modules has been included within this decommissioning cost estimate. (See Appendix D for additional details.)

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

B.2 MANPOWER COSTS

Salary data for the decommissioning staff positions used in this study are given in Table B.1. The labor costs shown in Table B.1 are representative of labor costs for this particular decommissioning project at the reference PWR, which is the Trojan plant, located at Rainier, Oregon. The utility overhead positions data shown in the table were supplied by the Portland General Electric Company, the majority owner and the operator of the Trojan plant, and include an overhead rate of 42%.

TABLE B.1. Labor Costs for Decommissioning[a]

($/yr) Utility Overhead Position	Base Pay ($/yr)	Assumed Over-Head Rate (%)	Cost
Plant Manager	91,210	42	129,518
Assistant Plant Manager	73,820	42	104,824
Secretary	20,500	42	29,110
Clerk	19,120	42	27,150
Accountant	48,610	42	69,026
Contracts/Procurement Specialist	48,610	42	69,026
Industrial Safety Specialist	47,600	42	67,592
Planning/Scheduling Engineer	52,630	42	74,735
Radioactive Ship. Specialist	55,950	42	79,449
Chemistry Supervisor	52,630	42	74,735
Chemistry Technician	30,290	42	43,012
Quality Assurance Manager	61,140	42	86,819
Quality Assurance Engineer	34,710	42	49,288
Quality Assurance Technician	30,290	42	43,012
Health Physics Manager	55,950	42	79,449
Sr. Health Physics Technician	51,440	42	73,045
Health Physics/ALARA Planner	51,440	42	73,045
Health Physics Technician	31,710	42	45,028
Nuclear Records Specialist[b]	43,260	42	61,429
Building Services Supervisor	61,430	42	87,231
Training Engineer	52,630	42	74,735
Operations Manager	68,620	42	97,440
Administration Manager	61,140	42	86,819
Operations Supervisor	61,140	42	86,819
Control Operator	51,400	42	72,988
Plant Equipment Operator	36,470	42	51,787
Plant Engineer	51,140	42	72,619
Maintenance Manager	67,190	42	95,410
Maintenance Supervisor	61,430	42	87,231
Licensing Engineer	50,890	42	72,264
Craftsman	42,810	42	60,790
Custodian	22,710	42	32,248
Security Manager	61,140	42	86,819
Security Shift Supervisor	27,070	42	38,439
Security Patrolman	24,560	42	34,875
DOC Overhead Position[c]			
Project Manager	91,210	141.5	220,272
Assistant Project Manager	73,820	141.5	178,275
Secretary/Clerk	19,805	141.5	47,829
Industrial Safety Specialist	47,600	141.5	114,954
Planning/Scheduling Engineer	52,630	141.5	127,101
Radioactive Shipment Specialist	55,950	141.5	135,119

TABLE B.1. (contd)

($/yr) Utility Overhead Position	Base Pay ($/yr)	Assumed Over-Head Rate (%)	Cost
Lawyer/Financial Administrator[b]	62,420	141.5	150,744
Contracts/Accounting Supervisor	62,420	141.5	150,744
Contracts Specialist/Buyer[b]	48,600	141.5	117,369
Procurement Specialists	44,200	141.5	106,743
Accountant	48,600	141.5	117,369
Operations Supervisor	61,140	141.5	147,653
Health Physics Supervisor	61,550	141.5	148,643
Health Physics/ALARA Planner[b]	51,440	141.5	124,228
Engineering Supervisor	61,140	141.5	147,653
D&D Operations Supervisor	61,140	141.5	147,653
Engineers	50,890	141.5	122,899
Drafting Specialist[b]	28,080	141.5	67,813
Quality Assurance Supervisor	61,140	141.5	147,653
Quality Assurance Engineer	34,710	141.5	83,825
Quality Assurance Technician	31,710	141.5	76,580
Sr. Health Physics Technician	51,440	141.5	124,228
Health Physics Technician	31,710	141.5	76,580
Protective Equipment Technician	31,770	141.5	76,725
Tool Crib Attendant	31,770	141.5	76,725
Protective Clothing Attendant	31,770	141.5	76,725
Licensing Engineer	50,890	141.5	122,899
Safety Consultant[b]	242,200	---	242,200
Dedicated Decontamination Workers			
Crew Leader	47,230	141.5	114,060
Craftsman	42,810	141.5	103,386
Laborer	22,710	141.5	54,845
Utility Operator	36,470	141.5	88,075

(a) Salary rates are in 1993 [illegible]rs, assuming 2080 hours per man-year.
(b) Study estimate.
(c) Salary rates include 1[illegible]% overhead, plus 15% Decommissioning Operations Contractor (DOC) profi[illegible] [illegible]abor.

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

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

B.3 MOBILIZATION AND DEMOBILIZATION COSTS

There are significant costs associated with a contractor establishing its presence at the work site. These costs, called mobilization and demobilization costs, will vary with the size and complexity of the job. These costs include temporary office facilities, obtaining the required special equipment, and assembling the work force. Similarly, there are costs associated with closing down a work site. For the dismantlement of a large PWR, these costs were previously estimated by an engineer experienced in estimating costs for utility construction projects to be about $1.25 million (without contingency) in 1978 dollars.[4,5] Applying an escalation factor of 2.11, based on the Implicit Price Deflator,[6] brings the mobilization and demobilization costs to $2.64 million, without contingency, in 1993 dollars.

B.4 RADIOACTIVE WASTE PACKAGING COSTS

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

TABLE B.2. Packaging for Radioactive Materials

Description	Burial Volume (m^3)	Application	Estimated Unit Cost ($)
Steel cask liner for 8-120B cask; 62 in. OD x 72 in. high; 2,000 lb empty	3.57	Shallow-land burial of activated RPV internals & insulation	4,695
Steel cask liner for 8-120B cask; 16.5 in. x 60 in. x 52 in.; 1,200 lb empty	0.84	Shallow-land burial of activated RPV	4,695
Canister; 9-in. square by 180-in. high; 300 lb empty	0.24	Deep geologic disposal of GTCC low-level waste (reactor core components)	520
B-25 metal container; 4 ft x 4 ft x 6 ft; 600 lb empty	2.72	Shallow-land burial of low-level waste	645
Special metal container, U-shaped; 174 in. dia. x 210 in. long x 45 in. high; 1,500 lb empty	13.31	Shallow-land burial of upper core assembly components	1,565
Special metal container, fitted to inner wall shape, welded to wall; 300 lb empty	1.77	Shallow-land burial of RPV nozzle sections	470
Special metal container, 10 ft x 10 ft x 15 ft; 4,600 lb empty	42.48	Shallow-land burial of spent fuel storage racks	4,170
High-Integrity Container (HIC); 75.5 in. dia. x 78 in. high; 900 lb empty	5.72	Dewatered, solids, or solidified water meeting the requirements of LSA material	5,750 - 9,900[a]
Maritime container (Sea-Van); 8 ft x 8.5 ft x 20 ft; 4,180 lb empty	38.51	Shallow-land burial of low-level waste	3,650
Modified Maritime container (Sea-Van); 8 ft x 4 ft x 20 ft; 4,000 lb empty	18.13	Shallow-land burial of low-level waste	4,965
DOT 17-H steel drum; 55-gal	0.21	Shallow-land burial of low-level waste	26.95

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

B.5 CASK CHARGES

Some of the waste material shipped to a burial site is sufficiently radioactive to require transport in reusable shielded casks. In general, it is more economical to rent such casks than to purchase them, especially the larger ones. The casks assumed in this study for use in shipping highly radioactive materials are listed in Table B.3, together with the application and the estimated rental charges.

TABLE B.3. Shielded Casks for Shipment of Radioactive Materials

Cask Description(a)	Application	Daily Rental ($)
NAC-LWT COC No. 9225/B(U)F(b)	Transport of greater-than-class-C (GTCC) LLW waste	3,130(c)
TN-8 OWT COC No. 9015B	Transport of greater-than-class-C LLW waste	3,340(c)
NuPac No. 10/142 COC No. 9208	Transport of high integrity container or 55-gal drums	1,250
NuPac No. 14/210H COC No. 9176	Transport of high integrity container or 55-gal drums	1,250
CNS No. 8-120B COC No. 9168	Transport of radioactive material in the form of activated reactor components	1,250

(a) NAC-LWT = Nuclear Assurance Corporation-Legal Weight Truck Cask; TN-8 OWT = Transnuclear, Inc. Over Weight Truck Cask; CNS = Chem-Nuclear Systems, Inc.; NuPac = Pacific Nuclear.
(b) COC No. means Certificate of Compliance Number as listed in Reference 7.
(c) The daily rental rate is predicated on a sliding scale, according to risk, with spent nuclear fuel being the highest risk cargo and the GTCC material assumed at the same rate in this study.

B.6 TRANSPORTATION COSTS

Most radioactive materials resulting from decommissioning are assumed to be shipped in exclusive-use[b] trucks to a burial site (U.S. Ecology, Inc., at Hanford), or, in the case of highly activated reactor components, to a geologic repository or other such disposal facility as the NRC may approve.

(b) Exclusive use, as defined in 49 CFR 173.401(i),[8] is also referred to as "sole use" or "full load." In any case, it means the sole use of a conveyance by a single consignor and for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee. Specific instructions for the maintenance of exclusive-use shipment controls must be issued in writing and included with the shipping paper information provided to the carrier by the consignor.

The exceptions, all assuming barge transport and overland transport, are the primary pumps and the pressurizer (see Chapter 3 for details), and the steam generators (see Appendix F for details).

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

Costs of transporting low-level waste to the disposal site are calculated using the CECP. The CECP data base (see Appendix C) contains great-circle distances from all commercial reactor sites to the postulated geologic repository at Yucca Mountain and to the low-level disposal sites at Barnwell and Hanford.

To calculate transportation costs, the CECP employs a different cost formula for each cask (CNS 8-120B, NuPac 14-210H, NAC-LWT, and TN-8) that will be used in decommissioning. These formulas, based on data supplied in Reference 9, are given below.

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

where

- R1 = cost of transporting empty cask from cask supplier (Barnwell) to reactor site = $11855.99,
- d1 = distance in miles between reactor site and the cask supplier,
- d10 = reference distance between reactor site and the cask supplier = 2799 miles,
- R2 = cost of transporting empty cask from the burial site (Hanford) back to supplier = $10122.75,
- d2 = distance in miles between burial site and supplier,
- d20 = reference distance between burial site and supplier = 2674 miles,
- n = number of casks to be shipped to the burial site,
- R3 = cost of transporting fully loaded cask from site to burial site = $2456.80,
- w = weight of loaded cask, in pounds,

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

w0 = weight of fully loaded cask = 74000 pounds,

d = distance between reactor site and burial site, in miles,

d0 = reference distance between reactor site and burial site = 297 miles,

R4 = cost of transporting empty cask from burial site back to reactor site = $1216.06,

OW1 = overweight charges = $219.05,

OW2 = overweight charges = $69.37, and

P = permit cost = $120.00.

Round-Trip CNS 8-120B Cost for the Barnwell Burial Site = n x (R1 x d/d0)
+ n x (R2 x d/d0 x w/w0 + OW + P)

where

R1 = cost of transporting empty cask from Barnwell to reactor site = $11855.99,

d = distance in miles between Barnwell and reactor site,

d0 = reference distance between Barnwell and reactor site = 2799 miles,

R2 = cost of transporting fully loaded cask from reactor site to Barnwell = $14185.80,

n = number of casks to be shipped to the burial site,

w = weight of loaded cask, in pounds,

w0 = weight of fully loaded cask = 74000 pounds,

OW = overweight and other charges = $1531.67 and

P = permit cost = $125.00.

Round-Trip 14-210H Cost for the Hanford Burial Site = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x d/d0 + OW + P)
+ (n - 1) x (R4 x d/d0)
+ n x R5 x d1/d10

where

R1 = cost of transporting empty cask from cask supplier (Barnwell) to reactor site = $5150.16,

d1 = distance in miles between reactor site and the cask supplier,

d10 = reference distance between reactor site and the cask supplier = 2799 miles,

R2 = cost of transporting empty cask from the burial site (Hanford) back to supplier = $4412.10,

d2 = distance in miles between burial site and supplier,

d20 = reference distance between burial site and supplier = 2674 miles,

n = number of casks to be shipped to the burial site,

R3 = cost of transporting fully loaded cask from site to burial site = $964.65,

d = distance between reactor site and burial site, in miles,

d0 = reference distance between reactor site and burial site = 297 miles,

R4 = cost of transporting empty cask from burial site back to reactor site = $914.76,

OW = overweight charges = $242.70,

P = permit cost = $120.00, and

R5 = cost of transporting HIC from supplier to the reactor site = $4210.50.

Round-Trip 14-210H Cost for the Barnwell Burial Site = n x (R1 x d/d0)
+ n x (R2 x d/d0 + OW + P)
+ n x (R3 x d/d0)

where

R1 = cost of transporting empty cask from Barnwell to reactor site = $5150.16,

d = distance in miles between Barnwell and reactor site,

d0 = reference distance between Barnwell and reactor site = 2799 miles,

R2 = cost of transporting fully loaded cask from reactor site to Barnwell = $5235.45,

n = number of casks to be shipped to the burial site,

OW = overweight and other charges = $1849.91,

P = permit cost = $125.00, and

R3 = cost of transporting HIC from supplier to the reactor site = $4210.50.

Round-Trip NAC-LWT Cost to the Geologic Repository = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x w/w0 x d/d0 + OW + P)
+ (n - 1) x (R4 x d/d0 + OW)

where

R1 = cost of transporting empty cask from cask supplier to reactor site = $9264.56,

d1 = distance in miles between reactor site and the cask supplier,

d10 = reference distance between reactor site and the cask supplier = 2799 miles,

R2 = cost of transporting empty cask from the repository back to supplier = $6279.36,

d2 = distance in miles between repository and supplier,

d20 = reference distance between repository and supplier = 2674 miles,

n = number of casks to be shipped to the repository,

R3 = cost of transporting fully loaded cask from site to repository = $3102.24,

w = weight of loaded cask, in pounds,

w0 = weight of fully loaded cask = 55200 pounds,

d = distance between reactor site and repository, in miles,

d0 = reference distance between reactor site and repository = 907 miles,

R4 = cost of transporting empty cask from repository back to reactor site = $2406.40,

OW = overweight charges = $268.00, and

P = permit cost = $120.00.

Round-Trip TN-8 Cost to the Geologic Repository = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x w/w0 x d/d0 + OW + P)
+ (n - 1) x (R4 x d/d0 + OW + P)

where

R1 = cost of transporting empty cask from cask supplier to reactor site = $18790.61,
d1 = distance in miles between reactor site and the cask supplier,
d10 = reference distance between reactor site and the cask supplier = 2799 miles,
R2 = cost of transporting empty cask from the repository back to supplier = $13551.44,
d2 = distance in miles between repository and supplier,
d20 = reference distance between repository and supplier = 2674 miles,
n = number of casks to be shipped to the repository,
R3 = cost of transporting fully loaded cask from site to repository = $5286.12,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask = 84040 pounds,
d = distance between reactor site and repository, in miles,
d0 = reference distance between reactor site and repository = 907 miles,
R4 = cost of transporting empty cask from repository back to reactor site = $4165.95,
OW = overweight charges = $365.00, and
P = permit cost = $120.00.

For non-cask truck shipments, the calculations are much simpler. For cargo consisting of 55-gallon drums, 96-ft^3 metal boxes, or maritime containers, the round-trip truck transportation charges are

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

where

R = the round-trip distance rate = $1211.82,
D = distance in miles between site and Hanford,
D0 = the reference distance, from Rainier, Oregon, to Hanford, Washington = 297 miles,
PC = permit cost = $120,

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

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

where

R = the round-trip distance rate = $4,226.49,
D = distance in miles between site and Barnwell,
D0 = the reference distance, from Rainier, Oregon, to Barnwell, SC = 2799 miles,
PC = permit cost = $95,

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

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

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

where

R = cost of transporting rack to Hanford = $966.54,

d = distance from reactor site to Hanford, in miles,

d0 = reference distance between reactor site and Hanford = 297,

P = permit cost = $95.00,

DF = drop frame charge = $100.00,

OW = over-width charge = $100.00,

OD = over-dimension charge = $65.00, and

T = tarpaulin charge = $35.00.

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

where

R = cost of transporting rack to Barnwell = $5712.36,

d = distance from reactor site to Barnwell, in miles,

d0 = reference distance between reactor site and Barnwell = 2799,

P = permit cost = $125.00,

DF = drop frame charge = $100.00,

OW = over-width charge = $582.00,

OD = over-dimension charge = $543.00, and

T = tarpaulin charge = $35.00.

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

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

where

R = cost of transporting crane to Hanford = $1100,

d = distance from reactor site to Hanford, in miles,

d0 = reference distance between reactor site and Hanford = 297 miles,

w = weight of loaded truck, in pounds,

w0 = weight of fully loaded truck = 40,000 pounds

P = permit cost = $95.00,

T = twist lock trailer cost = $120.00, and

OW = overweight charge = $69, if load exceeds 40,000 pounds; no charge, otherwise.

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

where

R = cost of transporting crane to Barnwell = $5984,

d = distance from reactor site to Barnwell, in miles,

d0 = reference distance between reactor site and Barnwell = 2799 miles,

w = weight of loaded truck, in pounds,

w0 = weight of fully loaded truck = 40,000 pounds

P = permit cost = $95.00, and

OW = overweight charge = $543, if load exceeds 40,000 pounds; no charge, otherwise.

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

B.7 WASTE DISPOSAL COSTS

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

B.7.1 Costs for Shallow-Land Burial

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

TABLE B.4. US Ecology Shallow-Land Burial Costs at Hanford

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

A. .ISPOSAL CHARGES

1. Packages (except as noted in Section 2)

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

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

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

B. Surcharge for Curies (per load)

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

C. Minimum Charge Per Shipments

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

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

SURCHARGES AND OTHER SPECIAL CHARGES

A. CASK HANDLING FEES

1. Truck Casks

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

2. Rail Cask

$50,000 each plus outside riggers' charges

B. POLY HICS IN ENGINEERED CONCRETE BARRIERS

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

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

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

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

D. SURCHARGE FOR SPECIAL NUCLEAR MATERIAL

Greater than 5 grams per shipment	$10.00 per gram

E. DECONTAMINATION SERVICES (IF REQUIRED)

Per Hour	$150.00
Supplies	Cost Plus 25%

F. OTHER SERVICES (IF REQUIRED)

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

TABLE B.4. (contd)

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

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

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

1560R

TABLE B.5. Chem-Nuclear Shallow-Land Burial Costs at Barnwell

CHEM-NUCLEAR SYSTEMS, INC.

140 Stoneridge Drive • Columbia, South Carolina 29210

BARNWELL LOW-LEVEL RADIOACTIVE
WASTE MANAGEMENT FACILITY
RATE SCHEDULE

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

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

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

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

Note 2: Base Disposal Charge includes:

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

2. SURCHARGES:

A. Weight Surcharges (Crane Loads Only)

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

Effective January 1, 1993

TABLE B.5. (contd)

Barnwell Rate Schedule — Effective January 1, 1993

B. Curie Surcharges For Shielded Shipment:

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

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

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

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

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

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

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

TABLE B.5. (contd)

Barnwell Rate Schedule — Effective January 1, 1993

E. Cask Handling Fee — $1,795.00 per cask, minimum

F. Special Nuclear Material Surcharge — $8.15 per gram

G. Barnwell Surcharge — 2.4%

3. MISCELLANEOUS:

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

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

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

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

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

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

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

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

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

Chem-Nuclear Systems, Inc.

Attachment 1

Barnwell Low-Level Radioactive Waste Management Facility
1993 Disposal Pricing

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

2. Surcharges

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

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

   B. Curie Surcharges for Shielded Shipment

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

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

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

Chem-Nuclear Systems, Inc.

4. Cask Handling Fee

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

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

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

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

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

NOTE 1: The above pricing schedule does not include the Southeast Compact Commission Access Fee of $220.00/ft^3.

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

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B.7.2 Costs for Geologic Disposal

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

B.7.3 Costs for Mixed Waste Disposal

Firm cost estimates for offsite services concerning disposal of solid mixed LLW were not obtained, since such services are not currently available in the U.S. No offsite disposal or treatment facility for mixed waste has been available since 1985. However, joint regulation by both the NRC and the EPA is expected to make the unit cost of disposing of mixed waste much higher than the cost of disposing of other low-level wastes. Utilities are finding ways to treat some of their mixed waste so that it is no longer a chemical hazard, thus making it possible to dispose of the radioactive component along with other LLW. The remainder of mixed waste, however, is currently stored onsite.[10,11]

An August 1991 Nuclear Waste News article reported: "Complications attending mixed waste disposal are expected to yield massive disposal costs, which are likely to rise still further as generators, seeking to avoid costs as high as $20,000 per cubic foot, cut their mixed waste output drastically, thereby pushing up costs for the remaining waste."[12]

For purposes of this study, the ultimate cost of disposal of mixed wastes (either liquid or solid) expected to be present on the reference PWR site at final shutdown are considered to be operational costs, since the majority of such wastes are postulated to be generated during operation of the plant. It should be recognized, however, that regardless of when solid mixed LLW is generated, commercial treatment, storage, and disposal services for the waste do not currently exist. Based on the aforementioned projected astronomical disposal costs and on the uncertainties surrounding the ultimate disposition of solid mixed wastes, it is assumed further that implementation of waste minimization techniques used during the operating years of the plant will also be used during decommissioning. Therefore, only a relatively small amount, if any, of additional solid mixed LLW is assumed to be generated during decommissioning of the reference PWR. Additional information concerning mixed wastes can be found in Appendix H.

B.8 COSTS OF SERVICES, SUPPLIES, AND SPECIAL EQUIPMENT

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

Energy:

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

During a recent long-term shutdown (i.e., > 9 months) with about 1,000 people onsite, the reference PWR's average site electricity consumption was reported to be about 5 MW. A significant portion of the electricity was used for heating, air conditioning, lights, etc. A similar inquiry to Rancho Seco concerning their average site consumption for their current possession-only status (i.e., a long-term shutdown mode with less than 200 people onsite and

TABLE B.6. Special Tools and Equipment Costs

Item	Estimated Number Required	Estimated Unit Cost ($000)
Remote manipulator for under-water, in-vessel cutting	1	1,102.5
Underwater plasma-arc cutting system	2	77.2
Cutting table, plus jigs	1	33.0
Oxyacetylene cutting system	1	3.3
Plasma-arc equipment	2	33.0
Track-mounted drive unit	4	4.4
Steam generator transport system:		
Upender	1	27.6[a]
Low-profile saddle	1	55.1[a]
Transfer skid	1	198.5[a]
Frame trailer w/shipping cradle	2	248.1[a]
Drum compactor	2	47.4[a]
Closed circuit, high-resolution television	(plant equip.)	55.1[b]
High-pressure water jet	1	176.4[c]
Kelly Decontamination System™	3	186.0[d]
Underwater lights, viewing windows/periscope	As required	11.0
Submersible pumps with disposable filter	3	6.6
Power-operated, mobile, scissors-type manlift (Sky Climber, Series 47)™	4	38.6
Genie Zoom-Boom™ manlift, 45-ft	1	52.9
Bobcat front-end loader (highly maneuverable, light-duty)	2	19.8
6818-kg forklift	3	99.2[e]
9100-kg mobile hydraulic crane	2	40.8
Safety nets	As required	50.7
Polyurethane foam generator	2	9.9
Wall-saw (35 h.p.) w/power unit	2	22.1
Slab-saw (35 h.p.)	2	4.4
Concrete drill with HEPA-filtered dust collection system	4	4.4
Concrete surface spaller	4	9.9
Portable ventilation enclosure	10	3.3
Vacuum cleaner (HEPA-filtered)	3	9.9
Filtered-exhaust fan unit	4	7.7

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

all fuel stored in their fuel pool) revealed an average site consumption of about 3.25 MW. Based upon the similarities of Rancho Seco's current shutdown situation to the postulated conditions at the slightly larger reference PWR after final shutdown, an approximate site electricity consumption value (i.e., base load) of about 4 MW is assumed in this study for the reference PWR during active periods of decommissioning. The daily unit cost for electricity is calculated as follows:

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

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

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

Protective Clothing and Equipment Services

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

Hanford Site Support Services

On the Hanford site, which is controlled by the U.S. Department of Energy, contractors and subcontractors obtain services from the Operations and Maintenance contractors for the movement of large objects, such as the steam generators, to the low-level waste burial ground. Included in the cost of these services are road preparation and maintenance, utilities, fire protection, security, patrol, transportation, medical aid, etc. Based upon discussions with industry contacts, these services, including labor, equipment, and materials, are estimated to cost about $132,300 per trip, resulting in a total cost of $529,200 for these services for the four steam generators, and $132,300 each for the four primary pumps and for the pressurizer.

Material Costs

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

		Piping			Tanks
Material		0 - 2 in. dia.	2 - 14 in. dia.	32 - 37 in. dia.	1/2 in. tank wall
Abs. Matl.	@ $0.32/ft^2$	10 ft^2 $3.20	15 ft^2 $4.80	20 ft^2 $6.40	length x dia.x $0.32
Plastic	@ $0.04/ft^2$	25 ft^2 $1.00	37.5 ft^2 $1.50	50 ft^2 $2.00	length x dia.x $0.04
Gases	@ $6.75/hr	0.017 hr $0.11	0.033 hr $0.22	0.33 hr $2.23	Hours of cut x $6.75
		$4.32/cut	$6.52/cut	$10.63/cut	As calculated per tank
Including 15% DOC profit:		$4.97/cut	$7.50/cut	$12.22/cut	1.15 x As calculated per tank

Small Tools and Minor Equipment

In decommissioning, the cost for small tools and minor equipment is often difficult to estimate. Many of these tools will become contaminated and ultimately will be disposed of by burial. The 1993 edition of R. S. Means[2] recommends a maximum allowance of 2% of the contractor's direct labor cost. For, say, $10 million of direct labor costs, 2% would be roughly $200,000. Further assuming an average small tool were to cost $1,100 (e.g., small chain hoists, saws, drills, oxyacetylene torches, sets of hand tools, etc.), the decommissioning operations contractor (DOC) would purchase approximately 180 tools for the crews.[13] This appears to be in the appropriate range for decommissioning work. Therefore, a 2% allowance for these items is incorporated into the cost calculations for the small tools and minor equipment.

Blades Used for Cutting Concrete

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

Scaffolding

Based upon discussions with Trojan plant personnel, sufficient scaffolding and associated equipment is kept in two staging areas onsite, to meet their needs during reactor outages. In addition, the supply of scaffolding is replenished as required. Therefore, the reference plant's inventory of scaffolding is deemed sufficient to meet decommissioning requirements, with one exception--the additional scaffolding anticipated to be needed for steam generators removal (see Appendix F for details).

B.9 PROPERTY TAXATION

Local property taxes for the reference PWR are based on the real estate book value (i.e., the original cost of the land), plus the value of the capital equipment installed in the facility. The capital equipment portion of the tax assessment is usually based upon an operating plant value. During decommissioning, however, local property taxes may be assessed on only the real estates' fair market value, depending on how the land is zoned. Overall, this approach results in a reduction in property tax assessment after plant shutdown, affecting both delayed decommissioning dormancy costs and local tax revenue.

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

B.9.1 Assumptions

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

- a dramatic decrease in property values after final shutdown, when the operating plant is removed from service and from the tax rolls

- only the fair market value associated with the land alone is assessed for tax purposes

- all the land is available for use, except for that small fraction of the site (about 34 acres) inside the exclusion areathe land outside the exclusion area is assessed at a value comparable with adjacent similar industrially-zoned property and the property within the exclusion area is assessed at essentially zero value

- property taxes are attributable to plant operations until Period 3, where they are allocated 90% to SNF storage, 10% to safe storage and 100% to decommissioning operations after the SNF inventory is reduced to zero at approximately 7 years after shutdown (see Section B.9.2 for details).

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

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

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

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

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

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

B.10 NUCLEAR INSURANCE COSTS

As delineated in NUREG/CR-0130,[1] the basis for the 1978 nuclear insurance costs given in that study were originally developed in 1975 by American Nuclear Insurers (ANI).[d] Cost projections for this commitment have increased significantly since then. In addition, cost estimates in the 1978 time frame typically only included insurance premiums associated with nuclear liability policies. More recent information, obtained from industry personnel and their brokers, suggests that additional insurance coverage will be needed to limit owner liability immediately after final shutdown, during subsequent decommissioning and dismantling operations, and for a prudent period of time following termination of the possession-only license.

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

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

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

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

TABLE B.7. Summary of Estimated Post-Shutdown Insurance Costs in 1993 Dollars

Stage	Cost Category	
	Decommissioning Cost, $[a]	SNF Management Cost, $[a,b]
Transition (first 1-1/2 years following shutdown, until receipt of Property Rule waiver)	1,703,754[c]	2,449,146[c]
Following general plant layup preps and receipt of Property Rule waiver	0	1,107,600/year
Extended Safe Storage with the Fuel Pool Empty	600,000/year	0
During periods of active decommissioning	1,198,600/year	0
After Termination of the Possession-Only License	17,250/year	0

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Shown for completeness; these costs are not decommissioning costs.
(c) During the first year following shutdown, about 32 weeks of decommissioning activities are postulated (e.g., chemical decontamination of the reactor coolant system, cutting and packaging of the reactor pressure vessel internals, etc.); therefore 32/52 x $2,768,600/year premium, or about $1,703,754 is attributable to decommissioning operations. The remainder, about $1,064,846, is postulated to be attributable to SNF management operations for the first year following shutdown. Following cessation of the initial decommissioning operations, all of the insurance costs are postulated to be attributable to SNF management operations until: 1) active decommissioning operations begin again in about 6-1/2 years or 2) extended safe storage commences.

B.10.1 Assumptions

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

1. The reference plant is insured by ANI for primary property insurance, and carries full limits of property, liability, and business interruption coverage. The shutdown reactor is defueled completely to the spent fuel pool, and is granted a waiver of Property Rule insurance limit requirements as have other decommissioning facilities to date. This waiver can be expected to require from one year to eighteen months to obtain.

   Note: For purposes of this study, it is conservatively estimated to take 18 months, after shutdown, to receive the waiver.

With the waiver granted, a $200 million limit of Property Damage insurance is determined to be sufficient to protect essential cooling, monitoring, and defueling systems. This is a conservatively high figure when viewed against those in place at current decommissioning facilities, and assumes that plant conversion or other use of site assets are ot anticipated.

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

edits of forty percent (40%) and fifty percent (50%) are applied to I Property and Liability premiums, respectively, to recognize the manently shutdown nature of the plant. These credits are extended ty percent up front, and fifty percent at policy year end subject to e plant operation and acceptable loss prevention efforts.

ear Electric Insurance Limited, NEIL I (business interruption)(f) mmediately suspended following plant permanent shutdown. A loss very under NEIL I is not technically feasible for a plant which has anently ceased power generation.

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ric Insurance Limited is an industry self-insurance corporation organized in 1980 for the oviding protection for power replacement costs when a reactor has suffered an outage caused by Since then, NEIL has initiated a second type of insurance coverage (NEIL II) that provides e excess coverage. The NEIL-II coverage provides a second layer of insurance up to a specified racks the primary coverage that a utility has with another insurer.

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

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

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

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

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

11. A $200 million level of Suppliers' and Transporters' (S&T)[i] coverage is maintained in anticipation of a large number of radiological shipments during the preliminary decommissioning process.

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

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

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

(g) An insurance company evaluation for rating the perceived safety and risk.
(h) The rating factor is a premium multiplier, based upon the insurance company's evaluation for rating the perceived safety and risk.
(i) S&T is Nuclear Liability Suppliers and Transporters Form that provides third party liability protection in amounts up to $200 million for bodily injury or property damage resulting from specific nuclear perils; S&T is generally utilized by companies who supply parts, equipment, materials, services, and transportation to owners and operators of nuclear facilities.

B.10.1 Assumptions

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

1. The reference plant is insured by ANI for primary property insurance, and carries full limits of property, liability, and business interruption coverage. The shutdown reactor is defueled completely to the spent fuel pool, and is granted a waiver of Property Rule insurance limit requirements as have other decommissioning facilities to date. This waiver can be expected to require from one year to eighteen months to obtain.

   Note: For purposes of this study, it is conservatively estimated to take 18 months, after shutdown, to receive the waiver.

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

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

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

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

(f) Nuclear Electric Insurance Limited is an industry self-insurance corporation organized in 1980 for the purpose of providing protection for power replacement costs when a reactor has suffered an outage caused by an accident. Since then, NEIL has initiated a second type of insurance coverage (NEIL II) that provides property damage excess coverage. The NEIL-II coverage provides a second layer of insurance up to a specified maximum that tracks the primary coverage that a utility has with another insurer.

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

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

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

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

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

11. A $200 million level of Suppliers' and Transporters' (S&T)[i] coverage is maintained in anticipation of a large number of radiological shipments during the preliminary decommissioning process.

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

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

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

(g) An insurance company evaluation for rating the perceived safety and risk.
(h) The rating factor is a premium multiplier, based upon the insurance company's evaluation for rating the perceived safety and risk.
(i) S&T is Nuclear Liability Suppliers and Transporters Form that provides third party liability protection in amounts up to $200 million for bodily injury or property damage resulting from specific nuclear perils; S&T is generally utilized by companies who supply parts, equipment, materials, services, and transportation to owners and operators of nuclear facilities.

Property

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

Liability

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

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

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

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

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

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

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

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

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

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

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

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

(j) Limit would likely be lowered to account for reduction in property value and required core defueling/monitoring equipment. This example assumes coverage is lowered from $200 to $100 million.

(k) Assumes limit is maintained at $200 million in anticipation of continued shipping exposure.

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

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

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

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

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

The total insurance costs for the first 18 months following shutdown of the reference PWR (i.e., the "transition period" pending receipt of a waiver of Property Rule limit requirements) are estimated to be about $4,152,900. Following defueling to the spent fuel pool, completion of general plant layup preparations, and receipt of the Property Rule waiver, the annual premium is projected to be $1,107,600. Subsequently, premiums will likely fluctuate according to the level of activity onsite. However, because the SNF inventory must remain in the spent fuel pool for a 7-year period, it is postulated that all of the nuclear liability insurance costs, except for a proportionate share of the annual premium covering about 32 weeks during the first year following shutdown when active decommissioning operations occur, are attributable to SNF management operations during the 7-year period. Upon reduction of the SNF inventory to zero and active decommissioning activity commences, subsequent insurance costs are attributable to decommissioning operations.

During periods of active decommissioning and dismantlement, the annual insurance costs could rise again to $1,198,600. The reduction in estimated insurance expenses for the reference PWR following a planned permanent cessation of operations is significant compared with the operating level premiums.

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

For the purpose of this study, $5 million in nuclear liability insurance is postulated to be carried for 30 years following termination of the possession-only license, at an estimated annual cost of $17,250. This lower insurance coverage for this relatively small annual premium is deemed prudent, since it provides "discovery term"[1] protection for the insured covering the entire life of the policy, plus 10 years after cancellation of the policy. It should be recognized, however, that liability is limited to whatever amount of insurance was in effect during the period for which a claim might be made - i.e., the period covering the operating years, the period following permanent cessation of operation, the decommissioning period, and the 30 years (in this case) following termination of the possession-only license. In summary, what this means is that upon cancellation of the policy, the clock starts ticking on the 10-year discovery term for any claims that might be made covering the lifetime of the policy (as defined above), but after the 10 years have elapsed, no claims against the policy can be made. Again, it should be recognized that any change in credit of the normal operating premium would need approval by the NRC and the nuclear liability pools.

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

B.11 LICENSE TERMINATION SURVEY COSTS

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

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

- Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors (NRC 1974),
- Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Materials (NRC 1987), Office of Nuclear Material Safety and Safeguards (NMSS), and
- Branch Technical Position for Disposal or Onsite Storage of Thorium or Uranium Water from Past Operations (46 FR 52061, October 23, 1981).

In addition, the decommissioning rule[14] requires submittal of a final radiation survey plan as part of the decommissioning plan. Plans for a final termination survey[m] should be designed to provide evidence, with a high degree of assurance, that residual radioactive contamination levels will meet criteria for release for unrestricted use. A final termination survey plan should also be designed so that procedures, results, and interpretations can be verified by the NRC staff.

Currently, the NRC has a draft guidance manual, NUREG/CR-5849,[15] for conducting radiological surveys in support of license termination. This manual updates information contained in NUREG/CR-2082,[16] and provides guidance for licensees on conducting radiological surveys of their facilities and sites to demonstrate that residual radioactive contamination levels, as

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

derived from NUREG/CR-5512,[17] meet NRC criteria for unrestricted use.[n] The guidance emphasis in NUREG/CR-5849 is on the termination survey, which should demonstrate that the facility and site meet the criteria for unrestricted use.

The NRC requires that the termination survey be performed in a manner that assures the results are complete and accurate. Surveys are to be performed by trained individuals who are following standard, written procedures. Properly calibrated survey instruments, sensitive to the identified contaminants at levels specified in the NRC decommissioning criteria, should be used. The custody of samples must be tracked from collection to analysis. Data must be recorded in an orderly and verifiable way and must be reviewed for accuracy and consistency. Every step of the survey, from training of personnel, to the calculation and interpretation of the results, must be documented in a way that lends itself to audit. These requirements are achieved through a formal program of quality assurance and quality control (QA/QC). The draft manual, NUREG/CR-5849, provides acceptable approaches for: 1) survey planning and design, 2) radiological instrumentation, 3) survey techniques, 4) laboratory procedures, 5) interpretation of survey results, and 6) survey documentation and reports.[18]

The needs of both licensee and inspector for design of their respective final surveys, having somewhat divergent objectives, should be kept in mind. One is an integral part of the other insofar as the licensee's final information is input to the inspector's final survey design for verification of the licensee's compliance. Therefore, the survey plan prepared by the licensee (or his radiological contractor, as assumed in this reevaluation study)[o]

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

(o) To the extent that monitoring requires hardware (analysis equipment, calibration standards, supplies, etc.) as contrasted with services (computer programming, data storage and analysis routines, interpretation, etc.), selected elements of a quality assurance program on monitoring for compliance with decommissioning criteria--e.g., control of measuring and test equipment, control of special processes such as sampling procedures and statistical models, corrective action, etc.--may not apply to the extent that physical aspects of the monitoring program are contracted out to a specialized company with the hardware. Quality assurance of these categories then becomes the primary responsibility of the contractor or subcontractor. However, the site owner is jointly responsible for QA on the final results, namely compliance with the decommissioning criteria.[16]

should be reviewed by the certification inspector prior to initiation of the licensee's final survey plan. It should be anticipated that the certification inspector will emphasize review of the analytical techniques, quality assurance measures, and statistical bases for sampling. In turn, the licensee's radiological contractor should carefully consider the incorporation of comments offered by the certification inspector. This early agreement should minimize the need for a completely independent radiological survey by the certification inspector.[16]

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

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

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(p) **Affected areas** are areas that have potential radioactive contamination (based on plant operating history) or known radioactive contamination (based on past or preliminary radiological surveillance). This would normally include areas where radioactive materials were used or stored, where records indicate spills or other unusual occurrences that could have resulted in spread of contamination, and where radioactive materials were buried. Areas immediately surrounding or adjacent to locations where radioactive materials were used or stored, spilled, or buried are included in this classification because of the potential for inadvertent spread of contamination. **Unaffected areas** are areas not classified as affected. These areas are not expected to contain residual radioactivity, based on a knowledge of site history and previous survey information.[15]

TABLE B.8. Summary of Estimated Costs for the Termination Survey

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

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

reduce mobilization costs for the instrumented mobile laboratory postulated to be used by the radiological contractor.

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

TABLE B.9. Summary of Estimated Times for the Termination Surveys of the Buildings and Site

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

(a) Based on the methodology presented in References 15 and 16; includes supervision, QA, and clerical.
(b) With virtually no reason to expect contamination in this area, it is postulated that only spot checks will be required for this termination survey.
(c) An intensive survey in the area 10 m beyond the Group 1 and 2 buildings foundations.
(d) A thorough survey of the plant facilities area (0.1 km^2) outside the intensive survey area.
(e) A cursory survey over the remainder of the site with thorough coverage in any areas found to contain contamination twice above background.
(f) The number of hours shown is for computational accuracy and does not imply precision to that many significant figures.

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

TABLE B.10. Staffing and Labor Rates Postulated for Survey Crews

Labor Category	Labor Rates Number/Crew	$/hr[a]
H.P. Leader/Supervisor	1.0	70.99
H.P./Survey Technician	5.0	36.82
Laborer[b]	1.0	26.37
Sr. Chemical Technician[c]	0.5	54.40
Sr. Instrument Tech.[c]	0.5	54.40
Secretary/Clerk	0.5	22.99

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

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

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

or,

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

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

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

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

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

$2,408/wk x 24.4 wks = $58,755

After the site has been surveyed, samples collected and analyzed, the data must be evaluated and presented in a report which documents the findings of the survey. The estimated labor associated with report preparation shown in Table B.11 is taken from Reference 16 and the labor costs are based upon the DOC costs presented previously in Table B.1.

TABLE B.11. Estimated Labor Costs for Preparation of Termination Survey Report

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

(a) Study estimate.

When the licensee has completed the cleanup and documented the radiological condition of the site, the NRC (or its agent) is ready for the certification process. Based upon discussion with NRC and upon information contained in Reference 15, it is postulated that this confirmatory/verification survey

(q) For a large, complex site such as the reference nuclear power plant, the following instrumentation and equipment are anticipated to be required: portable survey instruments, laboratory detectors and electronics, sample analysis systems, sample preparation equipment, and miscellaneous supplies and equipment.[15]

of selected points will take about one month and is estimated to cost roughly 15% of the licensee's costs shown in Table B.8, or about $159,200. These costs are ultimately paid by the licensee under the NRC's full-cost recovery policy.

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

B.12 CASCADING COSTS

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

B.13 REGULATORY COSTS

The reference nuclear power plant (Trojan) has been operating since 1975. Trojan is operated by Portland General Electric Company (PGE). Trojan was licensed to operate by the NRC. Federal law gives the NRC sole authority over safety regulation for nuclear power plants. The NRC regulates Trojan's operation and inspects Trojan to ensure that its safety requirements are followed. The NRC uses a combination of inspectors assigned to the site (Resident Inspectors), inspectors that operate out of the NRC's Regional

(r) Cascading costs are defined as those costs associated with the removal of noncontaminated and releasable material in support of the decommissioning process (e.g., if it is considered necessary to remove portions of the top floors or a roof to get at a bottom floor nuclear component).

Office in California, and technical specialists from the NRC headquarters in Maryland, to oversee Trojan's operations.

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

With revision to 10 CFR Part 170, Fees for Facilities and Materials Licenses and Other Regulatory Services Under the Atomic Energy Act of 1954, as Amended, the NRC has established a policy of full-cost recovery for all NRC licensing services and inspections, including those activities associated with the renewal, dismantling/decommissioning, and termination of reactor licenses. NRC licensees are now expected to provide 100% of the agency's budget through user fees. For example, 10 CFR Part 170.20, as amended, changes the cost per professional staff hour for all full cost fees from $92 per hour for FY 1990 to $115 per hour for FY 1991 (a 25% increase over FY 1990) and to $123 per hour for FY 1992 (a 7% increase over FY 1991).[19] At the time of this writing, the professional staff-hour rate for FY 1993 was unavailable. For the purpose of this study, the professional staff-hour rate is estimated at $132 per hour (a seven percent increase over FY 1992). The professional

(s) The Nuclear Waste Fund (NWF) was established by section 302(c) of the Nuclear Waste Policy Act of 1982, 42 U.S.C. 10222(c). In general, the NWF is for functions or activities necessary or incident to the disposal of high-level radioactive waste or spent nuclear fuel.

staff-hour rates through FY 1995 will be published as a Notice in the Federal Register during the first quarter of each fiscal year.

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

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

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

The Administrator, Nuclear Safety and Energy Facilities Division, ODOE, and the Reactor Safety Manager, ODOE, are responsible for implementing the regulation program. Currently, ODOE has authorized a Reactor Safety Manager and two Resident Engineers. The Resident Engineers work full-time at the

Trojan Site and are anticipated to continue to do so during periods of active decommissioning. They conduct inspections of PGE activities, identify potential problems, and discuss corrective action with PGE. The Resident Engineers report on their activities to the Reactor Safety Manager, the Administrator, and the EFSC. The reports form the basis for discussions of Trojan status with the EFSC. This program is expected to continue during periods of active decommissioning. The cost of this program, together with a summary of estimated regulatory costs, is given in Table B.12.

B.14 CONTINGENCY

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

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

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

The inclusion of contingency in project estimates (construction, deconstruction or otherwise) is an industry-wide practice. In the U.S. Department of Energy Publication DOE Uniform Contractor Reporting System, Volume 1, September 1978, Form DOE533P illustrates specific use of project contingency. This form contains an item called "Management Reserve" which is defined as

TABLE B.12. Summary of Estimated Regulatory Costs

Entity	Cost Element	Estimated Cost, $ [a]
Licensee	Services:	
	• Oregon State DEQ (Onsite Inspection)	3,000/yr [b]
	• Oregon State DOE (Onsite Inspection Program) [c]	481,250/yr
	• Oregon State Health Division, Radiation Control Section license: [d]	3,000/yr
	Resolution & Response to NRC Review of the Decom. Plan	103,500 [e]
NRC	Environmental Assessment	23,230 [f]
	Decommissioning Plan [g]	230,600
	Regional Inspections during periods of safe storage:	
	• Two General Inspections/yr; 1-wk/inspection by 1 person	11,652 [h]
	• One Security Inspection/yr; 3-days by 1 person	3,532 [h]
	Resident Inspector (during periods of active decommissioning) [i]	115,300/yr
	Certification Survey [j]	159,155

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) The Oregon State Dept. of Environmental Quality (DEQ) conducts inspections of the Trojan sewage treatment plant 1-day/year, based upon the licensee's Water Discharge Permit. These inspections are conducted under the auspices of the Federal Program, National Pollution Discharge Elimination System, delegated by the EPA to Oregon State.
(c) Based on the reported billing cost by the Oregon State Dept. of Energy (ODOE) for the inspection program at Trojan for the period July 1, 1992 to June 30, 1993 (includes the salaries for 3 ODOE on-site inspectors).
(d) This annual fee is for the plant's Radioactive Waste Handling License issued by the State of Oregon for cleanup and/or disposal of materials and equipment.
(e) Study estimate based upon engineering judgment and the review of unanticipated costs and variables associated with selected past decommissionings.
(f) Based upon discussions with the NRC, this task is estimated to require about 1 man-month (a Period 1 cost).
(g) Discussions with NRC staff suggest that review, evaluation, and approval of a decommissioning plan for power reactors may require about a year (a Period 1 cost).
(h) Includes Federal Travel Rates of $91/day/person.
(i) Based upon discussions with the NRC, 1/2 FTE, with roughly 1/3 time actually spent onsite during periods of active decommissioning, would be a reasonable value to use for this cost element.
(j) Already included in Table B.8, but included here for completeness.

"Amount of Contingency...Available for Use..." As another example, the State of Connecticut's Department of Transportation employs contingency as an integral part of project estimates on budgeted construction jobs. This is done primarily to adequately allow for the "Unforeseeable Elements of Cost" such as:

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

These definitions and examples highlight the importance of including a provision for unforeseeable events that are likely to occur and that will increase costs. Virtually every nuclear and fossil fuel facility owner, architect-engineer, consultant, construction and demolition company in the country (and probably in the world) abides by the aforementioned contingency principle, either expressed or implied. Their experience in their respective fields have led them to recognize the propriety of a contingency provision in cost estimates.[13]

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

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

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

B.15 REFERENCES

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APPENDIX C

COST ESTIMATING COMPUTER PROGRAM

APPENDIX C

COST ESTIMATING COMPUTER PROGRAM

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

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

The CECP main menu is shown in Figure C.1. The first task for the user is to enter certain general data which the CECP will need later in calculating site-specific costs. This is done by selecting 1, 2, and 3 from the main menu. When the user types 1, for example, a portion of the data base is opened up permitting the user to enter labor costs, burial costs, overhead costs, consumables costs, physical constants (e.g., the density of reinforced concrete) and so on. When the user selects 1 for the first time, the default file is loaded into memory. The user may then modify whatever values he or she desires and save this new information to a file. In fact the user may save data to several files during the same session. The next time the user

```
CECP MAIN MENU

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

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

*** PRESS Alt-X TO EXIT; V TO VIEW FILES ***
```

FIGURE C.1. CECP Main Menu

accesses item 1 he or she will have several files to choose from: the default file (which is always available) and the files he or she created. Any of these files may be loaded into memory and used as a basis for creating a new file. The user may save up to 150 different files, but it is unlikely that more than about five will ever be needed. Data for items 2 and 3 are entered in the same way. If the user does not supply his or her own files for 1, 2, and 3, the CECP will still have the default files available.

Having entered general information into the data base, the user must now enter site-specific data. Data for menu items **A** and **B** are entered first, in either order, then data for items **C** through **H**, in any order. When the user selects items **C**, **D**, **E**, **F**, **G**, or **H**, the CECP requests the user to specify which input files (from 1 through 3 and **A** and **B**) to use. For each of the items **C** through **H**, the CECP calculates cost and exposure information in detail and then writes the results to appropriate output files. To get a complete site summary, combining data from items **A** through **H**, the user selects item **I**. The overall method for entering data is outlined in Figure C.2.

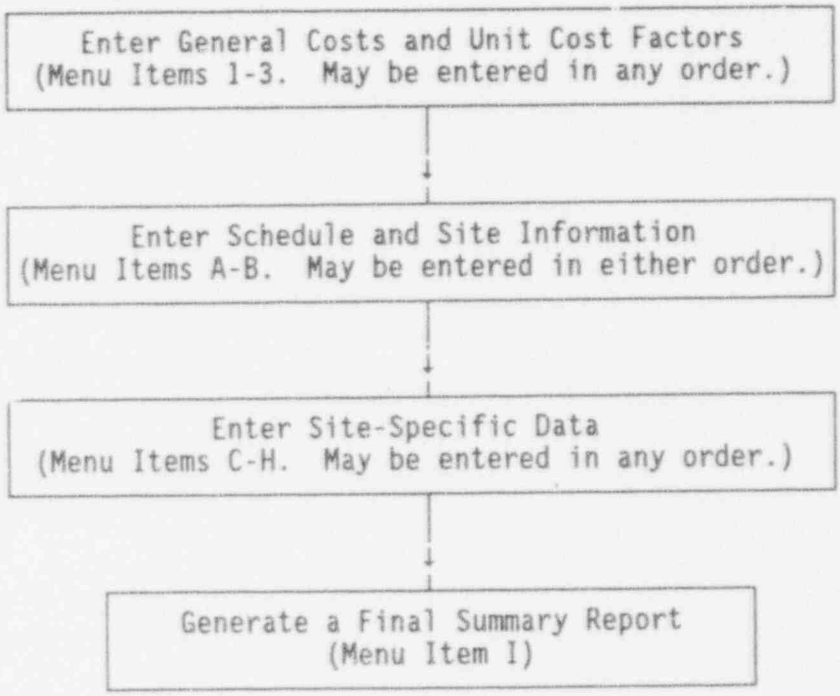

FIGURE C.2. Flow Diagram for Entering Data into the CECP

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

MENU ITEM E: CONTAMINATED SYSTEMS COSTS

System Name: Chemical and Volume Control System

	Component Description	Category	Disposal	Quantity
18	Seal Injection Filter	Tank	Mtl Box	2
19	Concentrate Holding Tank	Tank	Sea-Van	1
20	Evaporator Feed IX	Tank	Mtl Box	3
21	Evaporator Condensate IX	Tank	Mtl Box	2
22	Condensate Filter	Tank	Mtl Box	1
23	Concentrates Filter	Tank	Mtl Box	1
24	Conc. Hold. Tank Transfer Pump	Lg Pump	Sea-Van	2
25	Gas Stripper Feed Pump	Lg Pump	Sea-Van	2
26	Boric Acid Evaporator Condenser	Tank	Sea-Van	2
27	Boric Acid Evaporator Vent Condenser	Tank	Sea-Van	2
28	Boric Acid Evap. Distillate Condenser	Tank	Sea-Van	2
29	IX Filter	Tank	Mtl Box	1
30	Recirculation Pump	Lg Pump	Sea-Van	1
31	Standpipes	Tank	Sea-Van	4
32	6 Inch Valve	Lg Valve	Sea-Van	2
33	4 Inch Valve	Lg Valve	Sea-Van	35
34	3 Inch Valve	Sm Valve	Sea-Van	49

Number of records: 37 | File in use: BASE.INV

F1 F2 Select System Change System Name

↑↓→← Home End PgUp PgDn Select Item ↵ Enter Data Insert Item

Ctrl End Insert Item at End Delete Item Save Data to a File Alt-X Quit

FIGURE C.3a. System Inventory Information (Screen I)

MENU ITEM E: CONTAMINATED SYSTEMS COSTS

System Name: Chemical and Volume Control System

	Volume	Weight	Diameter	Length	Dose (mRem)
18	N/A	1650	0.8	6.3	100
19	N/A	3500	5.5	7.8	100
20	N/A	1050	2.2	5.4	100
21	N/A	1050	2.2	5.4	100
22	N/A	40	0.67	3.25	100
23	N/A	[illegible]0	0.67	3.25	100
24	3	200	1	0.167	25
25	3	200	1	0.167	100
26	N/A	20000	2.1	8.2	100
27	N/A	600	1.1	5	100
28	N/A	300	1.1	12.1	100
29	N/A	150	1	3.3	100
30	3	200	1	0.167	100
31	N/A	540	0.5	7	100
32	7.2	588	6	22	3[illegible]0
33	3.1	268	4	17	440
34	1.4	153	3	14	465

Number of records: 37 | File in use: BASE.INV

F1 F2 Select System Change System Name

↑↓→← Home End PgUp PgDn Select Item ↵ Enter Data Insert Item

Ctrl End Insert Item at End Delete Item Save Data to a File Alt-X Quit

FIGURE C.3b. System Inventory Information (Screen II)

The equipment category and disposal category parameters require further explanation. The user selects the equipment category from the following list: Lg Pipe, Sm Pipe, Lg Valve, Sm Valve, Tank, Lg Pump, Sm Pump, Lg HX, Sm HX, Lg Misc., and Sm Misc. Lg Pipe refers to piping greater than 2.5 inches in diameter and Sm Pipe is piping 2 inches or less in diameter. The other categories are similarly defined. The equipment category parameter is important because it provides the CECP with the correct unit cost factor to be used in determining removal costs.

The disposal category parameter is either Sea-Van (maritime container) or Metal Box (B-25 container). This parameter enables the CECP to apply the proper disposal cost algorithm to each component.

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

C.1 PLANT INVENTORY

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

C.1.1 Inventories of Process System Components

Inventories of process system components and the inventory of stainless steel piping that will have to be removed during decommissioning are compiled and presented in this section. These inventories are used in the CECP, together with appropriate unit cost factors and algorithms, to estimate the costs of removal, packaging, transport, and disposal for this material. The Reactor Coolant System, because of its complexity and large physical size, is

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

*** Radioactive Gaseous Waste System

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

*** Residual Heat Removal System

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

*** Safety Injection System

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

FIGURE C.4a. Partial CECP Output File for Contaminated Systems, Example 1

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+ POTENTIALLY RADIOACTIVE SYSTEMS:  CREW-HOURS, PERSON-HOURS, ETC. +
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*** Radioactive Gaseous Waste System

Component Description	Category	Disposal	Qty	Crew-Hrs	Pers-Hrs	Exp Hrs	Pers-Rem	Curies
Surge Tank	Tank	Sea-Van	1	11.7	64.3	40.9	0.0	0.016
Decay Tank	Tank	Sea-Van	4	101.3	556.9	353.9	0.3	0.595
Gas Compressor	Lg Misc.	Sea-Van	2	0.0	0.0	0.0	0.0	0.000
Moisture Separator	Sm Misc.	Sea-Van	2	0.0	0.0	0.0	0.0	0.000
Br. Seal Wtr. HX	Lg HX	Mtl Box	2	4.1	16.4	10.4	0.0	0.176
4 Inch Valve	Lg Valve	Sea-Van	1	3.0	16.3	10.4	0.2	0.000
3 Inch Valve	Sm Valve	Sea-Van	3	0.0	0.0	0.0	0.0	0.000
2 Inch Valve	Sm Valve	Sea-Van	16	0.0	0.0	0.0	0.0	0.000
1 1/2 Inch Valve	Sm Valve	Sea-Van	35	0.0	0.0	0.0	0.0	0.003
1 Inch Valve	Sm Valve	Sea-Van	12	0.0	0.0	0.0	0.0	0.000
3/4 Inch Valve	Sm Valve	Sea-Van	16	0.0	0.0	0.0	0.0	0.000
				120	654	416	1	0.790

*** Residual Heat Removal System

Component Description	Category	Disposal	Qty	Crew-Hrs	Pers-Hrs	Exp Hrs	Pers-Rem	Curies
Pump	Lg Pump	Sea-Van	2	4.1	16.4	10.4	0.0	0.003
HX Unit	Lg HX	Mtl Box	2	4.1	16.4	10.4	0.2	1.405
14 Inch Valve	Lg Valve	Sea-Van	7	20.8	114.2	72.6	0.6	0.027
12 Inch valve	Lg Valve	Sea-Van	3	8.9	48.9	31.1	0.3	0.008
10 Inch Valve	Lg Valve	Sea-Van	2	5.9	32.6	20.7	0.3	0.004
8 Inch Valve	Lg Valve	Sea-Van	18	53.4	293.7	186.6	2.7	0.024
2 Inch Valve	Sm Valve	Sea-Van	2	0.0	0.0	0.0	0.0	0.000
3/4 Inch Valve	Sm Valve	Sea-Van	10	0.0	0.0	0.0	0.0	0.000
				97	522	332	4	1.472

*** Safety Injection System

Component Description	Category	Disposal	Qty	Crew-Hrs	Pers-Hrs	Exp Hrs	Pers-Rem	Curies
Accuml. Tank	Tank	Sea-Van	4	113.5	624.3	396.7	3.2	0.826
Boron Injection Tank	Tank	Sea-Van	1	15.5	85.5	54.3	0.2	0.059
Safety Injection Pump	Lg Pump	Sea-Van	2	4.1	16.4	10.4	0.0	0.003
Refueling Water Storage Tank	Tank	Sea-Van	1	85.7	471.3	299.5	0.1	1.919
Primary Makeup Water Storage Tank	Tank	Sea-Van	1	61.1	336.2	213.6	0.1	1.071
10 Inch Valve	Lg Valve	Sea-Van	8	23.7	130.5	82.9	1.1	0.016
8 Inch Valve	Lg Valve	Sea-Van	8	23.7	130.5	82.9	1.2	0.010
6 Inch Valve	Lg Valve	Sea-Van	2	5.9	32.6	20.7	0.3	0.002
4 Inch Valve	Lg Valve	Sea-Van	9	26.7	146.8	93.3	1.7	0.004
3 Inch Valve	Sm Valve	Sea-Van	4	0.0	0.0	0.0	0.0	0.001
2 Inch Valve	Sm Valve	Sea-Van	1	0.0	0.0	0.0	0.0	0.000
1 1/2 Inch Valve	Sm Valve	Sea-Van	4	0.0	0.0	0.0	0.0	0.000
1 Inch Valve	Sm Valve	Sea-Van	33	0.0	0.0	0.0	0.0	0.001
3/4 Inch Valve	Sm Valve	Sea-Van	20	0.0	0.0	0.0	0.0	0.000
				360	1,974	1,254	8	3.912

FIGURE C.4b. Partial CECP Output File for Contaminated Systems, Example 2

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

*** Radioactive Gaseous Waste System

Component Description	Category	Disposal	Qty	Removal	Container	Transport	Disposal	Tot. Costs
Surge Tank	Tank	Sea-Van	1	2,233	123	33	1,031	3,420
Decay Tank	Tank	Sea-Van	4	19,561	5,958	1,598	50,024	77,141
Gas Compressor	Lg Misc.	Sea-Van	2	85	2,207	592	18,527	21,411
Moisture Separator	Sm Misc.	Sea-Van	2	6	28	7	232	273
Br. Seal Wtr. HX	Lg HX	Mtl Box	2	581	1,057	273	8,499	10,409
4 Inch Valve	Lg Valve	Sea-Van	1	572	37	10	310	929
3 Inch Valve	Sm Valve	Sea-Van	3	0	63	17	532	612
2 Inch Valve	Sm Valve	Sea-Van	16	0	199	53	1,667	1,919
1 1/2 Inch Valve	Sm Valve	Sea-Van	35	0	299	80	2,513	2,892
1 Inch Valve	Sm Valve	Sea-Van	12	0	83	22	695	800
3/4 Inch Valve	Sm Valve	Sea-Van	16	0	66	18	556	640
				23,037	10,119	2,704	84,586	120,445

*** Residual Heat Removal System

Component Description	Category	Disposal	Qty	Removal	Container	Transport	Disposal	Tot. Costs
Pump	Lg Pump	Sea-Van	2	581	1,876	503	15,748	18,708
HX Unit	Lg HX	Mtl Box	2	646	0	1,538	31,212	33,397
14 Inch Valve	Lg Valve	Sea-Van	7	4,001	2,665	715	22,372	29,752
12 Inch valve	Lg Valve	Sea-Van	3	1,715	816	219	6,851	9,600
10 Inch Valve	Lg Valve	Sea-Van	2	1,143	402	108	3,377	5,030
8 Inch Valve	Lg Valve	Sea-Van	18	10,288	2,554	685	21,448	34,975
2 Inch Valve	Sm Valve	Sea-Van	2	0	25	7	208	240
3/4 Inch Valve	Sm Valve	Sea-Van	10	0	41	11	347	400
				18,374	8,379	3,786	101,563	132,101

*** Safety Injection System

Component Description	Category	Disposal	Qty	Removal	Container	Transport	Disposal	Tot. Costs
Accuml. Tank	Tank	Sea-Van	4	22,022	42,202	11,320	354,337	429,882
Boron Injection Tank	Tank	Sea-Van	1	2,987	3,931	1,054	33,002	40,974
Safety Injection Pump	Lg Pump	Sea-Van	2	633	2,372	636	19,917	23,558
Refueling Water Storage Tank	Tank	Sea-Van	1	17,114	24,522	6,578	205,886	254,099
Primary Makeup Water Storage Tank	Tank	Sea-Van	1	12,122	13,681	3,670	114,870	144,343
10 Inch Valve	Lg Valve	Sea-Van	8	4,572	1,609	432	13,506	20,119
8 Inch Valve	Lg Valve	Sea-Van	8	4,572	1,135	305	9,532	15,545
6 Inch Valve	Lg Valve	Sea-Van	2	1,143	162	44	1,362	2,711
4 Inch Valve	Lg Valve	Sea-Van	9	5,144	333	89	2,793	8,359
3 Inch Valve	Sm Valve	Sea-Van	4	0	84	23	709	816
2 Inch Valve	Sm Valve	Sea-Van	1	0	12	3	104	120
1 1/2 Inch Valve	Sm Valve	Sea-Van	4	0	34	9	287	331
1 Inch Valve	Sm Valve	Sea-Van	33	0	228	61	1,911	2,199
3/4 Inch Valve	Sm Valve	Sea-Van	20	0	83	22	695	800
				70,309	90,388	24,246	758,910	943,854

FIGURE C.4c. Partial CECP Output File for Contaminated Systems, Example 3

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

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

FIGURE C.5a. Partial CECP Output File for Building Decontamination, Example 1

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

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

FIGURE C.5b. Partial CECP Output File for Building Decontamination, Example 2

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+ BUILDING DECONTAMINATION: COSTS +
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*** Fuel Bldg

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

FIGURE C.5c. Partial CECP Output File for Building Decontamination, Example 3

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+ SUMMARY OF BUILDING DECONTAMINATION COSTS (ALL COSTS IN DOLLARS) +
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          *** Fuel Bldg

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

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

          Concrete Removal--
            Surface Area:           6,570 ft2
            Weight Removed:        78,846 lb
            Removal Costs:        112,265
            Container Costs:        3,541
            Shipping Costs:         2,844
            Burial Costs:          47,158
            Burial Volume:            972 ft3
            Number of Drums:       131.41
            Crew Hours:               788
            Pers-Hours:             2,760
            Pers-Rem:                1.90

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

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

FIGURE C.5d. Partial CECP Output File for Building Decontamination, Example 4

COSTS (IN DOLLARS) FOR REACTOR PRESSURE VESSEL AND INTERNALS

COMPONENTS	CUTTING	CONTAINERS	TRANSPORT	DISPOSAL	TOTAL
Insulation	50,439	1,290 4,695	1,332 33,189	9,311 8,345	108,600
Top Plate	3,409	1,565	1,332	34,508	40,813
Upper Portion CRD Guides		1,290	1,332	11,441	
Upper Portion Post and Columns	79,304	2,580	1,332	18,622	212,155
Lower Portion, Posts, Columns, CRD Guides		9,390	39,852	47,013	
Upper Core Barrel	12,305	1,290 14,085	1,332 47,396	13,780 36,840	127,028
Thermal Shields	17,667	3,120	127,994	327,600	476,382
Shroud Plates and Formers	50,551	4,160	162,241	436,800	653,751
Upper/Lower Grid Plates	25,219	4,160	129,310	436,800	595,489
Upper Portion of Support Posts and Inst. Guides	22,930	1,040	61,446	109,200	194,616
Lower Core Barrel	67,720	11,440	401,358	1,201,200	1,681,718
Support Forging and Tie Plates	42,712	28,170	68,537	84,170	223,589
Lower Posts and Instrument Guides	22,930	4,695	33,449	11,643	72,717
Upper/Lower RPV Heads	28,224	4,515	4,661	107,139	144,539
Upper/Lower RPV Flanges	11,238	4,515	4,661	69,864	90,278
Nozzle Sections	4,346	3,760	5,327	66,847	80,281
Lower Wall	28,480	103,290	184,231	257,783	573,784
Studs & Nuts	0	1,290	1,332	14,636	17,258
CRD & Instrument Penetrations	37,468	645	1,332	4,656	44,101
TOTALS	504,943	210,985	1,312,975	3,308,196	5,337,100

FIGURE C.6. CECP Output File for RPV Internals

TABLE C.1. DECON Case for Reference PWR, Hanford Burial Site

Final Summary Report for DECON

PERIOD 1: Planning and Preparation (Year -2.5000 to Year 0.0000)

	Costs (dollars)										
Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	600,077	600,077	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,227,775	3,227,775	0	0	0	0.00
Totals	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00
Totals for PERIOD 1	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00

PERIOD 2: Defuel and Layup (Year 0.0000 to Year 0.6200)

	Costs (dollars)										
Removal of NSSS	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Removal of RPV Internals	0	395,187	92,970	1,111,430	2,787,273	0	4,386,859	3,454	1,216	10,947	61.83
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Sol.	1,074,600	0	1,725	0	23,278	0	1,099,602	480	3,936	11,808	12.00
Totals	14,324,600	395,187	94,695	1,111,430	3,276,852	0	19,202,763	8,534	6,560	31,203	119.53

	Costs (dollars)										
Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Dry Active Waste	0	0	11,050	7,185	149,130	0	167,365	3,075	0	0	0.00

	Costs (dollars)										
Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	310,464	310,464	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	7,904	7,904	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,485,948	9,485,948	0	0	87,069	87.07
Totals for PERIOD 2	14,324,600	395,187	105,745	1,118,615	3,425,982	9,485,948	28,856,076	11,610	6,560	118,272	206.60

TABLE C.1. (contd)

PERIOD 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)

	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Undistributed Costs											
Utility Staff	0	0	0	0	0	1,905,744	1,905,744	0	0	22,277	20.53
DOC Staff	0	0	0	0	0	965,549	965,549	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,842	42,842	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	6,862,509	6,862,509	0	0	22,277	20.53
Totals for PERIOD 3	0	0	0	0	0	6,862,509	6,862,509	0	0	22,277	20.53

PERIOD 4: Deferred Dismantlement (Year 6.9200 to Year 8.6200)

	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Removal of NSSS											
Removal of Reactor Pressure Vessel	0	109,756	118,015	201,545	520,924	0	950,241	2,924	338	3,040	16.24
Steam Generator--Direct Removal Costs	1,070,711	4,790,297	137,363	682,290	3,349,743	0	10,030,404	64,524	1,443	86,557	60.00
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	31,179	8,363	261,781	0	323,467	4,019	115	634	4.87
Large Miscellaneous RCS Piping	0	22,862	3,899	1,046	34,572	0	62,379	503	119	653	5.01
Small Miscellaneous RCS Piping	0	42,714	433	116	3,891	0	47,154	56	222	1,220	9.36
RCS Insulation	0	0	39,720	5,327	248,293	0	293,341	5,120	0	0	0.00
Pressurizer	0	8,112	0	172,294	118,327	0	298,733	2,440	16	90	0.69
Pressurizer Relief Tank	0	5,868	3,751	1,006	31,497	0	42,122	484	30	166	1.27
Primary Pumps	0	32,448	0	689,175	203,678	0	925,301	4,200	65	360	2.76
Spent Fuel Racks	0	661,500	63,680	16,601	1,006,162	0	1,747,944	18,113	267	2,400	1.20
Biological Shield	0	140,185	86,917	44,867	699,105	0	971,074	12,936	419	2,722	25.21
Totals	1,070,711	5,977,622	484,957	1,822,631	6,477,973	0	15,833,895	115,318	3,034	97,842	126.61

TABLE C.1. (contd)

Removal of Contaminated Plant Systems	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Component Cooling Water System	0	2,612	8,689	2,331	72,952	0	86,583	1,120	18	74	0.19
Clean Radioactive Waste Treatment System	0	47,722	17,230	4,629	144,655	0	214,236	2,222	253	1,354	5.26
Containment Spray System	0	14,823	8,711	2,337	73,135	0	99,005	1,123	79	423	1.97
Chemical and Volume Control System	0	135,519	46,032	12,394	388,407	0	582,352	6,024	711	3,859	21.19
Dirty Radioactive Waste Treatment System	0	18,600	3,808	1,022	31,976	0	55,406	491	102	533	1.34
Main Steam System (Within Containment)	0	51,893	27,175	7,289	228,161	0	314,518	3,503	269	1,480	7.69
Radioactive Gaseous Waste System	0	23,037	10,119	2,704	84,586	0	120,445	1,325	120	654	0.54
Residual Heat Removal System	0	18,374	8,379	3,786	101,563	0	132,101	1,552	97	522	4.15
Safety Injection System	0	70,309	90,388	24,246	758,910	0	943,854	11,651	360	1,974	7.94
Spent Fuel Cooling System	0	30,100	5,971	1,608	49,821	0	87,500	788	160	861	6.35
Stainless Steel Piping (3 - 24 Inches)	0	799,941	65,806	17,652	584,448	0	1,467,847	8,483	4,153	22,842	230.67
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,901	2,656	90,343	0	740,802	1,276	3,313	18,224	228.36
Retrofit Materials	0	16,486	1,089	292	9,169	0	27,035	140	86	471	4.00
Totals	0	1,867,318	303,298	82,945	2,618,124	0	4,871,685	39,698	9,722	53,269	519.66

Decontamination of Site Buildings	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Fuel Bldg	23,577	136,674	14,624	5,817	140,205	0	320,896	2,401	1,087	4,147	2.65
Containment Bldg	125,020	127,209	19,979	6,899	182,063	0	461,170	2,999	1,990	7,293	3.74
Auxiliary Bldg	64,318	173,951	8,156	5,062	95,065	0	346,552	1,839	1,855	6,410	3.89
Waste Water Solidification Costs	293,300	0	54,775	55,592	86,524	0	490,192	1,414	875	2,624	0.71
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	67,590	0	887,176	1,010	720	4,320	2.00
Concrete Cutting--Cascading Costs	0	48,168	0	0	0	0	48,168	0	392	980	0.75
Removal of HVAC Ducts	0	107,355	24,662	6,615	180,615	0	319,248	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	92,957	2,203,430	0	2,680,636	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	78,752	21,124	661,206	0	794,837	10,151	179	895	0.46
Bridge Crane	7,542	75,780	3,650	1,315	76,603	0	164,889	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	1,522	76,603	0	326,336	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	2,664	67,398	0	84,301	1,280	23	125	0.31
Floor Drains	0	248,660	7,925	4,091	63,746	0	324,423	1,180	1,715	5,145	1.09
Totals	1,275,509	1,230,588	638,019	203,652	3,901,049	0	7,248,822	72,843	10,832	40,046	17.73

Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Dry Active Waste	0	0	39,730	25,834	536,188	0	601,752	11,057	0	0	0.00

Site Termination Survey	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00

TABLE C.1. (contd)

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	3,390,654	3,390,654	0	0	29,744	11.97
DOC Staff	0	0	0	0	0	11,271,454	11,271,454	0	0	69,888	28.13
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	1,024,335	1,024,335	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	763,321	763,321	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	207,485	207,485	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	1,455,820	1,455,820	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	25,172,725	25,172,725	0	0	99,632	40.10
Totals for PERIOD 4	2,346,220	9,075,528	1,466,004	2,135,068	13,533,334	26,392,912	54,949,066	238,915	23,587	290,789	704.09
GRAND TOTALS	16,670,820	9,470,715	1,571,749	3,253,683	16,959,316	51,754,284	99,680,566	250,524	30,148	431,338	931.23
GRAND TOTALS with 25% contingency	20,838,525	11,838,394	1,964,686	4,067,104	21,199,145	64,692,855	124,600,708	250,524	30,148	431,338	931.23

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

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.746	68,614,018	85,767,523
B (energy and transportation):	0.069	6,363,380	7,954,225
C (waste burial):	0.184	16,959,316	21,199,145
	A + B + C ($)	91,936,714	114,920,893
	Taxes & Insurance ($)	7,743,852	9,679,815
	Grand Totals ($)	99,680,566	124,600,708

TABLE C.2. DECON Case for Reference PWR, Barnwell Burial Site

Final Summary Report for DECON

PERIOD 1: Planning and Preparation (Year -2.5000 to Year 0.0000)

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	600,077	600,077	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,227,775	3,227,775	0	0	0	0.00
Totals	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00
Totals for PERIOD 1	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00

PERIOD 2: Defuel and Layup (Year 0.0000 to Year 0.6200)

Removal of NSSS	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Removal of RPV Internals	0	395,187	92,970	1,363,542	4,329,456	0	6,181,155	3,454	1,216	10,947	61.83
Chemical Decontamination	13,250,000	0	0	0	2,105,580	0	15,355,580	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Sol.	1,074,600	0	1,725	0	134,600	0	1,210,924	480	3,936	11,808	12.00
Totals	14,324,600	395,187	94,695	1,363,542	6,569,636	0	22,747,660	8,534	6,560	31,203	119.53

Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Dry Active Waste	0	0	11,050	23,315	862,327	0	896,692	3,075	0	0	0.00

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	310,464	310,464	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	7,904	7,904	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,485,948	9,485,948	0	0	87,069	87.07
Totals for PERIOD 2	14,324,600	395,187	105,745	1,386,857	7,431,963	9,485,948	33,130,300	11,610	5,560	118,272	206.60

TABLE C.2. (contd)

PERIOD 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)

Undistributed Costs	Costs (dollars) Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	1,905,744	1,905,744	0	0	22,277	20.53
DOC Staff	0	0	0	0	0	965,549	965,549	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,842	42,842	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	6,862,509	6,862,509	0	0	22,277	20.53
Totals for PERIOD 3	0	0	0	0	0	6,862,509	6,862,509	0	0	22,277	20.53

PERIOD 4: Deferred Dismantlement (Year 6.9200 to Year 8.6200)

Removal of NSSS	Costs (dollars) Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Removal of Reactor Pressure Vessel	0	109,756	118,015	849,295	2,767,791	0	3,844,858	2,924	338	3,040	16.24
Steam Generator--Direct Removal Costs	1,070,711	5,180,298	137,363	3,397,610	18,169,872	0	27,955,854	64,524	1,443	86,557	60.00
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	31,179	27,138	1,146,999	0	1,227,460	4,019	115	634	4.87
Large Miscellaneous RCS Piping	0	22,862	3,899	3,394	143,432	0	173,586	503	119	653	5.01
Small Miscellaneous RCS Piping	0	42,714	433	377	15,931	0	59,455	56	222	1,220	9.36
RCS Insulation	0	0	39,720	17,286	1,441,130	0	1,498,136	5,120	0	0	0.00
Pressurizer	0	8,112	0	172,294	684,215	0	864,621	2,440	16	90	0.69
Pressurizer Relief Tank	0	5,868	3,751	3,265	138,003	0	150,888	484	30	166	1.27
Primary Pumps	0	32,448	0	689,175	1,177,747	0	1,899,370	4,200	65	360	2.76
Spent Fuel Racks	0	661,500	63,680	86,021	5,117,255	0	5,928,456	18,113	267	2,400	1.20
Biological Shield	0	140,185	86,917	145,585	3,789,282	0	4,161,968	12,936	419	2,722	25.21
Totals	1,070,711	6,367,623	484,957	5,391,439	34,591,657	0	47,906,388	115,318	3,034	97,842	126.61

TABLE C.2. (contd)

Removal of Contaminated Plant Systems	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Component Cooling Water System	0	2,612	8,689	7,563	319,640	0	338,503	1,120	18	74	0.19
Clean Radioactive Waste Treatment System	0	47,722	17,230	15,020	634,048	0	714,020	2,222	253	1,354	5.26
Containment Spray System	0	14,823	8,711	7,582	320,441	0	351,556	1,123	79	423	1.97
Chemical and Volume Control System	0	135,519	46,032	40,218	1,721,894	0	1,943,663	6,024	711	3,859	21.19
Dirty Radioactive Waste Treatment System	0	18,600	3,808	3,315	140,104	0	165,827	491	102	533	1.34
Main Steam System (Within Containment)	0	51,893	27,175	23,653	999,693	0	1,102,413	3,503	269	1,480	7.69
Radioactive Gaseous Waste System	0	23,037	10,119	8,773	379,443	0	421,372	1,325	120	654	0.54
Residual Heat Removal System	0	18,374	8,379	12,284	431,481	0	470,518	1,552	97	522	4.15
Safety Injection System	0	70,309	90,388	78,673	3,325,186	0	3,564,557	11,651	360	1,974	7.94
Spent Fuel Cooling System	0	30,100	5,971	5,218	225,783	0	267,073	788	160	861	6.35
Stainless Steel Piping (3 - 24 Inches)	0	799,941	65,806	57,277	2,420,864	0	3,343,888	8,483	4,153	22,842	230.67
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,901	8,618	364,253	0	1,020,674	1,276	3,313	18,224	228.35
Retrofit Materials	0	16,486	1,089	948	40,048	0	58,570	140	86	471	4.00
Totals	0	1,867,318	303,298	269,140	11,322,878	0	13,762,634	39,698	9,722	53,269	519.66

Decontamination of Site Buildings	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Fuel Bldg	23,577	136,674	14,624	18,874	680,373	0	874,122	2,401	1,087	4,147	2.65
Containment Bldg	125,020	127,209	19,979	22,387	852,006	0	1,146,600	2,999	1,990	7,293	3.74
Auxiliary Bldg	64,318	173,951	8,156	16,424	517,346	0	780,196	1,839	1,855	6,410	3.89
Waste Water Solidification Costs	293,300	0	54,775	117,564	513,275	0	978,914	1,414	875	2,624	0.71
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	373,800	0	1,193,386	1,010	720	4,320	2.00
Concrete Cutting--Cascading Costs	0	48,168	0	0	0	0	48,168	0	392	980	0.75
Removal of HVAC Ducts	0	107,355	24,662	21,466	902,221	0	1,055,704	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	301,626	12,609,939	0	13,295,815	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	78,752	68,545	2,897,092	0	3,078,143	10,151	179	895	0.46
Bridge Crane	7,542	75,780	3,650	7,199	384,551	0	478,721	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	8,490	385,551	0	642,252	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	8,643	362,302	0	385,184	1,280	23	125	0.31
Floor Drains	0	248,660	7,925	13,275	345,516	0	615,377	1,180	1,715	5,145	1.09
Totals	1,275,509	1,230,588	638,019	604,491	20,823,973	0	24,572,579	72,843	10,832	40,046	17.73

Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Dry Active Waste	0	0	39,730	83,826	3,100,450	0	3,224,006	11,057	0	0	0.00

Site Termination Survey	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00

TABLE C.2. (contd)

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	3,390,654	3,390,654	0	0	29,744	11.97
DOC Staff	0	0	0	0	0	11,271,454	11,271,454	0	0	69,888	28.13
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	1,024,335	1,024,335	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	763,321	763,321	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	215,285	215,285	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	1,455,820	1,455,820	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	25,180,525	25,180,525	0	0	99,632	40.10
Totals for PERIOD 4	2,346,220	9,465,529	1,466,004	6,348,897	69,838,958	26,400,712	115,866,320	238,[illegible]	23,587	290,789	704.09
GRAND TOTALS	16,670,820	9,860,716	1,571,749	7,735,753	77,270,921	51,762,084	164,872,043	250,524	30,148	431,338	931.23
GRAND TOTALS with 25% contingency	20,838,525	12,325,895	1,964,686	9,669,692	96,588,652	64,702,605	206,090,054	250,524	30,148	431,338	931.23

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

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.439	69,011,819	86,264,774
B (energy and transportation):	0.069	10,845,450	13,556,813
C (waste burial):	0.492	77,270,921	96,588,652
A + B + C ($)		157,128,191	196,410,239
Taxes and Insurance ($)		7,743,852	9,679,815
Grand Totals ($)		164,872,043	206,090,054

TABLE C.3. SAFSTOR Case for Reference PWR, Hanford Burial Site

Final Summary Report for SAFSTOR2

PERIOD 1: Planning and Preparation (Year -2.5000 to Year 0.0000)

Undistributed Costs	Costs (dollars) Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	600,077	600,077	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,227,775	3,227,775	0	0	0	0.00
Totals	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00
Totals for PERIOD 1	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00

PERIOD 2: Defuel and Layup (Year 0.0000 to Year 0.6200)

Removal of NSSS	Costs (dollars) Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Removal of RPV Internals	0	395,187	92,970	1,111,430	2,787,273	0	4,386,859	3,454	1,216	10,947	61.83
Chemical Decontamination	13,250,000	0	0	0	466,302	0	13,716,302	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Sol.	1,074,600	0	1,725	0	23,278	0	1,099,602	480	3,936	11,808	12.00
Totals	14,324,600	395,187	94,695	1,111,430	3,276,852	0	19,202,763	8,534	6,560	31,203	119.53

Dry Active Waste Costs for this Period	Costs (dollars) Decon	Remove	..ckage	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Dry Active Waste	0	0	11,050	7,185	149,130	0	167,365	3,075	0	0	0.00

Undistributed Costs	Costs (dollars) Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	310,464	310,464	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	7,904	7,904	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,485,948	9,485,948	0	0	87,069	87.07
Totals for PERIOD 2	14,324,600	395,187	105,745	1,118,615	3,425,982	9,485,948	28,856,076	11,610	6,560	118,272	206.60

TABLE C.3. (contd)

PERIOD 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	1,905,744	1,905,744	0	0	22,277	20.53
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,618	30,618	0	0	0	0.00
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,840	42,840	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53
Totals for PERIOD 3	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53

PERIOD 4: Extended Safe Storage (Year 6.9200 to Year 58.3000)

Layup Spent Fuel Pool	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	67,590	0	887,176	1,010	720	4,320	2.00
Totals	754,211	0	65,375	0	67,590	0	887,176	1,010	720	4,320	2.00

Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Dry Active Waste	0	0	1,213	789	16,367	0	18,368	338	0	0	0.00

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	41,529,842	41,529,842	0	0	213,741	86.02
DOC Staff	0	0	0	0	0	1,931,092	1,931,092	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	1,533,385	1,533,385	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	2,497,222	2,497,222	0	0	0	0.00
Laundry Services	0	0	0	0	0	572,410	572,410	0	0	0	0.00
Maintenance Allowance	0	0	0	0	0	892,933	892,933	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	576,483	576,483	0	0	0	0.00
Property Taxes	0	0	0	0	0	4,624,200	4,624,200	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	30,828,000	30,828,000	0	0	0	0.00
Totals	0	0	0	0	0	84,985,567	84,985,567	0	0	213,741	86.02
Totals for PERIOD 4	754,211	0	66,588	789	83,957	84,985,567	85,891,111	1,347	720	218,061	88.02

TABLE C.3. (contd)

PERIOD 5: Deferred Dismantlement (Year 58.3000 to Year 60.0000)

Removal of NSSS	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Removal of Reactor Pressure Vessel	0	109,756	118,015	201,545	383,554	0	812,870	2,924	338	3,040	0.02
Steam Generator--Direct Removal Costs	1,070,711	4,790,297	137,363	682,290	3,349,745	0	10,030,406	64,524	1,443	86,557	0.07
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	31,179	8,363	261,781	0	323,467	4,019	115	634	0.01
Large Miscellaneous RCS Piping	0	22,862	3,899	1,046	34,572	0	62,379	503	119	653	0.01
Small Miscellaneous RCS Piping	0	42,714	433	116	3,891	0	47,154	56	222	1,220	0.01
RCS Insulation	0	0	39,720	5,327	248,293	0	293,341	5,120	0	0	0.00
Pressurizer	0	8,112	0	172,294	118,327	0	298,733	2,440	16	90	0.00
Pressurizer Relief Tank	0	5,868	3,751	1,006	31,497	0	42,122	484	30	166	0.00
Primary Pumps	0	32,448	0	689,175	203,678	0	925,301	4,200	65	360	0.00
Spent Fuel Racks	0	661,500	63,680	16,601	1,006,162	0	1,747,944	18,113	267	2,400	1.20
Biological Shield	0	140,185	86,917	44,867	699,105	0	971,074	12,936	419	2,722	0.03
Totals	1,070,711	5,977,622	484,957	1,822,631	6,340,605	0	15,696,526	115,318	3,034	97,842	1.35

Removal of Contaminated Plant Systems	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Component Cooling Water System	0	2,612	8,689	2,331	72,952	0	86,583	1,120	18	74	0.00
Clean Radioactive Waste Treatment System	0	47,722	17,230	4,629	144,655	0	214,236	2,222	253	1,354	0.01
Containment Spray System	0	14,823	8,711	2,337	73,135	0	99,005	1,123	79	423	0.00
Chemical and Volume Control System	0	135,519	46,032	12,394	388,407	0	582,352	6,024	711	3,859	0.02
Dirty Radioactive Waste Treatment System	0	18,600	3,808	1,022	31,976	0	55,406	491	102	533	0.00
Main Steam System (Within Containment)	0	51,893	27,175	7,289	228,161	0	314,518	3,503	269	1,480	0.01
Radioactive Gaseous Waste System	0	23,037	10,119	2,704	84,586	0	120,445	1,325	120	654	0.00
Residual Heat Removal System	0	18,374	8,379	3,786	101,563	0	132,101	1,552	97	522	0.00
Safety Injection System	0	70,309	90,388	24,246	758,910	0	943,854	11,651	360	1,974	0.01
Spent Fuel Cooling System	0	30,100	5,971	1,608	49,821	0	87,500	788	160	861	0.01
Stainless Steel Piping (3 - 24 Inches)	0	799,941	65,806	17,652	552,515	0	1,435,915	8,483	4,153	22,842	0.27
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,901	2,656	83,134	0	733,593	1,276	3,313	18,224	0.27
Retrofit Materials	0	16,486	1,089	292	9,140	0	27,007	140	86	471	0.00
Totals	0	1,867,318	303,298	82,945	2,578,954	0	4,832,516	39,698	9,722	53,269	0.60

TABLE C.3. (contd)

	Costs (dollars)										
Decontamination of Site Buildings	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Fuel Bldg	23,577	136,674	14,624	5,817	140,205	0	320,896	2,401	1,087	4,147	0.00
Containment Bldg	125,020	127,209	19,979	6,899	182,063	0	461,170	2,999	1,990	7,293	0.00
Auxiliary Bldg	64,318	173,951	8,156	5,062	95,065	0	346,552	1,839	1,855	6,410	0.00
Waste Water Solidification Costs	293,300	0	54,775	55,592	86,524	0	490,192	1,414	875	2,624	0.71
Concrete Cutting--Cascading Costs	0	48,168	0	0	0	0	48,168	0	392	980	0.00
Removal of HVAC Ducts	0	107,355	24,662	6,615	180,615	0	319,248	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	92,957	2,203,430	0	2,680,636	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	78,752	21,124	661,206	0	794,837	10,151	179	895	0.46
Bridge Crane	7,542	75,780	3,650	1,315	76,603	0	164,889	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	[illegible],650	1,522	76,603	0	326,336	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	2,664	67,398	0	84,301	1,280	23	125	0.00
Floor Drains	0	248,660	7,925	4,091	63,746	0	324,423	1,180	1,715	5,145	1.09
Totals	521,298	1,230,588	572,644	203,658	3,833,459	0	6,361,647	71,833	10,112	35,726	4.40

	Costs (dollars)										
Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Dry Active Waste	0	0	38,517	25,045	519,821	0	583,384	10,719	0	0	0.00

	Costs (dollars)										
Site Termination Survey	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00

	Costs (dollars)										
Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	3,390,654	3,390,654	0	0	29,744	0.01
DOC Staff	0	0	0	0	0	11,271,454	11,271,454	0	0	69,888	0.03
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	1,024,335	1,024,335	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	751,981	751,981	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	207,485	207,485	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	1,455,820	1,455,820	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	25,161,385	25,161,385	0	0	99,632	0.05
Totals for PERIOD 5	1,592,009	9,075,528	1,399,416	2,134,279	13,272,840	26,381,572	53,855,645	237,567	22,867	286,469	6.39

TABLE C.3. (contd)

GRAND TOTALS	16,670,820	9,470,715	1,571,749	3,253,683	16,782,778	135,762,960	183,512,705	250,524	30,148	645,078	321.55
GRAND TOTALS with 25% contingency	20,838,525	11,838,394	1,964,686	4,067,104	20,978,473	169,703,700	229,390,881	250,524	30,148	645,078	321.55

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

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.831	116,594,013	145,742,516
B (energy and transportation):	0.049	6,939,862	8,674,827
C (waste burial):	0.120	16,782,778	20,978,473
A + B + C ($)		140,316,653	175,395,816
Taxes and Insurance ($)		43,196,052	53,995,065
Grand Totals ($)		183,512,705	229,390,881

TABLE C.4. SAFSTOR Case for Reference PWR, Barnwell Burial Site

Final Summary Report for SAFSTOR2

PERIOD 1: Planning and Preparation (Year -2.5000 to Year 0.0000)

	Costs (dollars)										
Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	600,077	600,077	0	0	0	0.00
DOC Staff	0	0	0	0	0	4,827,733	4,827,733	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	357,330	357,330	0	0	0	0.00
Special Tools and Equipment	0	0	0	0	0	3,227,775	3,227,775	0	0	0	0.00
Totals	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00
Totals for PERIOD 1	0	0	0	0	0	9,012,915	9,012,915	0	0	0	0.00

PERIOD 2: Defuel and Layup (Year 0.0000 to Year 0.6200)

	Costs (dollars)										
Removal of NSSS	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Removal of RPV Internals	0	395,187	92,970	1,363,542	4,324,201	0	6,175,900	3,454	1,216	10,947	61.83
Chemical Decontamination	13,250,000	0	0	0	2,105,580	0	15,355,580	4,600	1,408	8,448	45.70
Disposal of Concentrated Boron Solut	1,074,600	0	1,725	0	134,600	0	1,210,924	480	3,936	11,808	12.00
Totals	14,324,600	395,187	94,695	1,363,542	6,564,381	0	22,742,405	8,534	6,560	31,203	119.53

	Costs (dollars)										
Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Dry Active Waste	0	0	11,050	23,315	862,327	0	896,692	3,075	0	0	0.00

	Costs (dollars)										
Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	6,008,571	6,008,571	0	0	87,069	87.07
Regulatory Costs	0	0	0	0	0	370,800	370,800	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	30,134	30,134	0	0	0	0.00
Laundry Services	0	0	0	0	0	310,464	310,464	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	7,904	7,904	0	0	0	0.00
Chemical Decontamination Energy	0	0	0	0	0	302,900	302,900	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	738,643	738,643	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	1,716,532	1,716,532	0	0	0	0.00
Totals	0	0	0	0	0	9,485,948	9,485,948	0	0	87,069	87.07
Totals for PERIOD 2	14,324,600	395,187	105,745	1,386,857	7,426,708	9,485,948	33,125,045	11,610	6,560	118,272	206.60

TABLE C.4. (contd)

PERIOD 3: Spent Fuel Pool Operations (Year 0.6200 to Year 6.9200)

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	1,905,744	1,905,744	0	0	22,277	20.53
Regulatory Costs	0	0	0	0	0	22,579	22,579	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	C	30,618	30,618	0	0	0	0.00
Laundry Services	0	0	0	0	0	58,477	58,477	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	42,840	42,840	0	0	0	0.00
Property Taxes	0	0	0	0	0	56,700	56,700	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	3,780,000	3,780,000	0	0	0	0.00
Totals	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53
Totals for PERIOD 3	0	0	0	0	0	5,896,958	5,896,958	0	0	22,277	20.53

PERIOD 4: Extended Safe Storage (Year 6.9200 to Year 58.3000)

Layup Spent Fuel Pool	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Spent Fuel Pool Water Treatment	754,211	0	65,375	0	373,800	0	1,193,386	1,010	720	4,320	2.00
Totals	754,211	0	65,375	0	373,800	0	1,193,386	1,010	720	4,320	2.00

Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Dry Active Waste	0	0	1,213	2,559	94,640	0	98,412	338	0	0	0.00

Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Utility Staff	0	0	0	0	0	41,529,842	41,529,842	0	0	213,741	86.02
DOC Staff	0	0	0	0	0	1,931,092	1,931,092	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	1,533,385	1,533,385	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	2,497,222	2,497,222	0	0	0	0.00
Laundry Services	0	0	0	0	0	572,410	572,410	0	n	0	0.00
Maintenance Allowance	0	0	0	0	0	892,933	892,933	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	576,483	576,483	0	0	0	0.00
Property Taxes	0	0	0	0	0	4,624,200	4,624,200	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	30,828,000	30,828,000	0	0	0	0.00
Totals	0	0	- 0	0	0	84,985,567	84,985,567	0	-0	213,741	86.02
Totals for PERIOD 4	754,211	0	66,588	2,559	468,440	84,985,567	86,277,364	1,347	720	218,061	88.02

TABLE C.4. (contd)

PERIOD 5: Deferred Dismantlement (Year 58.3000 to Year 60.0000)

Removal of NSSS	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Removal of Reactor Pressure Vessel	0	109,756	118,015	849,295	1,289,611	0	2,366,678	2,924	338	3,040	0.02
Steam Generator--Direct Removal Costs	1,070,711	5,180,298	137,363	3,397,610	18,169,872	0	27,955,854	64,524	1,443	86,557	0.07
Steam Generator--Cascading Costs	0	141,736	0	0	0	0	141,736	0	0	0	0.00
RCS Piping	0	22,144	31,179	27,138	1,146,999	0	1,227,460	4,019	115	634	0.01
Large Miscellaneous RCS Piping	0	22,862	3,899	3,394	143,432	0	173,586	503	119	653	0.01
Small Miscellaneous RCS Piping	0	42,714	433	377	15,931	0	59,455	56	222	1,220	0.01
RCS Insulation	0	0	39,720	17,286	1,441,130	0	1,498,136	5,120	0	0	0.00
Pressurizer	0	8,112	0	172,294	684,215	0	864,621	2,440	16	90	0.00
Pressurizer Relief Tank	0	5,868	3,751	3,265	138,003	0	150,888	484	30	166	0.00
Primary Pumps	0	32,448	0	689,175	1,177,747	0	1,899,370	4,200	65	360	0.00
Spent Fuel Racks	0	661,500	63,680	86,021	5,117,255	0	5,928,456	18,113	267	2,400	1.20
Biological Shield	0	140,185	86,917	145,585	3,789,282	0	4,161,968	12,936	419	2,722	0.03
Totals	1,070,711	6,367,623	484,957	5,391,439	33,113,477	0	46,428,208	115,318	3,034	97,842	1.35

Removal of Contaminated Plant Systems	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
	Costs (dollars)										
Component Cooling Water System	0	2,612	8,689	7,563	319,640	0	338,503	1,120	18	74	0.00
Clean Radioactive Waste Treatment System	0	47,722	17,230	15,020	634,048	0	714,020	2,222	253	1,354	0.01
Containment Spray System	0	14,823	8,711	7,582	320,441	0	351,556	1,123	79	423	0.00
Chemical and Volume Control System	0	135,519	46,032	40,218	1,721,894	0	1,943,663	6,024	711	3,859	0.02
Dirty Radioactive Waste Treatment System	0	18,600	3,808	3,315	140,104	0	165,827	491	102	533	0.00
Main Steam System (Within Containment)	0	51,893	27,175	23,653	999,693	0	1,102,413	3,503	269	1,480	0.01
Radioactive Gaseous Waste System	0	23,037	10,119	8,773	379,443	0	421,372	1,325	120	654	0.00
Residual Heat Removal System	0	18,374	8,379	12,284	431,481	0	470,518	1,552	97	522	0.00
Safety Injection System	0	70,309	90,388	78,573	3,325,186	0	3,564,557	11,651	360	1,974	0.01
Spent Fuel Cooling System	0	30,100	5,971	5,218	225,783	0	267,073	788	160	861	0.01
Stainless Steel Piping (3 - 24 Inches)	0	799,941	65,806	57,277	2,420,864	0	3,343,888	8,483	4,153	22,842	0.27
Stainless Steel Piping (1/2 - 2 Inches)	0	637,902	9,901	8,618	364,253	0	1,020,674	1,276	3,313	18,224	0.27
Retrofit Materials	0	16,486	1,089	948	40,048	0	58,570	140	86	471	0.00
Totals	0	1,867,318	303,298	269,140	11,322,878	0	13,762,634	39,698	9,722	53,269	0.60

TABLE C.4. (contd)

	Costs (dollars)										
Decontamination of Site Buildings	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Fuel Bldg	23,577	136,674	14,624	18,874	680,373	0	874,122	2,401	1,087	4,147	0.00
Containment Bldg	125,020	127,209	19,979	22,387	852,006	0	1,146,600	2,999	1,990	7,293	0.00
Auxiliary Bldg	64,318	173,951	8,156	16,424	517,346	0	780,196	1,839	1,855	6,410	0.00
Waste Water Solidification Costs	293,300	0	54,775	117,564	513,275	0	978,914	1,414	875	2,624	0.71
Concrete Cutting--Cascading Costs	0	48,168	0	0	0	0	48,168	0	392	980	0.00
Removal of HVAC Ducts	0	107,355	24,662	21,466	902,221	0	1,055,704	3,179	1,275	3,826	1.62
Removal of HVAC Equipment	0	37,708	346,541	301,626	12,609,939	0	13,295,815	44,670	200	1,000	0.51
Removal of HVAC Coolers	0	33,754	78,752	68,545	2,897,092	0	3,078,143	10,151	179	895	0.46
Bridge Crane	7,542	75,780	3,650	7,199	384,551	0	478,721	1,360	216	1,176	0.00
Polar Crane	7,542	237,020	3,650	8,490	385,551	0	642,252	1,360	304	2,104	0.00
Refueling Cranes	0	4,309	9,930	8,643	362,302	0	385,184	1,280	23	125	0.00
Floor Drains	0	248,660	7,925	13,275	345,516	0	615,377	1,180	1,715	5,145	1.09
Totals	521,298	1,230,588	572,644	604,491	20,450,173	0	23,379,194	71,833	10,112	35,726	4.40
	Costs (dollars)										
Dry Active Waste Costs for this Period	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Dry Active Waste	0	0	38,517	81,268	3,005,809	0	3,125,594	10,719	0	0	0.00
	Costs (dollars)										
Site Termination Survey	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Termination Survey Costs	0	0	0	0	0	1,220,187	1,220,187	0	0	0	0.00
	Costs (dollars)										
Undistributed Costs	Decon	Remove	Package	Ship	Bury	Undist	Total	Cu Ft	C-Hrs	Pers-Hrs	Pers-Rem
Utility Staff	0	0	0	0	0	3,390,654	3,390,654	0	0	29,744	0.01
DOC Staff	0	0	0	0	0	11,271,454	11,271,454	0	0	69,888	0.03
Consultant/Other Staff	0	0	0	0	0	121,100	121,100	0	0	0	0.00
DOC Mobilization/Demobilization Costs	0	0	0	0	0	2,640,000	2,640,000	0	0	0	0.00
Regulatory Costs	0	0	0	0	0	1,024,335	1,024,335	0	0	0	0.00
Environmental Monitoring Costs	0	0	0	0	0	82,625	82,625	0	0	0	0.00
Laundry Services	0	0	0	0	0	751,981	751,981	0	0	0	0.00
Small Tools and Minor Equipment	0	0	0	0	0	215,285	215,285	0	0	0	0.00
Steam Generator--Undistributed Costs	0	0	0	0	0	1,455,820	1,455,820	0	0	0	0.00
Plant Power Usage	0	0	0	0	0	2,025,312	2,025,312	0	0	0	0.00
Property Taxes	0	0	0	0	0	153,000	153,000	0	0	0	0.00
Nuclear Liability Insurance	0	0	0	0	0	2,037,620	2,037,620	0	0	0	0.00
Totals	0	0	0	0	0	25,169,185	25,169,185	0	0	99,632	0.05
Totals for PERIOD 5	1,592,009	9,465,529	1,399,416	6,346,338	67,892,338	26,389,372	113,085,002	237,567	22,867	286,469	6.39

TABLE C.4. (contd)

GRAND TOTALS	16,670,820	9,860,716	1,571,749	7,735,753	75,787,486	135,770,760	247,397,284	250,524	30,148	645,078	321.55
GRAND TOTALS with 25% contingency	20,838,525	12,325,895	1,964,686	9,669,692	94,734,358	169,713,450	309,246,605	250,524	30,148	645,078	321.55

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

Cost Category	Cost Fraction	Costs (Dollars) w/o Contingency	Costs (Dollars) with 25% Contingency
A (labor and materials):	0.573	116,991,814	146,239,767
B (energy and transportation):	0.056	11,421,932	14,277,415
C (waste burial):	0.371	75,787,486	94,734,358
	A + B + C ($)	204,201,232	255,251,540
	Taxes and Insurance ($)	43,196,052	53,995,065
	Grand Totals ($)	247,397,284	309,246,605

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

Analysis Approach

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

The quantities of piping associated with each system are, in most cases, not known sufficiently well to attempt to assign lengths of piping to individual systems. Rather, the total inventory of piping purchased for construction of the plant is listed, and is segregated according to size and material, a conservative approach. Because the stainless steel piping is primarily associated with the reactor coolant system, and with associated safety and support systems, all of the stainless steel piping is assumed to be removed during decommissioning.

The basic approach in this analysis is that only those systems likely to be contaminated, or which must be removed to facilitate removal of contaminated systems, are removed to satisfy the requirements for license termination. Thus, only those portions of the carbon steel piping associated with the main steam system that are within the reactor containment building are assumed to be removed, to facilitate the final cleanup and decontamination of the containment building. Because the remaining carbon steel systems which serve the turbine, service cooling water, potable water, sanitary sewer, etc., are assumed to be uncontaminated, they do not need to be removed to satisfy the requirements for license termination, and they remain in place for a demolition contractor to remove, should the owner choose to demolish the clean structures.

Inventory Listings

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

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

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

TABLE C.5. Reference PWR System Components and Piping Inventories

Component Cooling Water System

Probably Clean

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

Potentially Contaminated

Number	Component	Weight (each)	Physical Dimensions	Volume/Area (each)
9 ea.	Sample HX	7,000 lb.	1 ft dia. x 10 ft	

Valves (weight and volume per valve)

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

Clean Radioactive Waste Treatment System

Number	Component	Weight (each)	Physical Dimensions	Volume/Area (each)
1 ea.	Rx Cool. Drain Tk.	1,670 lb	3 ft dia. x 8 ft long	area = 90 ft^2
2 ea.	Rx Cool. Drain Pump	500 lb	4 ft x 1 ft x 2 ft	volume = 8 ft^3
1 ea.	Rx Cool. Drain Filter	350 lb	1.3 ft dia. x 4.7 ft long	volume = 6.3 ft^3
1 ea.	Spent Resin Storage Tk.	6,800 lb	9 ft dia. x 11 ft long	area = 438 ft^2
2 ea.	Clean Waste Recv. Tk.	10,958 lb	10 ft dia. x 30 ft high	area = 1100 ft^2
2 ea.	Clean Waste Recv. Pump	500 lb	4 ft x 1 ft x 2 ft long	volume = 8 ft^3
2 ea.	Treated Waste Mon. Tk.	11,200 lb	10 ft dia. x 26 ft long	area = 974 ft^2
2 ea.	Treated Waste Mon. Pump	230 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
1 ea.	Aux Bldg. Drain Tk.	2,090 lb	6 ft dia. x 9 ft high	area = 226 ft^2
2 ea.	Aux Bldg. Drain Pump	1,300 lb	15 ft high	volume = 12 ft^3
1 ea.	Chem. Waste. Drain Tk.	5,400 lb	10 ft dia. x 15 ft high	area = 528 ft^2
2 ea.	Chem. Waste. Drain Pump	200 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
1 ea.	Waste. Conc. Hold. Tk.	2,090 lb	6 ft dia. x 10 ft high	area = 245 ft^2
1 ea.	Waste. Conc. Hold. Pump	230 lb	3 ft x 1 ft x 1 ft	volume = 3 ft^3
1 ea.	Clean Waste Filter	67 lb	0.6 ft dia. x 2.2 ft long	volume = 1 ft^3
1 ea.	Cln. Radwst. Evaporator	40,000 lb	19 ft x 9 ft x 12 ft	volume = 2,052 ft^3

TABLE C.5. (contd)

Clean Radioactive Waste Treatment System (contd)

1 ea. Cln. Radwst. Evaporator	40,000 lb	19 ft x 9 ft x 12 ft	volume = 2,052 ft^3
1 ea. Cln. Radwst. Evap Condens			

Valves (weight and volume per valve)

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

Containment Spray System

Number	Component	Weight (each)	Physical Dimensions	Volume/Area (each)
2 ea.	Pump	6,800 lb	4 ft dia. x 9 ft long	volume = 113 ft^3
2 ea.	Pump	100 lb	1 ft dia. x 2 ft long	volume = 2 ft^3
1 ea.	Tank		9 ft dia. x 10 ft high	area = 410 ft^2

Valves (weight and volume per valve)

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

Chemical and Volume Control System

Number	Component	Weight (each)	Physical Dimensions	Volume/Area (each)
3 ea.	Regenerative HX	6,600 lb	1.2 ft dia. x 18' long	volume = 21 ft^3
1 ea.	Seal Water HX	1,700 lb	1.2 ft dia. x 14' long	volume = 17 ft^3
1 ea.	Letdown HX	1,900 lb	1.5 ft dia. x 18' long	volume = 32 ft^3
1 ea.	Excess Letdown HX	1,600 lb	0.9 ft dia. x 11' long	volume = 7 ft^3
2 ea.	Centrif. Chrg Pump	17,090 lb	17.8 ft x 4.2 ft x 4.6 ft	volume = 344 ft^3
1 ea.	Vol. Control Tank	4,850 lb	7.5 ft dia. x 10.4 ft long	area = 333 ft^2
1 ea.	Chem. Mix Tank	77 lb	0.75 ft dia. x 2.5 ft long	volume = 1 ft^3
3 ea.	Holdup Tank	30,000 lb	18 ft dia. x 34 ft long	area = 2,432 ft^2
2 ea.	Monitor Tank	20,000 lb	20 ft dia. x 10 ft high	area = 1,257 ft^2
2 ea.	Boric Acid Tank	20,000 lb	12 ft dia. x 34 ft high	area = 1,508 ft^2
1 ea.	Batch Tank	1,450 lb	4 ft dia. x 5.8 ft high	area = 98 ft^2
1 ea.	Resin Fill Tank,	260 lb	5.3 ft dia. x 6.2 ft high	area = 148 ft^2
1 ea.	Reciprocal Charg. Pump	17,700 lb	14 ft x 5.7 ft x 4.3 ft	volume = 343 ft^3
2 ea.	Boric Acid Pump	618 lb	4.3 ft x 1.25 ft x 1.75 ft	volume = 10 ft^3
1 ea.	Reactor Coolant Filter	200 lb	1.25 ft dia. x 4.25 ft long	volume = 6 ft^3
2 ea.	Mixed Bed Demineralizer	1,050 lb	2.2 ft dia. x 5.4 ft long	volume = 21 ft^3
1 ea.	Cation IX	1,050 lb	2.2 ft dia. x 5.4 ft long	volume = 21 ft^3

TABLE C.5. (contd)

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

Valves (weight and volume per valve)

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

Dirty Radioactive Waste Treatment System

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

TABLE C.5. (contd)

Valves (weight and volume per valve)

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

Radioactive Gaseous Waste System

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

Valves (weight and volume per valve)

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

Main Steam System (within containment)

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

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

Residual Heat Removal System

Number	Component	Weight (each)	Physical Dimensions	Volume/Area (each)
2 ea.	Pump	6,800 lb	2 ft dia. x 9 ft long	volume = 28 ft^3
2 ea.	HX Unit	23,100 lb	3 ft dia. x 30 ft long	volume = 212 ft^3

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
14	7	2,760	31.1
12	3	1,972	24.2
10	2	1,458	18.2

TABLE C.5. (contd)

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
8	18	1,029	14.6
2	2	90	1.0
¾	10	30	0.2

Safety Injection System

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

Valves (weight and volume per valve)

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

Spent Fuel Cooling System

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

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
10	8	1,458	18.2
8	12	1,029	14.6
6	1	588	7.2
4	16	268	3.1

TABLE C.5. (contd)

Valves (weight and volume per valve)

Size (in.)	Number	Weight (lb)	Volume (ft^3)
3	9	153	1.4
2	2	90	1.0
1	10	50	0.3
¾	5	30	0.2

Stainless Steel Piping[a]

Pipe Size	Nuclear Class	Thickness (in.)	Weight (lb./ft)	Volume (ft^3/ft)	Linear ft
24 in.	I	0.375	94.62	3.14	170
18 in.	III	0.375	70.59	1.77	30
16 in.	II	0.375	62.58	1.40	300
14 in.	I	1.250	170.22	1.07	170
	II	0.250	36.71	1.07	200
	II	0.375	54.57	1.07	270
	III	0.375	54.57	1.07	610
12 in.	I	1.125	139.68	0.89	150
	II	0.375	49.56	0.89	400
	III	0.406	53.53	0.89	270
10 in.	I	1.000	104.13	0.63	330
	II	0.165	18.70	0.63	320
	II	0.365	40.48	0.63	360
	III	0.365	40.48	0.63	60
	(b)	0.165	18.70	0.63	1,000
8 in.	I	0.906	74.69	0.41	250
	II	0.322	28.55	0.41	530
	II	0.500	43.39	0.41	50
	II	0.906	74.69	0.41	20
	III	0.322	28.55	0.41	620
	(b)	0.148	13.40	0.41	400
	(b)	0.322	28.55	0.41	130
6 in.	I	0.718	45.30	0.24	550
	II	0.134	9.29	0.24	100
	II	0.280	18.97	0.24	500
	III	0.280	18.97	0.24	90
	(b)	0.134	9.29	0.24	1,400
4 in.	I	0.531	22.51	0.11	280
	II	0.120	5.61	0.11	250
	II	0.237	10.79	0.11	500
	II	0.337	14.98	0.11	70
	II	0.531	22.51	0.11	180
	III	0.237	10.79	0.11	1,340
	(b)	0.120	5.61	0.11	2,200
3 in.	I	0.437	14.32	0.07	40
	II	0.120	4.33	0.07	220
	II	0.216	7.58	0.07	2,000
	II	0.437	14.32	0.07	1,100
	III	0.216	7.58	0.07	1,460
	(b)	0.120	4.33	0.07	5,000
	(b)	0.216	7.58	0.07	20

TABLE C.5. (contd)

2 in.	I	0.343	7.44	0.03	550
	II	0.154	3.65	0.03	200
	II	0.218	5.02	0.03	800
	II	0.343	7.44	0.03	1,450
	III	0.154	3.65	0.03	4,100
	(b)	0.154	3.65	0.03	1,400
1¼ in.	I	0.281	4.86	0.02	700
	II	0.145	2.72	0.02	200
	II	0.200	3.63	0.02	800
	II	0.281	4.86	0.02	200
	III	0.145	2.72	0.02	1,700
	(b)	0.145	2.72	0.02	1,500
1 in.	I	0.250	2.84	0.01	100
	II	0.133	1.68	0.01	100
	II	0.179	2.17	0.01	300
	II	0.250	2.84	0.01	600
	III	0.133	1.68	0.01	1,500
	(b)	0.133	1.68	0.01	2,000
3/4 in.	I	0.218	1.94	0.006	290
	II	0.113	1.13	0.006	200
	II	0.154	1.47	0.006	300
	II	0.218	1.94	0.006	700
	III	0.113	1.13	0.006	900
	(b)	0.113	1.13	0.006	1,000
1/2 in.	I	0.187	1.30	0.004	105
	II	0.147	1.09	0.004	200
	II	0.187	1.30	0.004	200
	III	0.109	0.85	0.004	800
	(b)	0.109	0.85	0.004	1,000

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

C.2 UNIT COST FACTORS AND WORK DIFFICULTY FACTORS

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

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

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

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

General work difficulty factors are presented in Section C.2.1. Labor rates, crew staffing levels and consumables costs for the cutting and packaging crews are discussed in Section C.2.2. In Sections C.2.3 through C.2.20, the assumptions of C.2.1 and C.2.2 are applied to specific system components to arrive at the reference PWR unit cost factors.

C.2.1 Analysis of Work Durations and Available Time

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

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

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

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

$$[\ 1 + 0.098 + 0.393 + 0.082]\ \times 305 = 480$$

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

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

Radiation Exposure time = estimated work duration x 1.3

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

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

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

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

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

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

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

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

• Install scaffolding at cut location	15 min.
• Remove insulation at cut location	5 min.
• Attach track-mounted torch system	5 min.
• Install contamination control system	5 min.
• Cut pipe	1 min.[(a)]
• Remove track-mounted torch system	5 min.
• Bag ends of piping section	5 min.
• Remove contamination control system	5 min.
• Transfer the piping section to a maritime container	5 min.[(b)]
• Remove scaffolding and move to next location	15 min.
Crew-minutes for making one cut (actual duration)	61 min.

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

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

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

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

• Install scaffolding at cut location	15 min.
• Remove insulation at cut location	10 min.
• Install track-mounted torch system	10 min.
• Attach lifting devices to pipe section	10 min.
• Install contamination control system	10 min.
• Cut pipe	2 min.[(a)]
• Remove track-mounted torch system	5 min.
• Bag ends of piping section	5 min.
• Remove contamination control system	5 min.
• Transfer the piping section to a maritime container	10 min.[(b)]
• Remove scaffolding and move to next location	15 min.
Crew-minutes for making one cut(actual duration)	87 min.

Work Difficulty Adjustments:

Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration	1.3 x actual duration = 113 min.

Non-productive time adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration per cut	1.574 x adjusted duration = 178 min.
Crew-Hours per cut	= 2.97 hrs.
Total Labor Cost per cut	2.96 x $190.13/crew-hr = $562.78
Crew Exposure Hours per cut (adjusted duration)	= 1.88 hrs.
Exposure person-hours per cut @ 5.5 pers-hours/crew-hour	= 10.36 hrs.

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

C.2.5 Removal and Packaging of Contaminated RCS Piping, 32 in. Dia. to 37 in. Dia.

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

• Install scaffolding at cut location	30 min.
• Remove insulation at cut location	20 min.
• Attach lifting devices to piping section	20 min.
• Install track-mounted torch system	20 min.
• Install contamination control system	15 min.
• Cut pipe	20 min.[(a)]
• Remove track-mounted torch system	15 min.
• Bag ends of piping section	10 min.
• Remove contamination control system	10 min.
• Transfer the piping section to a maritime container	30 min.[(b)]
• Remove scaffolding and move to next location	30 min.
Crew-minutes for making one cut (actual duration)	190 min.

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

(a) Nominal time for cutting rate of 8 in./min.
(b) This activity is in parallel with scaffold removal/next installation.

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

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

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

The number of major cuts per tank is given by:

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

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

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

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

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

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

A = [L/(cutting rate in ft/min.)]/N

Work Difficulty Adjustments:

Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration	1.4 x actual duration

Non-productive time adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration

Cumulative crew-hours per tank	1.3 x 1.574 x actual duration
or	1.3 x 1.574 x [90 + N x (30 + A)]/60

Other Calculations:

Total Labor Cost per Tank: (Crew-hours/tank)(Dollars/crew-hour)

One crew-hour = 5.5 person-hours. The cost per crew-hour is defined to be $190.13

Crew Exposure Hours per Tank (adjusted duration) = 1.3 x [90 + N x (30 + A)]/60

Exposure pers-hours per tank @ 5.5 pers-hours/crew-hour = 5.5 x [1.3 x [90 + N x (30 + A)]/60

EXAMPLE CALCULATION: - Pressurizer Relief Tank

Diameter = 10.7 ft, height = 27 ft

N, the number of major cuts is given by:

N = [1 + (27/7.5){rounded to next integer}]
  + [π x 10.7/3.5]{rounded to next integer} + 6 = 1 + 4 + 10 + 6 = 21

L, the total length of cut in sectioning the tank is given by:

L = π x 10.7 x (1 + 4) + 27 x 10 + 6 x 10.7 = 503 ft

A, the average cutting time, is given by:

A = L/N/(cutting rate) = 503 ft / 21 cuts / 4 ft/min. = 6 min./cut

Crew-hours per tank = 1.3 x 1.574 x [90 + N x (30 + A)]/60
  = 2.046 x [90 + 21 x (30 + 6)]/60 = 28.85 crew-hours

Person-hours per tank = 28.85 x 5.5 pers-hours/crew-hour = 158.7 pers-hours

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

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

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

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

Average labor cost, 2-shift operations $136.35[c]

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

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

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

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

Abs. Matl. @ $\$0.32/ft^2 = 3 \times vol^{2/3} \times \$0.32 \times 1.15$

Plastic @ $\$0.04/ft^2 = 3 \times vol^{2/3} \times \$0.04 \times 1.15$

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

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

• Disconnect power/instrument/sensor lines		20 min.
• Unbolt item from its mounting		10 min.
• Rig and move item to packaging area		10 min.
Crew-minutes for removing one item	(actual duration)	40 min.

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

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

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

• Install scaffolding at equipment location		30 min.
• Disconnect power/instrument/sensor lines		30 min.
• Unbolt equipment from its mounting		20 min.
• Rig and move item to packaging area		10 min.
Crew-minutes for removing one item	(actual duration)	90 min.

Work Difficulty Adjustments:		
Height/Access adjustment for scaffold work	10% of actual duration	
Respiratory protection adjustment	20% of actual duration	
Adjusted Work Duration per item	1.3 x actual duration = 117 min.	

Non-productive time adjustments:		
Radiation/ALARA adjustment	8.2% of adjusted duration	
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration	
Work breaks (2 per shift)	9.8% of adjusted duration	
Total Work Duration per item	1.574 x adjusted duration	= 184 min.
Crew-Hours per item		= 3.07 hrs.
Total labor cost per item (3.07 x $136.35/crew-hr)		= $418.95
Crew Exposure Hours per item (adjusted duration)		= 1.95 hrs.
Exposure Pers-hours per item @ 4.0 pers-hours/crew-hour		= 7.80 hrs.

C.2.10 Removal and Packaging of Pressurizer

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

• Install scaffolding around pressurizer	15 min.
• Remove insulation from pressurizer vessel	30 min.
• Cap open piping ports	150 min.
• Attach lifting devices to pressurizer vessel	120 min.
• Lift the pressurizer vessel to the operating deck	120 min.
• Secure the pressurizer vessel to the shipping cradle	30 min.
• Remove scaffolding and move to next location	15 min.
Crew-minutes for removing pressurizer (actual duration)	480 min.

Work Difficulty Adjustments:	
Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration	1.3 x actual duration = 624 min.

Non-productive time adjustments:	
Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Work breaks (2 per shift)	9.8% of adjusted duration
Total Work Duration	1.574 x adjusted duration = 982 min.
Crew-Hours per cut	16.37 hrs.
Total labor cost (16.37 x $190.13/crew-hr)	$3,112.43
Crew Exposure Hours (adjusted duration)	10.4 hrs.
Exposure Person-hours @ 5.5 pers-hours/crew-hour	57.2 hrs.
Radiation Dose Rate (mrem/hr)	4.6
Transport cradle (modified steam generator cradle)	$5,000
Total estimated cost for removal and packaging pressurizer	$8,112

C.2.11 Removal and Packaging of Primary Pumps

Each primary pump is supported on 3 hinged support posts and stabilized horizontally with tie rods and seismic snubbers. Lubrication and seal coolant lines are attached. The attached piping is presumed severed from the pump body previously (accounted for under RCS Piping Removal). The pump ports are sealed with steel plates welded in place, lifting attachments are connected to the pump/motor assembly, the supports and stabilizers are removed, and the unit is lifted to the operating deck and placed in a horizontal shipping cradle. The basic operations are listed below, together with the estimated clock times required to accomplish each operation.

• Install scaffolding at cut location	60 min.
• Remove pump cooling system ducts	30 min.
• Remove insulation from pump body	30 min.
• Disconnect lubrication and seal cooling lines	20 min.
• Disconnect instrument/sensor lines	10 min.
• Cap inlet and outlet pump ports	30 min.
• Attach lifting devices to pump assembly	120 min.
• Disconnect pump supports and stabilizer units	90 min.
• Lift the pump assembly to the operating deck	60 min.
• Secure the pump assembly to the shipping cradle	30 min.
• Remove scaffolding and move to next location	60 min.
Crew-minutes for removing one pump (actual duration)	480 min.

Work Difficulty Adjustments:

Height/Access adjustment for scaffold work	10% of actual duration
Respiratory protection adjustment	20% of actual duration
Adjusted Work Duration per pump	1.3 x actual duration = 624 min.

Non-productive time adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration	
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration	
Work breaks (2 per shift)	9.8% of adjusted duration	
Total Work Duration per pump	1.574 x adjusted duration = 982 min.	
Crew-Hours per pump		= 16.4 hrs.
Total labor cost per pump (16.37 x $190.13/crew-hr)		= $3,112.43
Crew Exposure Hours per pump (adjusted duration)		= 10.4 hrs.
Exposure Person-hours per pump @ 5.5 pers-hours/crew-hour		= 57.2 hrs.

C.2.12 High-Pressure Water Wash/Vacuuming of Surfaces

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

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

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Dose Rate (mrem/crew-hr)
2.0	Laborer	26.37	52.74	2
1.0	Crafts	49.70	49.70	0
0.5	H. P. Tech.	36.82	--[b]	0
0.5	Crew Leader	54.84	27.42	0
4.0			129.86	2

Average labor cost, 2-shift operations $136.35[c]

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

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

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

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

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

Material costs to support system operation include:

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

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

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

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

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

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

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

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

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

Summary

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

C.2.13 Cutting Uncontaminated Concrete Walls and Floors

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

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

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

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)
1.0	Laborer	26.37	26.37
1.0	Crafts	49.70	49.70
0.5	Crew Leader	54.84	27.42
2.5			103.49
	Average labor cost, 2-shift operations		$108.66[b]

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

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

Cutting Concrete Walls

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

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

Work Difficulty Adjustments:

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

Non-productive Time Adjustments:

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

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

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

Cutting Concrete Floors

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

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

Work Difficulty Adjustments:

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

Non-productive Time adjustments:

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

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

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

C.2.14 Removal of Contaminated Concrete Surfaces

Those contaminated horizontal surfaces which are not sufficiently decontaminated using the high-pressure washing system are removed using a commercially available pneumatically operated surface removal system. Commercial systems which use very high-pressure water jets for surface removal are also available. For this analysis, a specific commercial system manufactured by

Pentex, Inc. is assumed (the Moose™ and associated smaller units) which chips off the surface and collects the dust and chips into a waste drum, and filters the air to prevent recontamination of the cleaned surfaces.

It is postulated that the depth of concrete to be removed will vary from location to location, but that on the average, removal of about one inch will be sufficient to remove the residual radioactive contamination. Because the removal system selected removes about 0.125 inch of material per pass, an average of 8 passes will be required over the contaminated areas. Because the Moose™ cannot get closer to walls than about 6 inches, smaller units of the same type (Squirrel III™, and Corner Cutter™) are used to clean the perimeter areas of rooms. For this analysis, it is postulated that the perimeter areas comprise about 20% of the total surface area to be cleaned. For 1-pass removal operations, the Moose™ is assumed to clean at the rate of about 115 ft^2 per hour and the Squirrel™ cleans at the rate of about 30 ft^2 per hour. Combining these rates by weighing with the fractions of surface removed by each unit, the nominal removal rate becomes about 100 ft^2/hr. Assuming an average of 8 passes are required, the effective average cleaning rate becomes 12.5 ft^2/hr.

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

Pers-hrs/crew-hr	Category	Labor Rate($/hr) ($/labor-hr)	Cost[(a)] ($/crew-hr)	Dose Rate (mrem/crew-hr)
3.00	Laborer	26.37	79.11	3
0.25	H. P. Tech.	36.82	--[(b)]	0
0.25	Crew Leader	54.84	13.71	0
3.50			92.82	3

Average for 2-shift operation $97.46[(c)]

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

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

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

or 320 minutes net working time using the cleansing system. Assuming a cleansing rate of 12.5 ft^2/hour, about 67 ft^2 can be cleansed in one shift. Thus, the labor cost per square foot of surface cleansed is given by:

$$(\$97.46/\text{crew-hr}) \ / \ (320/480 \times 12.5) \ \text{ft}^2/\text{hr} = \$11.70/\text{ft}^2$$

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

The duration of the removal effort would be about 32 weeks, based on 21,600 ft^2 to be removed, the 12.5 ft^2/hr removal rate, two shifts per day, and a daily operating time of 5.33 hours per shift. Because of the relatively short time that the equipment is needed, rental would be preferable to purchase. Assuming a 5-yr lifetime, straight-line depreciation, and a 25% utilization factor, the equipment cost of about $148,000 would be amortized at a rate of about $2,300/wk, or about $43.12 per hour of operation.

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

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

$$[\$13/\text{hr. (bits)} + \$2.50/\text{hr. (filters)} + \$43.12/\text{hr. (system)} + \$8.76/\text{hr. (compressor)}]/12.5 \ \text{ft}^2/\text{hour} + \$0.539/\text{ft}^2 \ \text{(drums)} = \$5.93/\text{ft}^2$$

Thus, the total cost per square foot of horizontal surface removal is estimated as \$11.70 (labor) + \$5.93 (material and rental) = \$17.63/ft^2. The smaller units (Squirrel III™ and Corner Cutter™) could be utilized on vertical surfaces. The cost per square foot of vertical surface removed would be approximately four times the horizontal cost, due to the lower removal rates of the smaller units:

4 x [\$11.70 (labor) + \$5.39 (material)] + \$0.539 (drums) = \$68.90/ft^2

<u>Summary</u>

Unit cost factor (horizontal surfaces) = \$17.63/ft^2
Unit cost factor (vertical/overhead) = \$68.90/ft^2
Waste volume generated (1 in. removed) = 0.083 ft^3/ft^2
Radiation Exposure = 0.24 mrem/ft^2

C.2.15 <u>Removal of Activated/Contaminated Concrete by Controlled Blasting</u>

The activated portion of the reactor biological is removed from the containment building by controlled drilling and blasting. The volume of concrete to be removed (6335 ft^3) is a hollow cylinder with an inner radius of 10 feet, an outer radius of 14 feet, and a height of about 21 feet, based on a calculated residual radioactivity on the remaining portion of the shield of 10 mrem/yr, as given in Section 3.4.6. In this analysis, the shield will be removed in 4 layers. Each layer consists of 4 concentric rings 1 foot thick and about 5 feet high. After one set of rings has been removed, the next set in the layer beneath is removed, and so on, until all 4 sets have been removed. Because the rings are large, only half a ring will be removed at a time.

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

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

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

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)
2.0	Laborer	26.37	52.74
2.0	Crafts	49.70	99.40
0.5	H. P. Tech.	36.82	--[b]
1.0	Crew Leader	54.84	54.84
1.0	Engineer	59.09	59.09
6.5			266.07

Average lab or cost, 2-shift operations $279.37[c]

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

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

Net Time = STO + NL x [ST + (8 x MT) + TPH x NH + RCT* + DRL*] + CT,

where,

STO = equipment set-up time for the job as a whole: the time required to set up scaffolding, fog spray systems, and erect barriers to contain dust and debris in work areas and pit = 120 minutes

NL = number of layers = 4

ST = set-up time, the time required to set up all the equipment for each layer = 60 minutes/layer

MT = time to perform tasks required for each half-ring, namely
- install blasting mats and start fog spray = 30 minutes
- evacuate area and detonate charges = 15 minutes
- remove blasting mats and stop fog spray = 30 minutes

NH = number of holes in one layer = 145 (calculated below)

TPC = time per cut, the time required to cut through a piece of re-bar = 2 minutes

TPH = time required for preparing each hole, namely,
- drill hole 5 feet deep = 10 minutes
- place charge in hole = 5 minutes
- verify charge has detonated = 1 minute

DR = debris removal = 120 minutes: removal of four boxes of rubble from one half-ring and replacing them with empty ones. Done in parallel with drilling holes in one half-ring and cutting rebar in the previous half-ring

NC = number of cuts of #18 re-bar in one layer = 145 (calculated below)

*RCT = re-bar cutting time per layer: TPC x NC = 290 minutes, done in parallel with drilling holes and debris removal. Not time limiting.

*DRL = debris removal per layer: 8 x DR = 8 x 120 = 960 minutes, done in parallel with drilling holes and rebar cutting. Not time limiting.

and

CT = clean-up time, the time required to sample area for radioactivity and remove equipment and any remaining debris = 240 minutes.

The number of holes in the 4 rings, NHR1, NHR2, NHR3, and NHR4, assuming 2-foot centers, are

$$NHR1 = 2 \times \pi \times R1/2 = \pi \times 10 = 31.42 = 31$$
$$NHR2 = 2 \times \pi \times R2/2 = \pi \times 11 = 34.56 = 35$$
$$NHR3 = 2 \times \pi \times R3/2 = \pi \times 12 = 37.70 = 38$$
$$NHR4 = 2 \times \pi \times R4/2 = \pi \times 13 = 40.84 = 41$$

Thus NH = 31 + 35 + 38 + 41 = 145.

Re-bar is assumed to be spaced uniformly throughout, on 1 foot centers. The number of cuts for the 4 rings, NCR1, NCR2, NCR3, NCR4, are:

$$NCR1 = 2 \times \pi \times R1 = \pi \times 20 = 62.83 = 63$$

$$NCR2 = 2 \times \pi \times R2 = \pi \times 22 = 69.12 = 69$$

$$NCR3 = 2 \times \pi \times R3 = \pi \times 24 = 75.40 = 75$$

$$NCR4 = 2 \times \pi \times R4 = \pi \times 26 = 81.68 = 82$$

Thus, NC = 63 + 69 + 75 + 82 = 289.

Using the values above gives

Net Time = 12280 minutes = 204.67 hours.

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

Work Duration = 1.3 x 1.574 x (Net Time) = 418.73 hrs.

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

Work Duration = 418.73/16 = 26.2 work days = 7/5 x 26.2 = 36.6 calendar days

Material costs are:

Air compressor (750 CFM)	$2575/month/(30 days/month) x 36.6 days	= $3,141.50
Drill Bits	$165.60/bit/(10 holes/bit) x 145 holes x 4 layers	= $9,604.80
Fog Spray System	4 nozzles @ $139.09	= $556.36
Blasting Mats	5 x $22/day x 36.6 days	= $4,026.00
Gas torch consumables	$6.75/hr x (2/60) hrs/cut x 289 cuts x 4 layers	= $260.10
Explosives	$1.33/lb x 2 lbs/hole x 145 holes x 4 layers	= $1,542.80
Blasting Caps	$1.79/hole x 145 holes x 4 layers	= $1,038.20
Total materials cost		= $20,169.76
Total, including 15% DOC overhead		= $23,193.22

Total Labor costs = $279.37/hr x 418.73 hrs	= $116,981
Total material costs	= $ 23,195
Total cost for removal of shield	= $140,176
Total removal costs per ft^3 = $140,176/6300 ft^3	= $ 22

Radiation exposures times are assumed to be:

Engineer (setting charges) = 6 minutes/hole x 145 holes x (work difficulty adjustment) x 4 layers
= 6 x 145 x 1.3 x 4 layers = 4524 minutes = 75.40 hours

Laborers and crafts (100%) = 1.3 x 12280 = 15964 minutes = 266.07 hours

Crew Leader and H. P. Technician (assume exposure comparable with engineer) = 75.40 hours

Assuming a radiation field of 20 mrem/hour, the total radiation exposure at shutdown is
Total radiation exposure = (75.40 x 1 + 266.07 x 4 + 75.40 x 1.5) x 20/1000 = 25 pers-rem

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

- Removal: $140,200
- Container: $86,900
- Transport: $44,900
- Disposal: $699,000

C.2.16 Removal and Packaging of Contaminated Metal Surfaces

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

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

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

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

$$N = Nhoriz + Nvert,$$

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

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

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

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

The average time for each major cut is

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

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

EXAMPLE CALCULATION: - Sectioning a steel surface 40 feet high by 80 feet wide.
H = 40, W = 80.
The number of horizontal cuts, Nhoriz, is given by
Nhoriz = TRUNC(40/7.5) = 5,
and the number of vertical cuts, Nvert, is
Nvert = TRUNC(80/18) = 4.
Thus, the total number of cuts is given by
N = Nhoriz + Nvert = 9.

N = Nhoriz + Nvert = 9.

Putting this together gives for the average length of time per cut:

A = (Nhoriz x W + Nvert x H)/N/Rate = (5 x 80 + 4 x 40)/9/4 = 15.6 minutes/major cut.

Total crew hours = 1.3 x 1.574 x [60 + N(30 + A)]/60

= 1.3 x 1.574 x [60 + 9(30 + 15.6)]/60 = 16.0 hours.

The factors 1.3 and 1.574 are the work difficulty and non-productive time adjustments, developed in Section C.2.6.

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

All contaminated ducts are assumed to be galvanized steel, 20 to 16 gauge. The ducts are assumed to be separated into about 8-ft sections. The time bases are drawn from R.S. Means 1992 for duct removal. The average rate of removal in linear feet per 8-hour day for the inventory of ductwork in the reference PWR is calculated to be about 62 linear feet, by interpolation of the Means data. Thus, the average time per section of duct removed is about 60 minutes, including scaffolding. Subtracting 4 minutes per hour for work breaks leaves 56 minutes of direct labor per 8-ft section. The time duration factors that need to be considered are respiratory protection, protective clothing changes, work breaks and ALARA. The postulated crew size, cost, and associated radiation dose are given below.

Pers-hrs/crew-hr	Category	Labor Rate ($/pers-hr)	Cost[a] ($/crew-hr)	Dose Rate (mrem/crew-hr)
2.0	Laborer	26.37	52.74	2
0.5	H. P. Tech.	36.82	--[b]	0
0.5	Crew Leader	54.84	27.42	0
3.0			80.16	2

Average labor cost, 2-shift operations $84.17[c]

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

The removal operations and associated time durations are listed below.

- Install scaffolding at cut location --
- Remove duct section 56 min.
- Bag ends of duct section 5 min.

•	Flatten section	5 min.
•	Transfer the flattened section to a maritime container	5 min.
•	Remove scaffolding and move to next location	--

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

Work Difficulty Adjustments:

Respiratory protection adjustment 20% of actual duration

Adjusted Work Duration 1.2 x actual duration = 85 min.

Non-productive time adjustments:

Radiation/ALARA adjustment	8.2% of adjusted duration
Suit-up/un-suit in anti-contamination clothing	39.4% of adjusted duration
Break time	9.8% of adjusted duration
Total Work Duration per section	1.574 x adjusted duration = 134 min.

Crew-Hours per 8 ft section 2.23

Total Labor Cost per section 2.22 x $84.17/crew-hr = $187.70

Operations: 2 crews per shift, 2 shifts per day

Crew Exposure Hours per section (Adjusted Duration)	= 1.50 hrs.
Radiation Dose per section	= 3.0 mrem
Radiation Dose per ft removed	= 0.38 mrem

C.2.18 Removal of Steel Floor Grating

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

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

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

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

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

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

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

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

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

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

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

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

It is estimated that about 3.31 maritime containers at $4,965/each will be required, resulting in a total container cost of $16,500. The unit cost for packaging is: $16,500 / 11,265 ft^2 = $1.46/$ft^2$

Thus, the total removal cost per ft^2 is estimated to be:
$3.08 (labor) + $0.14 (torch gases) + $1.46 (maritime containers) = $4.68/$ft^2$

<u>Summary</u>

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

C.2.19 <u>Decontamination of Handrails</u>

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

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

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

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

The decontamination operations and associated time durations are listed below.

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

Crew-minutes for decontamination of 1 LF (actual duration) = 3.0 min.

Work Difficulty Adjustments: None required.

Adjusted Work Duration: 1.0 x actual duration = 3.0 min.

Non-productive time adjustments:

Radiation/ALARA adjustment — 3.1% of adjusted duration

Suit-up/un-suit in anti-contamination clothing — 37.5% of adjusted duration

Work breaks (2 per shift) — 9.4% of adjusted duration

Total Work Duration per LF 1.500 x adjusted duration = 4.50 min.

Crew-Hours per LF 0.075 hrs.

Total Labor Cost per 1 LF 0.05 x $84.17/crew-hr = $6.31

(a) Assumed to be washed twice, rinsed once, and dried.
(b) The move is made in parallel with the survey.

Crew Exposure Hours per 1 LF (adjusted duration) = 0.033 hrs.
Exposure Pers-hours per 1 LF @ 2.0 pers-hours/crew-hour = 0.10 hrs.
Radiation Dose-rate (mrem/hr) = 1.0

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

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

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

Costs of materials used in the decontamination operations:

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

Principal material costs are: 1) industrial wipes (at an estimated usage rate of 10 wipes/6-ft section) for an equivalent cost of about $0.09/LF and 2) cleansing solution (about 26 gallons) for an equivalent cost of about $0.03/LF. In addition, it is estimated that eight hand-held dispensers are needed, for an equivalent cost of about $0.01/LF. Ten used wipes are estimated to occupy about 0.0324 ft^3, or a total space of about 60.62 ft^3. The estimated total space required, including space for the 26 gallon containers (about 3.5 ft^3), is about 64.12 ft^3. About nine 55-gallon drums are needed for this waste, resulting in an estimated equivalent cost of about $0.02/LF. Thus, the total cleansing cost per lineal foot is estimated to be:

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

Summary

Unit cost factor = $6.46/LF
Waste volume generated = 0.0054 ft^3/LF
Radiation exposure = 0.067 mrem/LF

C.2.20 Removal of Contaminated Floor Drains

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

Based upon information provided by the Trojan staff, it is estimated that there are approximately 210 drains that could be radioactively contaminated. The volume of a "typical" drain is conservatively estimated to be about 2.80 ft^3, using a rough approximation to calculate the space occupied by the "plug" that is postulated to be removed by a core drill. Each plug is estimated to weigh about 550 pounds, based on a 16-in-diameter concrete plug (containing the drain) being cut from a nominal 2-ft-thick reinforced concrete floor.

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

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

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

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

• Above Drain: drill anchor hole for drill stand, set anchor, and bolt drill stand to floor; cover drain with plastic; water & vacuum clean in place	10 min.[a]
• Below Drain: install scaffolding; drill bolt holes and affix steel strapping; rig plastic trough/bucket	35 min.
• Core drill the drain plug	206 min.[b]
• Collect and dispose of waste water	30 min.[c]
• Rig, lift, move, and place plug in disposal container	30 min.
• Secure prefabricated cover over hole	5 min.
• Remove scaffolding and equipment and move to next location	15 min.
Crew minutes for removing one drain (actual duration)	291 min.

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

Work Difficulty Adjustments:

Height/Access adjustment	7% of actual duration
Adjusted Work Duration	1.07 x actual duration = 311 min.

The total crew-minutes per drain removal activity =

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

Radiation Exposure time =

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

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

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

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

Crew-Hours per drain	= 8.0 hrs
Total Labor Cost per drain (8.0 x $108.66/crew-hr)	= $869.28
Crew Exposure Hours per drain (adjusted duration)	= 5.2 hrs.
Exposure Pers-hours per drain @ 2.0 pers-hours/crew-hour	= 10.4 hrs.
Radiation Dose-rate (mrem/hr)	= 0.5

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

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

- diamond-core bit replacements at \$4.60/inch depth

  \$4.60/inch depth x 24-in. thick floor = \$110.40/drain

- absorbent materials and plastic are estimated at \$5.80/drain

- equipment rentals

  (4 power units at \$1,035/wk + 4 drain plug pullers at \$138/wk) / 5 days/wk = \$938.40/day

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

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

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

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

Summary[a]

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

C.3 TRANSPORTATION COSTS

The CECP data base contains distances from all commercial reactor sites to the postulated geologic repository at Yucca Mountain and to the low-level disposal sites at Hanford and Barnwell. The distances provided are suggested distances only and may be changed as desired by the user. If the user does not find the desired site in the site listing, he or she may add his or her own site name and distances. In addition to site name and distances, the user

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

specifies the name of the desired low level waste disposal site. This site information, along with the plant inventory and reactor pressure vessel characteristics, enables the CECP to calculate transportation costs.

To calculate transportation costs, the CECP employs a different cost formula for each cask (CNS 8-120B, NuPac 14-210H, NAC-LWT, and TN-8) that will be used in decommissioning. These formulas, based on data supplied in Reference 1, are given below.

Round-Trip CNS 8-120B Cost for the Hanford Burial Site = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x w/w0 x d/d0 + OW1 + P)
+ (n - 1) x (R4 x d/d0 + OW2)

where

R1 = cost of transporting empty cask from cask supplier (Barnwell) to reactor site = $11855.99,
d1 = distance in miles between reactor site and the cask supplier,
d10 = reference distance between reactor site and the cask supplier = 2799 miles,
R2 = cost of transporting empty cask from the burial site (Hanford) back to supplier = $10122.75,
d2 = distance in miles between burial site and supplier,
d20 = reference distance between burial site and supplier = 2674 miles,
n = number of casks to be shipped to the burial site,
R3 = cost of transporting fully loaded cask from site to burial site = $2456.80,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask = 74000 pounds,
d = distance between reactor site and burial site, in miles,
d0 = reference distance between reactor site and burial site = 297 miles,
R4 = cost of transporting empty cask from burial site back to reactor site = $1216.06,
OW1 = overweight charges = $219.05,
OW2 = overweight charges = $69.37, and
P = permit cost = $120.00.

Round-Trip CNS 8-120B Cost for the Barnwell Burial Site = n x (R1 x d/d0)
+ n x (R2 x d/d0 x w/w0 + OW + P)

where

R1 = cost of transporting empty cask from Barnwell to reactor site = $11855.99,
d = distance in miles between Barnwell and reactor site,
d0 = reference distance between Barnwell and reactor site = 2799 miles,
R2 = cost of transporting fully loaded cask from reactor site to Barnwell = $14185.80,

n = number of casks to be shipped to the burial site,

w = weight of loaded cask, in pounds,

w0 = weight of fully loaded cask = 74000 pounds,

OW = overweight and other charges = $1531.67, and

P = permit cost = $125.00.

Round-Trip 14-210H Cost for the Hanford Burial Site = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x d/d0 + OW + P)
+ (n - 1) x (R4 x d/d0)
+ n x R5 x d1/d10

where

R1 = cost of transporting empty cask from cask supplier (Barnwell) to reactor site = $5150.16,

d1 = distance in miles between reactor site and the cask supplier,

d10 = reference distance between reactor site and the cask supplier = 2799 miles,

R2 = cost of transporting empty cask from the burial site (Hanford) back to supplier = $4412.10,

d2 = distance in miles between burial site and supplier,

d20 = reference distance between burial site and supplier = 2674 miles,

n = number of casks to be shipped to the burial site,

R3 = cost of transporting fully loaded cask from site to burial site = $964.65,

d = distance between reactor site and burial site, in miles,

d0 = reference distance between reactor site and burial site = 297 miles,

R4 = cost of transporting empty cask from burial site back to reactor site = $914.76,

OW = overweight charges = $242.70,

P = permit cost = $120.00, and

R5 = cost of transporting HIC from supplier to the reactor site = $4210.50.

Round-Trip 14-210H Cost for the Barnwell Burial Site = n x (R1 x d/d0)
+ n x (R2 x d/d0 + OW + P)
+ n x (R3 x d/d0)

where

R1 = cost of transporting empty cask from Barnwell to reactor site = $5150.16,

d = distance in miles between Barnwell and reactor site,

d0 = reference distance between Barnwell and reactor site = 2799 miles,

R2 = cost of transporting fully loaded cask from reactor site to Barnwell = $5235.45,

n = number of casks to be shipped to the burial site,

OW = overweight and other charges = $1849.91,

P = permit cost = $125.00, and

R3 = cost of transporting HIC from supplier to the reactor site = $4210.50.

Round-Trip NAC-LWT Cost to the Geologic Repository = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x w/w0 x d/d0 + OW + P)
+ (n - 1) x (R4 x d/d0 + OW)

where

R1 = cost of transporting empty cask from cask supplier to reactor site = $9264.56,
d1 = distance in miles between reactor site and the cask supplier,
d10 = reference distance between reactor site and the cask supplier = 2799 miles,
R2 = cost of transporting empty cask from the repository back to supplier = $6279.36,
d2 = distance in miles between repository and supplier,
d20 = reference distance between repository and supplier = 2674 miles,
n = number of casks to be shipped to the repository,
R3 = cost of transporting fully loaded cask from site to repository = $3102.24,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask = 55200 pounds,
d = distance between reactor site and repository, in miles,
d0 = reference distance between reactor site and repository = 907 miles,
R4 = cost of transporting empty cask from repository back to reactor site = $2406.40,
OW = overweight charges = $268.00, and
P = permit cost = $120.00.

Round-Trip TN-8 Cost to the Geologic Repository = R1 x d1/d10
+ R2 x d2/d20
+ n x (R3 x w/w0 x d/d0 + OW + P)
+ (n - 1) x (R4 x d/d0 + OW + P)

where

R1 = cost of transporting empty cask from cask supplier to reactor site = $18790.61,
d1 = distance in miles between reactor site and the cask supplier,
d10 = reference distance between reactor site and the cask supplier = 2799 miles,
R2 = cost of transporting empty cask from the repository back to supplier = $13551.44,
d2 = distance in miles between repository and supplier,
d20 = reference distance between repository and supplier = 2674 miles,
n = number of casks to be shipped to the repository,
R3 = cost of transporting fully loaded cask from site to repository = $5286.12,
w = weight of loaded cask, in pounds,
w0 = weight of fully loaded cask = 84040 pounds,
d = distance between reactor site and repository, in miles,
d0 = reference distance between reactor site and repository = 907 miles,
R4 = cost of transporting empty cask from repository back to reactor site = $4165.95,
OW = overweight charges = $365.00, and
P = permit cost = $120.00.

For non-cask truck shipments, the calculations are much simpler. For cargo consisting of 55-gallon drums, 96-ft^3 metal boxes, or maritime containers, the round-trip truck transportation charges are

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

where

R = the round-trip distance rate = $1211.82,

D = distance in miles between site and Hanford,

DO = the reference distance, from Rainier, Oregon, to Hanford, Washington = 297 miles,

PC = permit cost = $120,

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

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

where

R = the round-trip distance rate = $4226.49,

D = distance in miles between site and Barnwell,

DO = the reference distance, from Rainier, Oregon, to Barnwell, SC = 2799 miles,

PC = permit cost = $95,

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

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

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

where

R = cost of transporting rack to Hanford = $966.54,

d = distance from reactor site to Hanford, in miles,

d0 = reference distance between reactor site and Hanford = 297,

P = permit cost = $95.00,

DF = drop frame charge = $100.00,

OW = over-width charge = $100.00,

OD = over-dimension charge = $65.00, and

T = tarpaulin charge = $35.00.

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

where

R = cost of transporting rack to Barnewell = $5712.36,

d = distance from reactor site to Barnwell, in miles,

d0 = reference distance between reactor site and Barnwell = 2799,

P = permit cost = $125.00,

DF = drop frame charge = $100.00,

OW = over-width charge = $582.00,

OD = over-dimension charge = $543.00, and

T = tarpaulin charge = $35.00.

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

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

where

R = cost of transporting crane to Hanford = $1100,

d = distance from reactor site to Hanford, in miles,

d0 = reference distance between reactor site and Hanford = 297 miles,

w = weight of loaded truck, in pounds,

w0 = weight of fully loaded truck = 40,000 pounds

P = permit cost = $95.00,

T = twist lock trailer cost = $120.00, and

OW = overweight charge = $69, if load exceeds 40,000 pounds; no charge, otherwise.

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

where

R = cost of transporting crane to Barnwell = $5984,

d = distance from reactor site to Barnwell, in miles,

d0 = reference distance between reactor site and Barnwell = 2799 miles,

w = weight of loaded truck, in pounds,

w0 = weight of fully loaded truck = 40,000 pounds

P = permit cost = $95.00, and

OW = overweight charge = $543, if load exceeds 40,000 pounds; no charge, otherwise.

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

C.4 REFERENCES

1. Tri-State Motor Transit Company, published tariffs, Interstate Commerce Commission (ICC), Docket No. MC-109397 and Supplements, 1991.

APPENDIX D

EFFECTS OF THE SPENT NUCLEAR FUEL INVENTORY ON DECOMMISSIONING ALTERNATIVES

APPENDIX D

EFFECTS OF THE SPENT NUCLEAR FUEL INVENTORY ON DECOMMISSIONING ALTERNATIVES

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

The analyses presented in this appendix reflect the expected situation at the reference pressurized water reactor (PWR), the Trojan plant near Rainier, Oregon, if the plant operated until expiration of its operating license, and therefore are representative of other large PWRs that do operate until their licenses expire. These analyses do not necessarily reflect the actual situation at the Trojan reactor, which was prematurely closed late in 1992.

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

Based upon the current regulatory environment and upon the SNF cooling time analyses presented in this appendix, the minimum period for spent fuel pool operation and plant safe storage prior to dismantlement at the reference PWR is estimated to be 7 years, provided that the owner constructs and licenses an onsite ISFSI under Part 72. Without an onsite ISFSI, the minimum period for pool operation and plant safe storage prior to decommissioning is estimated to be 14 years. This 14-year estimate presumes the utility maintains its fuel pool under a Part 50 possession-only license after shutdown, together with reliance on the DOE's acceptance of the SNF under the 10 CFR Part 961 contractual agreement to empty the fuel pool.

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

- regulatory considerations governing SNF disposal
- postulated allocation of the waste management system's annual acceptance capacity for the reference PWR
- background information related to post-shutdown storage of SNF
- generic considerations related to post-shutdown storage of SNF, including the range of storage/disposition alternatives and a methodology for evaluating the present value of the total storage system life-cycle costs for two basic options of SNF storage
- required SNF cooling time following discharge before dry storage
- rationale for the spent fuel storage option postulated for the reference PWR.

D.1 REGULATORY CONSIDERATIONS GOVERNING SNF DISPOSAL

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

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

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

(a) As delineated in Title 10 CFR Part 961, Appendix E.[4] SNF is broadly classified into three categories - standard fuel, nonstandard fuel, and failed fuel. Most, if not all, SNF from the reference PWR is assumed to fall into the standard fuel category. One of the General Specifications for standard fuel is a minimum cooling time of five (5) years.

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

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

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

With regard to DOE's beginning operations in 1998, DOE's intention, consistent with the NWPA and the Contract, is to initiate acceptance of spent fuel from Purchasers as soon as a DOE facility commences operations. DOE anticipates that waste acceptance at a Monitored Retrievable Storage (MRS) facility could begin in 1998 if the initiatives detailed in the November 1989 "Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program"(6) are fully implemented. Until waste acceptance begins, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel.

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

Under the terms of the Standard Disposal Contract (Article IV), the DOE issues an Annual Capacity Report (ACR)(5) wherein DOE's annual SNF/HLW receiving capacity is projected and the annual acceptance ranking allocations to the Purchasers are presented for 10 years following the projected commencement of DOE facility operations. As specified in the Contract, the ACR is for planning purposes only and thus is not contractually binding on either DOE or the Purchasers. The Standard Disposal Contract states that beginning April 1991, DOE shall issue the first annual Acceptance Priority Ranking for receipt of SNF/HLW. The Contract further specifies that, beginning in January 1992, and based on the Acceptance Priority Ranking, the Purchasers shall submit Delivery Commitment Schedules (DCSs) to DOE identifying the SNF/HLW that the Purchasers propose to deliver to the Federal Waste Management System (FWMS). The Contract provides that the approved DCSs will become the bases for Final Delivery Schedules, which are to be submitted by the Purchasers not less than 12 months before the designated year of DOE's anticipated acceptance of title to the SNF/HLW and subsequent transport to a DOE facility.

D.1.2 Waste Acceptance Projections

The waste acceptance projections used in the ACR are representative of a FWMS configuration authorized by the Nuclear Waste Policy Amendments Act of 1987 (Amendments Act),(7) which includes an MRS facility. Article II of the Standard Contract specifies that "The services to be provided by DOE under this contract shall begin, after the commencement of facility operations, not later than January 31, 1998...." DOE recognizes that, under current conditions, waste acceptance at a DOE facility can begin in 1998 only if the Federal Government is able to consummate a timely agreement, which is enacted into Federal law, with a host State or Indian Tribe for the siting of an MRS facility. The Nuclear Waste Negotiator, which is a representative of the Federal Government appointed by the President, is actively seeking a State or Indian Tribe willing to host an MRS facility or a geological repository.[5]

DOE's projected acceptance rates for the first 10 years of FWMS operation, extracted from the ACR,[5] are given in Table D.1. These rates do not reflect the MRS facility schedule linkages with the repository development that were imposed by the Amendments Act, but are consistent with the 10,000-MTU storage capacity limit contained in the Amendments Act for an MRS facility before a repository starts operation. These acceptance rates assume commencement of facility operations in 1998. If the current linkages between MRS facility construction and repository construction authorization are maintained, it is estimated that commencement of MRS facility operations could not start until at least 2007.[5]

TABLE D.1. Projected Waste Acceptance Rates for Spent Nuclear Fuel

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

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

Operation of the FWMS with the waste acceptance rates presented in Table D.1 would result in the receipt of 8,200 MTU of SNF at the MRS facility during the first 10 years of operations. This table provides only the current estimate of the system throughput rates and is subject to change depending on the system design and configuration and Congressional action regarding the conditions for the siting of an MRS facility. DOE will further define and specify the system operating and waste acceptance parameters as the program progresses and inform the Purchasers accordingly at the earliest feasible time. Under current conditions, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel until acceptance by DOE.[5]

D.2 POSTULATED ALLOCATION OF THE WASTE MANAGEMENT SYSTEM'S ANNUAL ACCEPTANCE CAPACITY FOR THE REFERENCE PWR

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

The quantities of SNF from the reference PWR eligible for acceptance in each of the first 10 years of projected FWMS operation are presented in Table D.2, together with projections done for this study of the additional transfers of SNF necessary to deplete the SNF inventory at the reference PWR. The data shown in the table are based upon the projected acceptance rates, shown previously in Table D.1, but continue until approximately 10,000 MTU (the legal limit) are stored at the MRS in 2010, at which time the repository is scheduled to begin operation. Beyond 2010, the FWMS is projected to operate at an annual receipt rate of 3,000 MTU. The final shipments of SNF from the reference PWR are projected to occur in the year 2029.

TABLE D.2. Postulated SNF Disposition Schedule for the Reference PWR[a]

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

(a) Based on Reference 5 and on the postulated acceptance projections done for this study (see text for details). Does not represent the actual situation at the prematurely shutdown Trojan reactor, but is reasonably representative of large PWRs that operate for their licensed lifetime.
(b) CY 2015 is the EIA projected year of final shutdown for the reference PWR (see text for details).
(c) CY 2029 is the year in which the reference PWR's SNF inventory is reduced to zero on the OFF allocation basis.

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

It should be noted that Trojan's current operating license expires in CY-2011, based upon a 40-year license period, beginning with the start of construction. The NRC now permits the operating license periods of commercial nuclear reactor power stations to begin at the start of commercial operation of those reactors. The Energy Information Administration's (EIA) projected year of final shutdown for the Trojan plant is CY-2015 (the date shown in Table D.2).[8] This license end-date used by the EIA assumes that the 40-year licensing period began at the start of commercial operation of the Trojan plant, not at the start of construction. The EIA's shutdown date of CY-2015 is used throughout this study for the purpose of developing decommissioning schedules.

D.3 BACKGROUND INFORMATION RELATED TO POST-SHUTDOWN STORAGE OF SPENT NUCLEAR FUEL

The DOE's Office of Civilian Radioactive Waste Management (OCRWM) submitted the "Final Version Dry Cask Storage Study" to NRC in January 1989 for final review. Information copies of the document were also provided to Congress. After receiving final NRC comments on the study, OCRWM formally submitted the "Final Version Dry Cask Storage Study,"[6] to Congress in March 1989 accompanied by NRC's comments. The Study presents two major conclusions: 1) existing technologies are technically feasible, safe and environmentally acceptable options for storing spent fuel at civilian reactor sites until such time as a federal facility is available to accept the spent fuel, and 2) OCRWM is not authorized to provide direct financial support for at-reactor storage. The latter conclusion is based on the NWPA, which established the Nuclear Waste Fund. As stated in Section 111(a)(5), "the generators and owners of high-level radioactive waste and spent nuclear fuel have the primary responsibility to provide for, and the responsibility to pay the costs of, the interim storage of such waste and spent fuel until such waste and spent fuel is accepted by the Secretary of Energy in accordance with the provisions of this

Act." Thus, it is the DOE's position that the utilities are responsible for storing spent fuel at reactor sites until an operating federal facility is available to accept the fuel.[10]

In a generic environmental impact statement on spent fuel storage,[11] the NRC expressed confidence that the regulations now in place will ensure adequate protection of the public health and safety and the environment during the period when the SNF is in storage. The reactor operating license may be amended at the end of the plant operating life. Thus, spent fuel may be stored in the reactor pool under an amended reactor operating license pursuant to 10 CFR Part 50.[1] The reactor license, however, cannot be terminated until the reactor is decommissioned. To fully decommission the reactor, all spent fuel must be removed from the fuel pool.

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

Several storage system designs are presently licensed or about to be licensed for storage of SNF in the U.S. These include water pools for wet storage, and metal casks, concrete casks, horizontal concrete modules, and air-cooled vaults for dry storage. Transportable metal storage casks, for at-reactor dry storage, are not currently certified in the U.S. To use metal casks designed for dual-purpose service, a utility would have to obtain an NRC license for storage under 10 CFR Part 72[2] and specify a cask certified for storage by the NRC and for transportation in accordance with regulations in

10 CFR Part 71.[12] In addition, the licensing and certification of these casks would have to address concerns about using the casks for transportation after extended use for storage. Concrete casks and horizontal storage modules cannot be transported intact. However, the metal canisters containing the fuel may be able to fit inside a transportable cask. Nonetheless, some form of storage unit-to-transport cask transfer capability would be required on the reference site, to provide for recovery from a cask seal failure or some abnormal condition occurring with the storage units.

On the other hand, the safety of storage in spent fuel pools has been widely demonstrated. In the review of its Waste Confidence Decision,[13] the NRC concluded that spent fuel can be stored safely and without significant environmental impacts for at least 30 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor at its spent fuel storage basin or at either an onsite or an offsite ISFSI. This finding was supported by the NRC's experience in conducting more than 80 individual safety evaluations of spent fuel storage. In particular, the NRC noted that the cladding of the spent fuel is highly resistant to failure under the conditions of pool storage, and the NRC cited up to 18 years of continuous-storage experience for Zircaloy-clad fuel.

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

D.4 GENERIC CONSIDERATIONS RELATED TO POST-SHUTDOWN STORAGE OF SNF

An important consideration when selecting the decommissioning mode to employ on a retired power reactor facility is what to do with the SNF stored onsite. The range of storage/disposition alternatives of SNF is discussed in

Section D.4.1. A methodology for evaluating the present value of the total storage system life-cycle costs is presented in Section D.4.2, together with an evaluation for two basic alternatives for SNF storage.

D.4.1 Storage/Disposition Alternatives for SNF

The following discussion on the disposition alternatives for SNF is based on information extracted from a study on such alternatives for Rancho Seco Nuclear Generating Station[14] and other sources. Based on those sources, an overview of post-shutdown spent fuel storage alternatives is presented in Figure D.1. The disposition alternatives for SNF shown in the figure appear to illustrate the range of alternatives currently available upon final shutdown. It can be seen from the figure that two major groups of alternatives are available, onsite and offsite storage.

The onsite storage alternatives can be subdivided into wet and dry storage. Wet storage could be accomplished by utilizing the existing spent fuel pool (SFP) or by transferring the SNF to a wet ISFSI. Both alternatives are included as possibilities in Figure D.1. It should be noted that a bypass is provided around the improvements associated with modifying the existing pool (i.e., a reduction in support systems necessary to maintain SNF in wet storage) in the event the time of storage in the SFP can be limited, thereby reducing the incentive for incurring the costs of the changes.

In the case of dry storage, five alternatives are shown in Figure D.1: metal storage casks, concrete casks, vault storage, horizontal storage modules, and transportable or dual-purpose casks. These five methods of dry storage have been studied previously and officially evaluated by DOE.[9] Depending upon the type of dry storage selected, a transfer to a shipping cask may be necessary before transport to the DOE repository. That mode of transfer can be wet or dry as illustrated in Figure D.1. However, it should be recognized that the NRC may require the licensee to maintain fuel transfer capability in case of emergencies as long as fuel is onsite.[a] Under the

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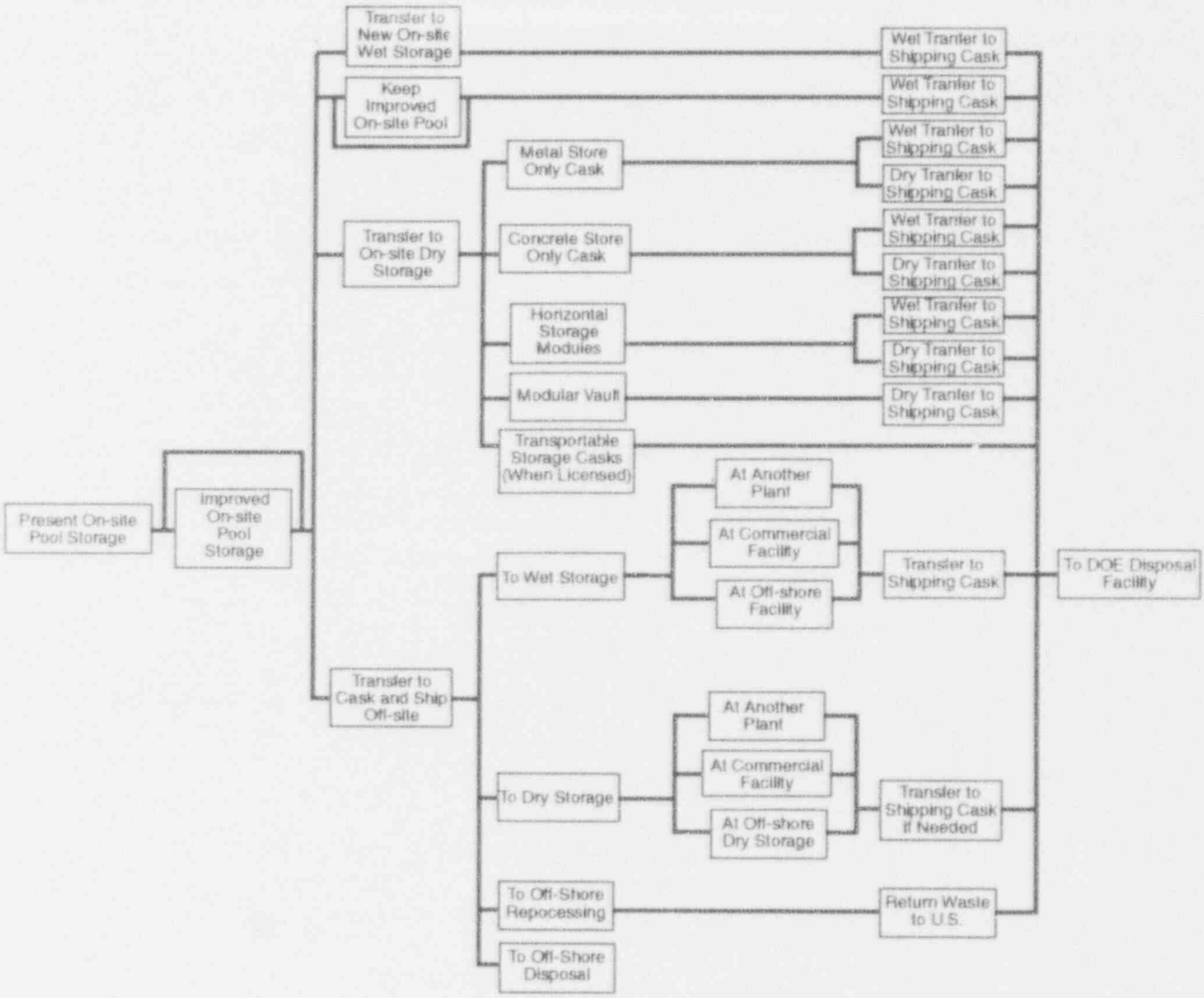
(a) For an at-reactor-site ISFSI that is to become its own separate site, it is necessary, as part of decommissioning design requirements, that the ISFSI be capable of direct spent fuel shipments to the MRS or geologic repository. Currently, the issue of compatibility of dry storage designs with offsite transportation system designs for shipment to an MRS or geologic repository remains un-



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

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FIGURE D.1. Storage/Disposition Alternatives for Spent Nuclear Fuel[(a)]

off-site group of alternatives, wet and dry storage possibilities are included for storing SNF at another plant, a commercial storage facility, and

resolved. Achievement of compatibility in design means that spent fuel in dry storage would not need to be returned to the reactor pool for unloading and the loading into a shipping cask. Vendors are exploring various means to meet NRC policy on this matter. Presently, they include dual-purpose cask design and shipment of sealed canistered spent fuel.[(15)] In addition, dry transfer facilities are also under consideration.

off-shore. The possibilities of foreign reprocessing and disposal are included in Figure D.1, even though no serious opportunity for foreign disposal currently exists. In the case of reprocessing, all wastes arising from that process that are returned to the United States should be in a form acceptable to the DOE for final disposal, as shown in Figure D.1.

In the Rancho Seco study[14] the possibility of carrying out a demonstration program with transportable dry storage casks, and shipping 56 low-burnup Rancho Seco fuel assemblies for reinsertion in another nuclear plant was considered. The demonstration program was selected by Rancho Seco because a dual-purpose cask demonstration program with long-term storage prior to shipment has not yet been carried out. It was concluded in the study that none of the alternatives with economic viability evaluated for their spent fuel storage and disposition were precluded specifically because of lack of an applicable structure of federal safety regulations. However, differences did emerge among the attractiveness of alternatives due to cost of compliance with applicable regulations. The study also concluded that many of the alternative paths for Rancho Seco spent fuel disposition are not viable because of a combination of technical, economic and recipient acceptance barriers. Included in this category are:

- early shipment to storage at another plant, commercial, or government site
- disposal offshore
- offshore storage or reprocessing

The Rancho Seco study[14] showed that offshore storage/reprocessing had the highest cost relative to other options evaluated for Rancho Seco as well as the greatest number of regulatory and non-regulatory impediments.

Other conclusions drawn from the Rancho Seco study[14] are:

- storage in concrete storage-only casks or storage in the modified SFP are the lowest cost options, <u>if</u> Congressional or DOE policies and programs delay initiation of delivery services of the spent fuel well beyond 1998
- the lower the fuel pool security, monitoring and maintenance cost actually achieved, the more attractive is the fuel pool option

- the longer the predicted storage time (after the initial years that the fuel must remain in the pool to remove decay heat), the more economically attractive is dry storage in concrete casks relative to storage in the modified pool

- the crucial problem with all the storage-only options is the uncertainty in predicting delivery time plus the necessity of managing a one- to two-year backend loading-to-shipping-cask campaign, cask disposal, and a cask facility dismantling program in the indefinite future.

Overall, the study concluded that for several reasons the Rancho Seco situation with regard to spent fuel storage and final disposition was unique and that the higher capital cost transportable cask alternative should be pursued. However, it should be recognized that a similar conclusion may be unlikely at other PWR power stations, because of differences in their fuel storage and disposition situations.

D.4.2 Consideration of Two Basic Alternatives for SNF Storage

Because of delays in the implementation of the FWMS, many reactors will have large inventories of SNF, and in some situations may have already been forced to install external dry storage facilities on their sites to contain SNF that exceeded their pool capacities. An additional complication arises because the FWMS will only be able to accept SNF at a finite rate, and, under the terms of the contract between DOE and the U.S. nuclear utilities, allocation of acceptance rights to the utilities is to be based on an OFF basis, and the SNF must be cooled in the reactor pool for at least five years before acceptance. Because of the large backlog of SNF in the utilities' pools, periods ranging from 5 to 26 years after reactor shutdown will pass before an individual reactor's pool could be emptied and the pool decommissioned (see Table D.3).

Faced with the need to store the SNF for an extended period of time, a utility has to evaluate its storage options to determine which decommissioning mode best suits its particular situation. If, for example, the utility had strong reasons for pursuing DECON, it would be necessary to transfer the SNF from the pool to an onsite dry ISFSI as soon after shutdown as possible, to make it possible to proceed with decontamination and disassembly of the

TABLE D.3. Distribution of Sites Storing SNF for Given Number of Years Following Shutdown[a]

Years After Shutdown Until Spent Nuclear Fuel Inventory Reaches Zero	Number of Sites
5	7
6	3
7	10
8	5
9	12
10	7
11	5
12	4
13	2
14[b]	11
15	28
16	12
17	7
18	1
19	1
20	1
24	2
25	2
26	3

(a) Derived from information contained in Reference 16.
(b) The reference PWR's (Trojan's) inventory is reduced to zero in the year 2029, or 14 years after final shutdown, assuming the plant operates until 2015.

reactor facility in a timely manner. If, on the other hand, the utility preferred to place the reactor facility in SAFSTOR for an extended period (< 60 years), the utility could choose to maintain the pool under a Part 50 possession-only license (POL) until the FWMS had accepted all of the site SNF inventory, or to place all of the SNF in an ISFSI (wet or dry) initially, even though the facility was placed in SAFSTOR, depending upon the amount of SNF in the inventory and the length of the storage period until the inventory was removed. Two basic alternatives are evaluated further in subsequent subsections:

- continue operation of the spent fuel pool at the reactor (under a modified Part 50 license)
- transfer all SNF to an on-site ISFSI (wet or dry), and maintain fuel transfer capability.

In some circumstances, a given reactor site may have already installed a dry ISFSI onsite to handle the overflow from its reactor pool. In that case, the options involve continuing to operate both storage facilities or to transfer the pool SNF inventory to the onsite ISFSI. In all of these situations, a major factor in the decision-making process is the total life-cycle cost of the planned operations. To assist in making these decisions, a methodology has been developed which evaluates the present value of the life-cycle cost of each of the utility's options. A number of factors influence these evaluations, including such things as:

- What is the total onsite SNF inventory at reactor shutdown?
- When does the reactor terminate power operations?
- When does the FWMS begin accepting SNF from the site?
- At what rate does the FWMS accept SNF from the site?
- What would be the minimum time required for DOE to accept all of the utility's SNF?

  Note: In accordance with 10 CFR Part 961 (the Contract), the minimum time to deliver the last discharge of SNF would be 5 years following shutdown.

- If no ISFSI exists at shutdown, what are the costs of building and licensing, under 10 CFR Part 72, an onsite ISFSI (wet or dry)?
- What are the costs of continuing wet storage in the existing reactor pool(s)?
- What are the costs per unit quantity of SNF for dry storage devices?
- What are the annual operating costs associated with the existing wet storage mode and/or an ISFSI (wet or dry)? What are the decommissioning costs for the existing wet storage mode and/or an ISFSI (wet or dry)?

  Note: Regarding the potential impacts on the selection of decommissioning alternatives, the following statement is made in 10 CFR Part 50.54(bb) concerning how reasonable assurance will be provided that funds will be available to manage and provide funding for the spent fuel upon expiration of the reactor operating license. "For operating nuclear power reactors, the licensee shall, no later than 5 years before expiration of the reactor operating license, submit written notification to the Commission for its review and preliminary approval of the program by which the licensee intends to manage and provide funding for the management of all irradiated fuel at the reactor upon expiration of the reactor operating license until title to the irradiated fuel and possession of the fuel is transferred to the Secretary of Energy for its ultimate disposal. Final Commission review will be undertaken as part of any proceeding for continued licensing under Part 50 or Part 72. The licensee must demonstrate to NRC that the elected actions will be consistent with NRC requirements for licensed possession of irradiated nuclear fuel and that the actions will be implemented on a timely basis. Where implementation of such actions requires NRC authorizations, the licensee shall verify in the notification that submittals for such actions have been or will be made to NRC and shall identify them. A copy of the notification shall be retained by the licensee as a record until expiration of the reactor operating license. The licensee shall notify the NRC of any significant changes in the proposed waste management program as described in the initial notification."

D.4.3 Present Value Life-Cycle Costs of Two Alternatives for SNF Storage

The present value of the total storage system life-cycle cost can be estimated for each system, for purposes of comparison. The following expression yields the present value of the life-cycle cost for the case of utilizing the spent fuel pool until the total inventory of SNF has been transferred to DOE.

$$PV = D_{p0} + \sum_{i=1}^{N} D_{pi}/(1+k)^{i} + DD_{p}/(1+k)^{N}$$

where D_{p0} is the cost of isolating the spent fuel pool from the retired plant systems; D_{pi} is the annual operating costs of the wet storage facility in constant dollars of Year 0; k is the net discount rate (interest minus inflation) which is assumed constant over the storage period; i is the number of years since reactor shutdown for which the operations costs are being calculated; and N is the number of years after reactor shutdown required for the on-site inventory to reach zero. Once the inventory is zero, the existing storage facility is decommissioned, at a cost of DD_p, in constant Year 0 dollars.

A similar expression can be used to calculate the present value of the life-cycle cost of utilizing the spent fuel pool until the hottest fuel assemblies can be safely placed into dry storage, then using dry storage until the total inventory of SNF has been transferred to DOE.

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

where n is the number of years after reactor shutdown that the hottest SNF must cool before being placed into dry storage; D_{d0} is the cost of creating and loading the dry ISFSI in Year n; D_{di} is the annual cost of operating and maintaining the dry ISFSI; and DD_d is the cost of decommissioning the dry ISFSI, all values in Year 0 dollars. Other terms are as defined above. Because the costs of deactivating and decommissioning the pool are included in the normal plant decommissioning costs, they are not costed in these life-cycle cost analyses.

The estimated annual costs of operating the SNF storage pool or the ISFSI storage facility are given in Table D.4. The cost of separating the spent fuel pool systems from the balance of plant systems is estimated to be about $0.5 million, and operating and maintaining the spent fuel storage pool

TABLE D.4. Estimated SNF Storage Operational Costs at the Reference PWR[a,b]

Cost Category	Estimated Annual Cost (1993$)[c]		
Non-Personnel Costs	Pool	Safe Storage	ISFSI[d]
Instr. & Elect. Maint. (matl. & supplies)	113,958	--	10,000
Mech. Maint. (materials & supplies)	146,960	--	5,000
Chemistry (materials & supplies)	283,800	--	--
Radwaste On-site Processing (supplies)	59,980	--	10,000
Radwaste Contract Removal & Disposal	84,800	--	15,000
Environmental Monitoring (matl. & supplies)	43,743	4,860	43,743
Protective Clothing Laundry	83,539	9,282	27,300
Electric Power (@ $0.034/kWh)	61,200	6,800	30,000
Licensing & Inspection[e]	32,258	3,584	32,258
Nuclear Liability & Property Ins.[f]	507,600	600,000	507,600
Subtotal, Non-Personnel Costs	1,417,838	624,526	761,901
Personnel Costs			
Utility Staff Labor[g]	2,722,491	302,499	1,264,681
Total Annual Operating Cost	4,140,329	927,025	2,026,582

(a) Based on information found in Reference 17, and adjusted for use in this reevaluation study.
(b) The values given in the table do not contain a contingency allowance.
(c) The costs of operating the pool and providing safe storage for the plant are allocated 90% to pool operations and 10% to safe storage operations.
(d) ISFSI costs, with concurrent safe storage operations.
(e) Study estimate. As of this writing, the materials licenses annual fees for FY 1993 have not been published.
(f) Based on $1,107,600/yr for both pool and safe storage operations, and subsequent $600,000/yr for safe storage only (see Table B.7).
(g) Derived from Table 3.2.

during safe storage of the rest of the plant is estimated to be $4.1 million per year, as given in Table D.4. The net discount rate is assumed to be 3% per year, and the duration of pool operations is assumed to be 14 years (i.e., SNF inventory has reached zero; see Table D.3). With these assumptions, the present value of the SNF pool operations until the inventory has reached zero is evaluated to be about $48 million, without contingency.

Similarly, the initial cost of establishing a dry ISFSI (D_{d0}) during Year 6 includes the capital costs of casks, transporters, and other handling equipment, plus the labor costs of loading the SNF into the casks and transporting the casks to the ISFSI location for storage. Assuming a pool inventory of 1156 assemblies, storage capacity for about 541 metric tonnes of uranium (MTU) is required. Based on data from Reference 9, the estimated cost of storage capacity is about $65,000/MTU for about 49 concrete casks, for a total cost of about $35 million, expended during Year 6. Equipment and storage pads/fences/etc. would cost about an additional $5 million during Year 6. The labor costs for removing the SNF from the pool and placing it in the ISFSI during Year 6 are estimated to be about $0.3 million. Thus, the total initial cost of establishing and loading the ISFSI (D_{d0}) would be about $40.3 million in Year 6, without contingency. Labor and non-personnel costs associated with ISFSI operation (D_{d1}) are estimated to be about $2 million per year. Decommissioning costs for the ISFSI (DD_d) is estimated to be about 10% of the capital cost, or about $4 million during Year 15. The first 7 years of pool storage results in an initial cumulative expenditure of about $27 million (present value). Added to those initial pool costs are the large initial capital cost of the ISFSI ($33 million, present value), the cumulative present value of the ISFSI operating costs ($10.6 million) and the present value of ISFSI decommissioning costs ($2.6 million). The resulting present value of SNF storage operations utilizing 7 years of pool storage and 7 years of dry cask storage is about $73 million, without contingency. Thus, for the relatively short storage time considered in this analysis, it is more cost-effective to store the SNF in the fuel storage pool than to build a dry ISFSI. However, if the storage period were to be extended to 40 years or greater, the present value cost of the ISFSI would become less than that of the spent fuel pool, as shown in Figure D.2, where the present value of the cumulative costs for pool operation and for pool plus dry ISFSI operation and decommissioning are shown for 40 years following reactor shutdown.

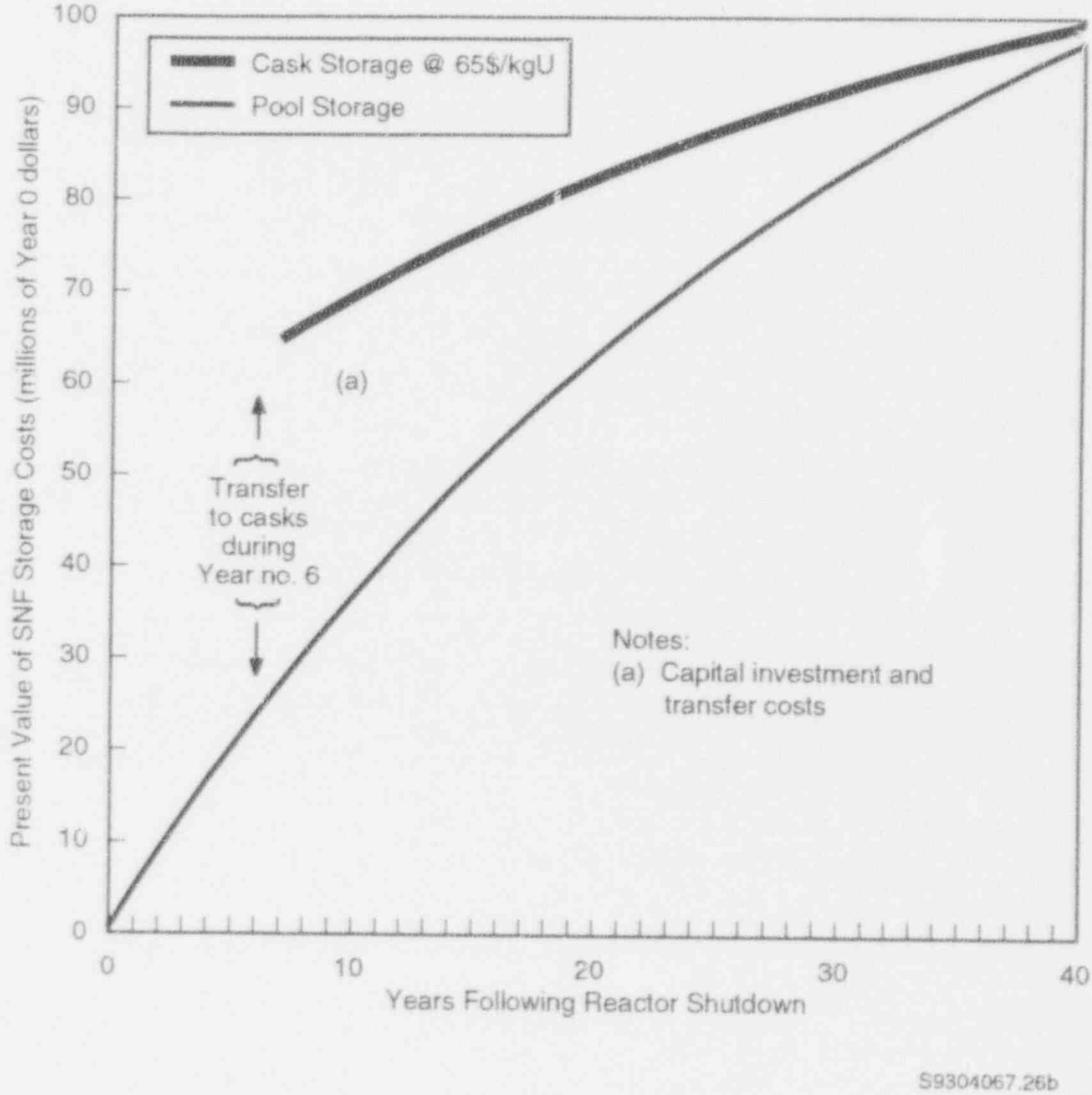

FIGURE D.2. Present Value Costs for SNF Storage Operations

D.5 REQUIRED SNF COOLING TIME FOLLOWING DISCHARGE BEFORE DRY STORAGE

To determine the cooling time required before fuel from Trojan could be placed in dry storage at the site, the assumption was made that the fuel would be stored in metal storage casks (which may or may not be transportable). The required time delay following discharge before spent fuel can be placed into the dry cask storage is primarily a function of the fuel burnup and reactor operating history (with a small sensitivity to initial enrichment). The first step in the approach taken to estimate the required delay time was to develop a curve of maximum cladding temperature for fuel stored in metal casks as a function of the decay heat output rate (watts/MTU). Data from three experimental programs at INEL were examined, wherein fuel rod cladding temperatures were inferred from measurements. These data sets included:

- An average value of 0.4582 MTU/assembly, derived from data contained in DOE/RL-90-44, Spent Fuel Storage Requirements 1990-2040[16] for the fuel used in the cask tests, based on fuel from Surry Reactor. Castor-V/21 28 kW heat load, 21 assemblies, 9.622 MTU/cask load, for a heat loading of 2910 watts/MTU and a maximum cladding temperature of 352, 368, and 424°C for cask atmospheres of helium,nitrogen, or vacuum, respectively, extracted from EPRI NP-4887, The Castor-V/21 PWR Spent-Fuel Storage Cask: Testing and Analyses.[18]

- MC-10 12.6 kW heat load, 24 assemblies, 10.9972 MTU/cask load, for a heat loading of 1146 watts/MTU and a maximum cladding temperature of 139, 181, and 217°C for cask atmospheres of helium, nitrogen, or vacuum, respectively, extracted from EPRI NP-5268, The MC-10 PWR Spent-Fuel Storage Cask: Testing and Analysis.[19]

- TN-24P 20.5 kW heat load, 24 assemblies, 10.9972 MTU/cask load, for a heat loading of 1862 watts/MTU and a maximum cladding temperature of 221, 241, and 290°C for cask atmospheres of helium, nitrogen, or vacuum, respectively, extracted from EPRI NP-5128, The TN-24P PWR Spent-Fuel Storage Cask: Testing and Analyses.[20]

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

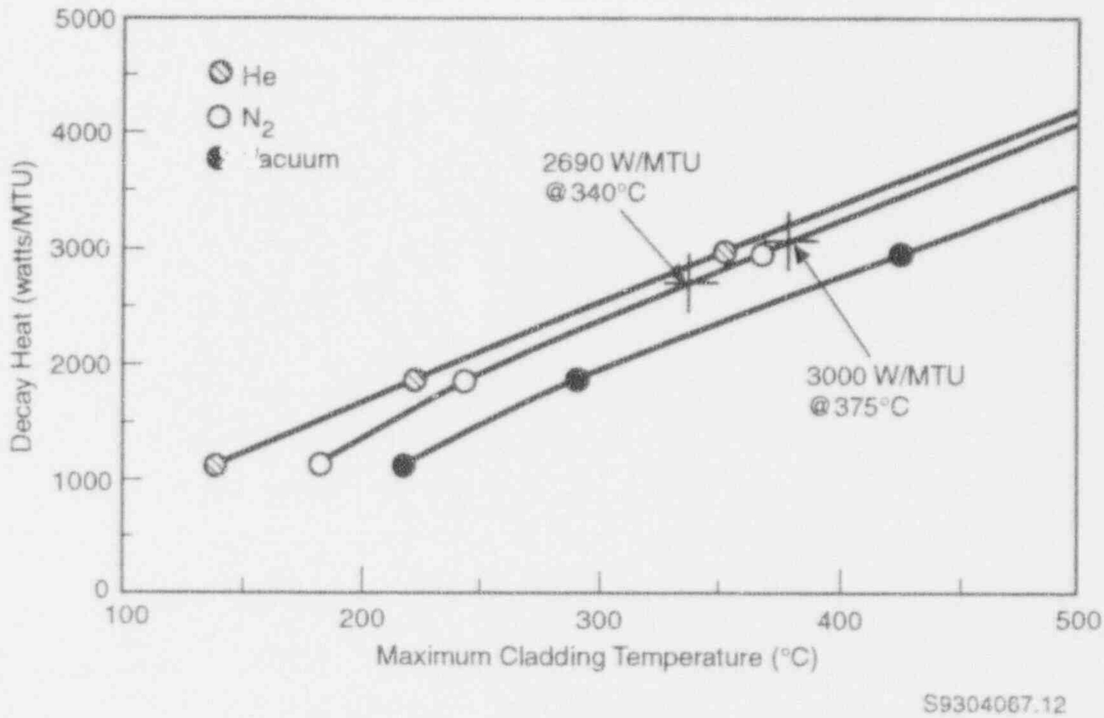

FIGURE D.3. Decay Heat Emission Rate as a Function of Maximum Cladding Temperature for PWR Fuel Stored in Metal Casks

The second step was to calculate the allowable maximum temperatures for two levels of internal fuel rod pressurization, for cooling times of 2 to 5 years. Assuming the use of standard 17x17 Westinghouse fuel assemblies, with rod internal gas pressure of 1293 psi while operating with the gas temperature at 382°C, hot cladding hoop stresses in the range from about 100 to 120 MPa for cladding temperatures ranging from about 300 to 420°C were calculated. The maximum allowable cladding temperature during dry storage was calculated using the methodology given in PNL-6639, DATING - A Computer Code for Determining Allowable Temperatures for Dry Storage of Spent Fuel in Inert and Nitrogen Gases.[20] Postulating a storage period of 300 years to avoid any sensitivity to storage duration, the allowable cladding temperatures were calculated for fuel with cooling times ranging from 2 to 5 years, for assumed cladding hoop stresses ranging from 50 to 120 MPa. The results of these calculations are shown in Table D.5, for hoop stresses of 100 and 120 MPa.

TABLE D.5. Calculated Allowable Cladding Temperatures in Dry Storage

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

Because the difference between the measured and calculated cladding temperatures in the cask tests discussed earlier tended to be in the vicinity of 30°C, a safety factor of 30°C was subtracted from the above values, resulting in allowable values ranging from 371 to 333°C.

Nominal values of 340 and 375°C were selected as a reasonable range of cladding temperatures to consider for limits, taking into account the safety factor. Maximum allowable decay heat rates for shielding temperatures of 340 and 375°C were read from the curve of Decay Heat versus Cladding Temperature (Figure D.3) to be about 2690 and 3000 watts/MTU, respectively.

To determine the required cooling times for spent fuel having differing levels of burnup and initial enrichment, calculated data on decay heat emission were read from tables contained in Regulatory Guide 3.54, Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation,[22] for cooling times of 1, 2, 5, and 10 years, at burnups of 18, 28, 33, 40, 46, 50, and 55 GWD/MTU, and for initial enrichments of 2.5, 3.3, 4.0, and 4.5 % ^{235}U in the fuel. Those data were plotted on a log-log scale and smooth curves were drawn through the points. The cooling times required for decay heat emission rates of 2690 and 3000 watts/MTU, as read from the curves for each level of burnup and initial enrichment, are tabulated in Table D.6. These values of required cooling time were plotted and the (eyeball-fit) curve of cooling time in years as a function of fuel burnup is shown in Figure D.4.

Information on the projected numbers of fuel assemblies having various levels of burnup that will be discharged from the Trojan reactor during its last 7 years of operation was obtained from the Spent Fuel Storage Requirements report,[16] which contains the spent fuel inventories and inventory projections for all U.S. commercial nuclear power plants made by the Energy

TABLE D.6. Required Cooling Times as Functions of Initial Enrichment and Cumulative Burnup, for Two Maximum Cladding Temperatures

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

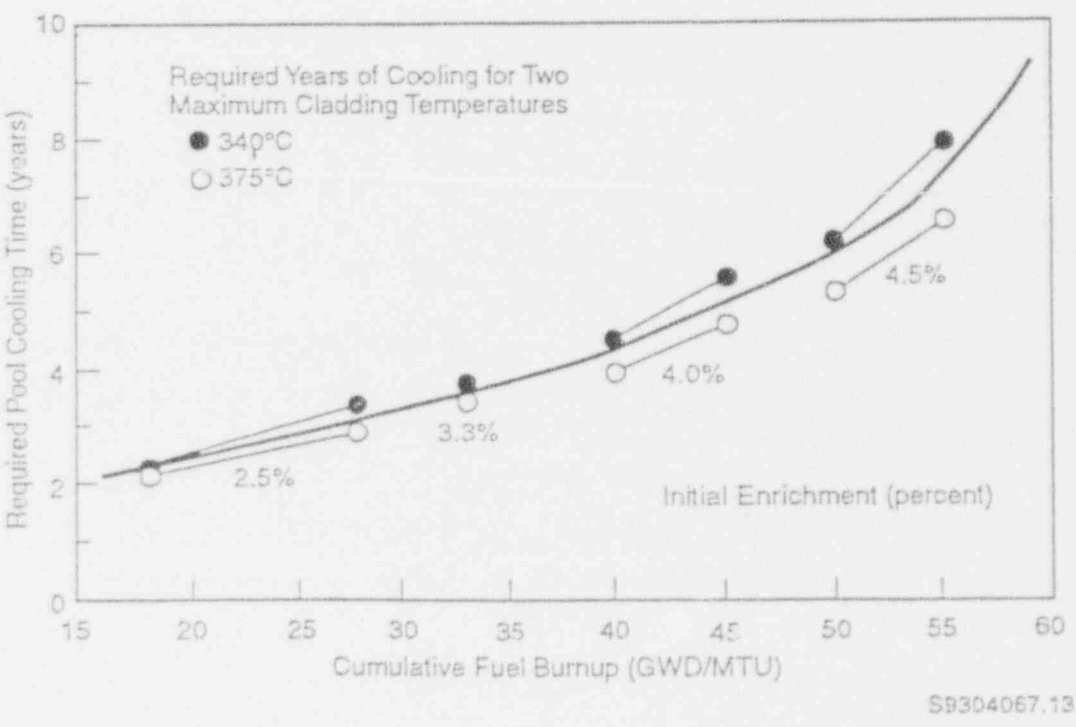

FIGURE D.4. Required Cooling Time as a Function of Fuel Burnup for Maximum Cladding Temperatures of 340°C and 375°C, for Various Initial Enrichments

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

TABLE D.7. Required Cooling Times Following Final Shutdown, for Last Seven Discharges from Trojan Reactor

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

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

D.6 RATIONALE FOR THE SPENT FUEL STORAGE OPTION POSTULATED FOR THE REFERENCE PWR

When the reference PWR is operating and space is available in its fuel pool, the incremental cost of storing spent fuel is relatively low because security services, fuel handlers, pool maintenance and monitoring personnel are already available at the site. When the plant is shut down, the facility operating license issued by the NRC needs to be modified to one permitting possession of the fuel and radioactive materials but not operation of the facility. This modification enables a significant reduction in the costs of maintaining the facility. A substantial portion of the costs required to maintain the shutdown facility becomes those associated with safe storage of the spent fuel. Even when the aforementioned license modifications are accomplished, it is anticipated that the reference PWR will sustain significant costs, unrelated to decommissioning, for spent fuel security, cooling, and monitoring. Such expenses will stop only when the fuel is removed from fuel pool storage. If the ultimate disposal of the fuel is the contemplated federal repository, the costs may extend over a long period of time, especially if the federal repository construction is delayed.

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

The costs of spent fuel storage at a shutdown nuclear plant vary depending on the characteristics of the storage site, the owner's future plans for it, and whether the utility has other nuclear plants. Typical considerations are as follows:

- If the shutdown plant is at a multi-unit nuclear site, such as in the case of Dresden-1, the costs of storing spent fuel will be relatively low and roughly equivalent to those for an operating plant. [The reference PWR, Trojan, is not a multi-unit nuclear site.]

- If the utility owns other nuclear plants, it can consider transshipment of the spent fuel from the shutdown plant to its remaining operating nuclear plants. Such a transfer could reduce costs, especially if the federal repository gets further and further delayed. [For the purpose of this study, it is assumed that the reference PWR's owners cannot consider transshipment of the reactor's fuel to another of its nuclear plants because the reactor is the only nuclear plant owned by the utility.]

- If the shutdown plant is at a site where other power generation units are located, such as in the case of Humboldt Bay and LaCrosse, the costs of storing spent nuclear fuel are reduced because security and maintenance services are available already. [At present, the reference PWR is exclusively a nuclear generating site.]

- When the shutdown plant is large in size, as is the case of the reference PWR, there could be incentives to repower the plant with other types of fuel. Such repowering is even more attractive if the nuclear plant can be decontaminated and decommissioned. The NRC regulations provide for two principal alternatives after a reactor has been shut down and defueled:

  - DECON - This option requires that the fuel be shipped off-site.[a] The equipment, structures, and portions of the facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations.[23] [This means that the reference plant (Trojan) cannot be decontaminated and released from regulatory controls until its fuel is shipped. In the OFF option, this cannot occur until at least 2029,[16] some 14 years after final reactor shutdown, unless another option for offsite spent fuel storage besides the permanent DOE repository can be developed. In this study, the OFF option is assumed to be the most <u>realistic</u> case. On the other hand, due to the exchange process contained in the Contract, the most

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(a) "Offsite" could be a wet or dry "independent spent fuel storage facility (ISFSI)," but it may be that this separate facility could be adjacent to the plant facility. Two "redefined" sites, a DECON reactor site and an ISFSI site, would result. Use permits and licenses for the resulting sites could conceivably be complicated by the interaction of the two sites.[14]

optimistic case would allow SNF delivery to DOE at shutdown plus 5 years (presumed in this study to be a highly unlikely event).

- SAFSTOR - This option permits placing the facility in a safe storage condition for up to 60 years. Fuel may be stored in the fuel pool. According to information contained in Reference 6, Trojan's licensed/maximum fuel pool capacity of 1408 assemblies (including full core reserve) will occur in 2004, with a total additional capacity needed for 472 assemblies through 2014. The end of plant life is projected by EIA to be 2015.[16] However, as previously shown in Table D.2, the reference PWR will have adequate pool capacity to accommodate its remaining inventory without the need for additional storage capability, assuming DOE receives SNF beginning in 1998 and at the rates given in Table D.1.

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

It is further concluded that immediate dismantlement (DECON) in the exact same manner as defined in the original PWR study[24] does not appear to be viable because decommissioning cannot start immediately after final reactor shutdown without removal of the stored SNF. Based upon the estimated SNF cooling-time analysis presented in Section D.5, the fuel pool could not be finally emptied until at least 7 years following reactor shutdown because of cladding temperature limitations for dry storage. The transfer of the fuel from the pool into dry storage could proceed beginning at shutdown, and continue throughout the intervening years until the final assemblies were removed; or, the transfer of the fuel could be done in a single campaign, beginning about seven years after shutdown.

For purposes of this study, it is assumed that the spent fuel pool is maintained under the POL and is not converted into an NRC-licensed ISFSI under 10 CFR Part 72, which might allow immediate dismantlement of the remainder of

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

the facility. The reasons provided by the NRC for not assuming conversion of the existing fuel pool into a licensed wet-storage ISFSI in this study are:

- Interpretation of the NRC definition of decommissioning does not allow conversion to a Part 72 license. The license must remain a Part 50 license until the reactor is decontaminated and the site restored for unrestricted use.
- Conversion to a Part 72 license is a costly and difficult undertaking and separating the reactor components from those needed to support a wet-ISFSI usually cannot be done in a satisfactory way to ensure the health and safety during the reactor dismantlement process because areas and equipment that support spent fuel pools have commonality with the existing reactor; dismantlement of the reactor could compromise the integrity of the wet-ISFSI.
- Costs for maintaining a Part 50 possession only license (POL) can be reduced by amendments or exemptions as requested by licensees with shutdown reactors. Amendments or exemptions have been made for reduction of on-site property damage insurance and the staff is also considering similar requests for liability insurance.

The modified DECON alternative developed for this study entails transferring the SNF, after an adequate cooling period, to an at-reactor-site ISFSI (dry-cask storage), which is licensed under Part 72, followed by decommissioning of the reference reactor facility. It is further assumed that the at-reactor-site ISFSI has fuel transfer capability in case of emergencies as long as fuel is onsite; however, it should be recognized that no licensed dry-storage technology currently provides such capability.

It is important to note here that there is a definite interaction between decommissioning decisions and any final selection for post-shutdown storage of a specific reactor's spent fuel, if required. Such decisions must include consideration of the final disposition schedule of the fuel within the context of the overall federal waste management system.

The results of the analyses presented in this appendix realistically reflect the available decommissioning alternatives for the reference PWR. It should be recognized, however, that the situation described in this appendix, with regard to spent fuel storage and its eventual delivery to DOE, is predicated on the current regulatory environment and on site-specific information associated with the reference PWR. Therefore, the conclusions reached herein concerning decommissioning alternatives for the reference PWR may not be the same for other PWR power stations.

D.7 REFERENCES

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APPENDIX E

REACTOR PRESSURE VESSEL AND INTERNALS DISMANTLEMENT AND DISPOSAL ACTIVITIES, MANPOWER, AND COSTS

APPENDIX E

REACTOR PRESSURE VESSEL AND INTERNALS DISMANTLEMENT AND DISPOSAL ACTIVITIES, MANPOWER, AND COSTS

The levels of neutron-activation in the metallic reactor pressure vessel (RPV) and its internals vary greatly with proximity to the fueled region of the vessel. Those components located close to the fueled region are very highly activated, with some segments being classified as Greater-Than-Class C (GTCC) radioactive waste (10 CFR 61.55).[1] The GTCC material must be packaged for transport to and disposal in a geologic repository or other such disposal facility as the Nuclear Regulatory Commission may approve. Transport of the GTCC material to the repository is postulated to be accomplished using spent fuel casks (NAC-LWT and TN-8, containing 1 and 2 canisters per shipment, respectively, because of weight limitations on the cask payload). Other components, located some distance from the fueled region, are still strongly activated but are classified as Class B or C waste and require packaging for shielded transport to and disposal in a licensed low level waste (LLW) burial site. Still other portions of these components are only slightly activated and are classified as Class A waste, acceptable for unshielded transport to a LLW burial site. In this analysis, the activation analyses for the reference PWR, originally presented in NUREG/CR-0130,[2] are used to define the classification of the various components and segments of those components, as described in Addendum 3 to NUREG/CR-0130,[3] and the various segments are segregated for packaging according to their activity levels.

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

E.1 BASIC DISASSEMBLY PLAN

To facilitate the disassembly and packaging operations, two plasma-arc cutting systems are postulated to be installed inside the reactor containment. One is mounted on the refueling bridge, principally for major disassembly of the core barrel and other internals. The second cutting system is mounted on a separate bridge/manipulator assembly at the far end of the refueling cavity, together with a cutting table and appropriate jigs for holding the various pieces during cutting operations in the refueling cavity. All cutting of stainless steel materials with the plasma-arc systems is performed under water, with the exception of the insulation surrounding the RPV and the Reactor Coolant System (RCS) piping.

Before cutting of the RPV internals begins, the reactor coolant is deionized, removing the residual dissolved boron and other residual contaminants, to avoid many of the difficulties encountered at TMI-2[5] and thereby improve performance of the plasma-arc cutting torches. The refueling cavity is maintained filled with deionized water until removal, sectioning, and packaging of the stainless steel RPV internals has been completed, after which it is drained and decontaminated.

During the deferred dismantlement period, a support structure is installed beneath the RPV, to support the RPV during the sectioning. The seal between the RPV and the biological shield enclosure is removed, so as to provide access for cutting the RCS piping at the nozzles, and for removing the insulation surrounding the vessel prior to beginning sectioning of the RPV. Following insulation removal, the oxy-acetylene cutting of the RPV gets under way, with the water level being maintained just below the level of the cutting operations. Cutting of the RPV is performed in air within the concrete biological shield, using an oxy-acetylene cutting system. The oxy-acetylene torch is applied to the outside of the RPV, thereby avoiding any problems in penetrating the stainless steel lining of the vessel. The viability of this approach was demonstrated by Lundgren[4] for cutting thick (9 in.) sections of carbon steel clad with thin stainless steel on one side.

The dimensions of the RPV and its internal structures used in these analyses are derived from information given in the reference PWR report[2] and from backup information supporting that report.

E.2 UPPER CORE SUPPORT ASSEMBLY

The Upper Core Support Assembly, illustrated in Figure E.1, is comprised of a top plate, 61 Control Rod Drive (CRD) guides, 79 support/mixer columns, and a bottom plate (called the upper grid plate). The upper grid plate is postulated to be GTCC material. The rest of the assembly is classified as Class A, Class B, or Class C material.

E.2.1 CRD Guides

Approximately 244 bolts which attach the CRD guide collars to the top plate of the upper core support assembly are removed or broken off. The 61 CRD guides, which are 7.6 in. dia. and 167 in. in length, are removed from the assembly by lifting up through the top plate and are placed on the cutting table in the refueling cavity. The lower 4 ft is cut from each tube and packaged for shielded shipment in an 8-120B cask liner (62 in. OD x 72 in. high) with a packaged volume of 126 ft^3 or 3.6 m^3. The upper sections of the tubes and the collars are packaged in 2 steel boxes (4 ft x 4 ft x 6 ft, packaged volume of 192 ft^3 or 5.4 m^3) for unshielded shipment. One hundred twenty-two cuts, for 2,928 linear inches, are required.

E.2.2 Top Plate

The 48 nuts are removed from the top ends of the support columns and mixer columns, freeing the top plate from the rest of the assembly. The top plate is removed to the cutting table for sectioning. The plate, which is 172 in. dia., is cut across the face on the 90-270 degree line, turned over and the support ring and webs severed on the same line. The two pieces are packaged in a special U-shaped steel box (174 in. dia. x 210 in. long x 45 in.

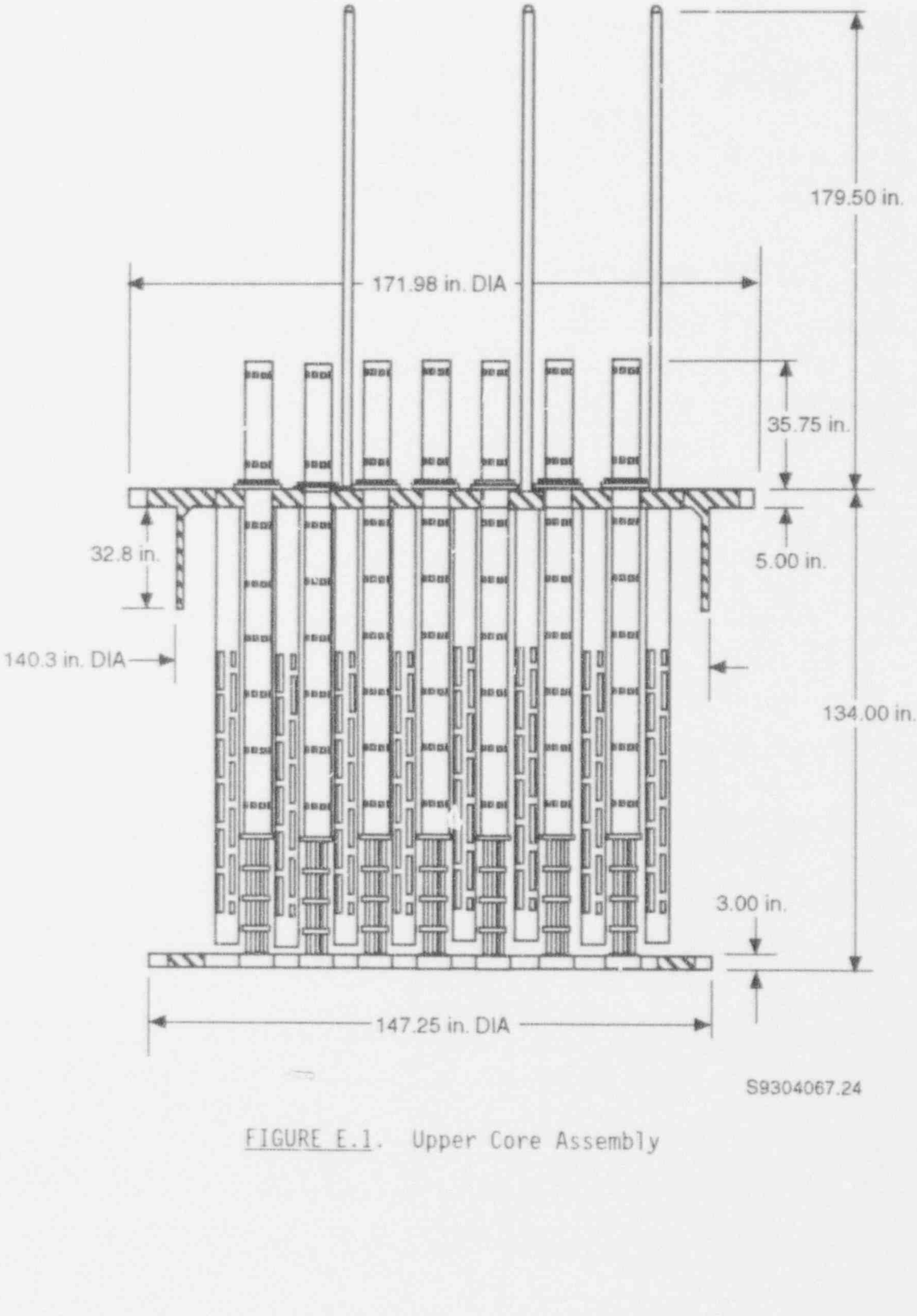

FIGURE E.1. Upper Core Assembly

high, package volume of 470 ft^3 or 13.3 m^3) for unshielded shipment. Seven cuts, for 353 linear inches, are required.

E.2.3 Posts and Columns

The 316 bolts that attach the 79 support posts and mixing columns to the upper grid plate are removed. The 79 columns, which are 7.6 in. dia. and from 126 to 134 in. in length, are removed to the cutting table and the lower 4 ft of each column is cut off for packaging in an 8-120B cask liner, together with the bolts. The upper sections of the columns are packaged in four steel boxes (4 ft x 4 ft x 6 ft packaged volume of 10.9 m^3) for unshielded shipment. The lower 4 ft of the columns are packaged in a cask liner for the 8-120B cask (packaged volume of 3.6 m^3) for shielded shipment. Seventy-nine cuts, for 1,896 linear inches, are required.

E.2.4 Upper Grid Plate

The upper grid plate, which is 147.25 in. in diameter and 3 in. thick, with 61 holes that are 8.8 in. diameter and 132 holes that are 5.6 in. diameter, is placed on the cutting table for sectioning. The calculated full-density volume of the plate is:

$$(\pi/4)[(147.25)^2 - 61(8.8)^2 - 132(5.6)^2] \text{ in.}^2 \times 3 \text{ in.} = 30{,}204 \text{ in.}^3\text{, or } 0.495 \text{ m}^3$$

The weight of the plate is:

$$30{,}204 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 8{,}759 \text{ lb, or } 3{,}973 \text{ kg}$$

This plate is cut into 8.5 in.-wide strips for packaging in the 9 in. x 9 in. x 180 in. long canisters postulated for GTCC material. The equivalent of 10.4 strips are cut, which are loaded 2 strips per canister. Thus, 5.2 canisters are loaded. It is assumed that the material leftover after filling 5 canisters can be placed into one of the other partially filled canisters, so that the packaged volume of the upper grid plate is 5 canisters. Eighteen cuts, for 2,115 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

5.2 canisters x 0.24 m^3 = 1.25 m^3.
3,973 kg / 5.2 canisters = 764 kg/can, and
3,973 kg / [5.2 cans x 0.24 m^3/can] = 3,183 kg/m^3.

This markedly lower density reflects the poorer loading efficiency and the reduced average density of the plate material due to the holes.

E.3 LOWER CORE ASSEMBLY

The lower core assembly, illustrated in Figure E.2, is comprised of the upper core barrel, the lower core barrel with thermal shields, the core shroud plates and shroud former plates, the lower grid plate, and the lower core support structure. This assembly is unbolted from the RPV and lifted from the RPV and placed upright on its stand in the refueling cavity. Disassembly and packaging of this assembly is described in the following subsections.

E.3.1 Upper Core Barrel

This component is a cylindrical shell which surrounds the upper core support assembly. The barrel has an outer diameter of 153.5 in., a length of 108 in., and a thickness of 2.5 in. Circumferential cuts are made in the upper core barrel at distances of approximately 46 in. and 108 in. below the barrel top flange. The rings are removed to the cutting table for further sectioning, with the upper ring cut into 11 pieces, 46 in. x 46.7 in., for packaging in two 4 ft x 4 ft x 6 ft steel boxes (packaged volume of 5.4 m^3), for unshielded shipment. The lower ring is sectioned into 10 pieces which are 62 in. in length (4 ea. 54 in. wide w/nozzle rings, 2 ea. 50 in. wide, 2 ea. 45 in. wide, 2 ea. 38 in. wide). The lower ring pieces are packaged in 3 cask liners (62 in. OD x 65 in. high) for the 8-120B cask (packaged volume of 3.1 m^3), for shielded shipment. Twenty-three cuts, for 2,090 linear inches, are required.

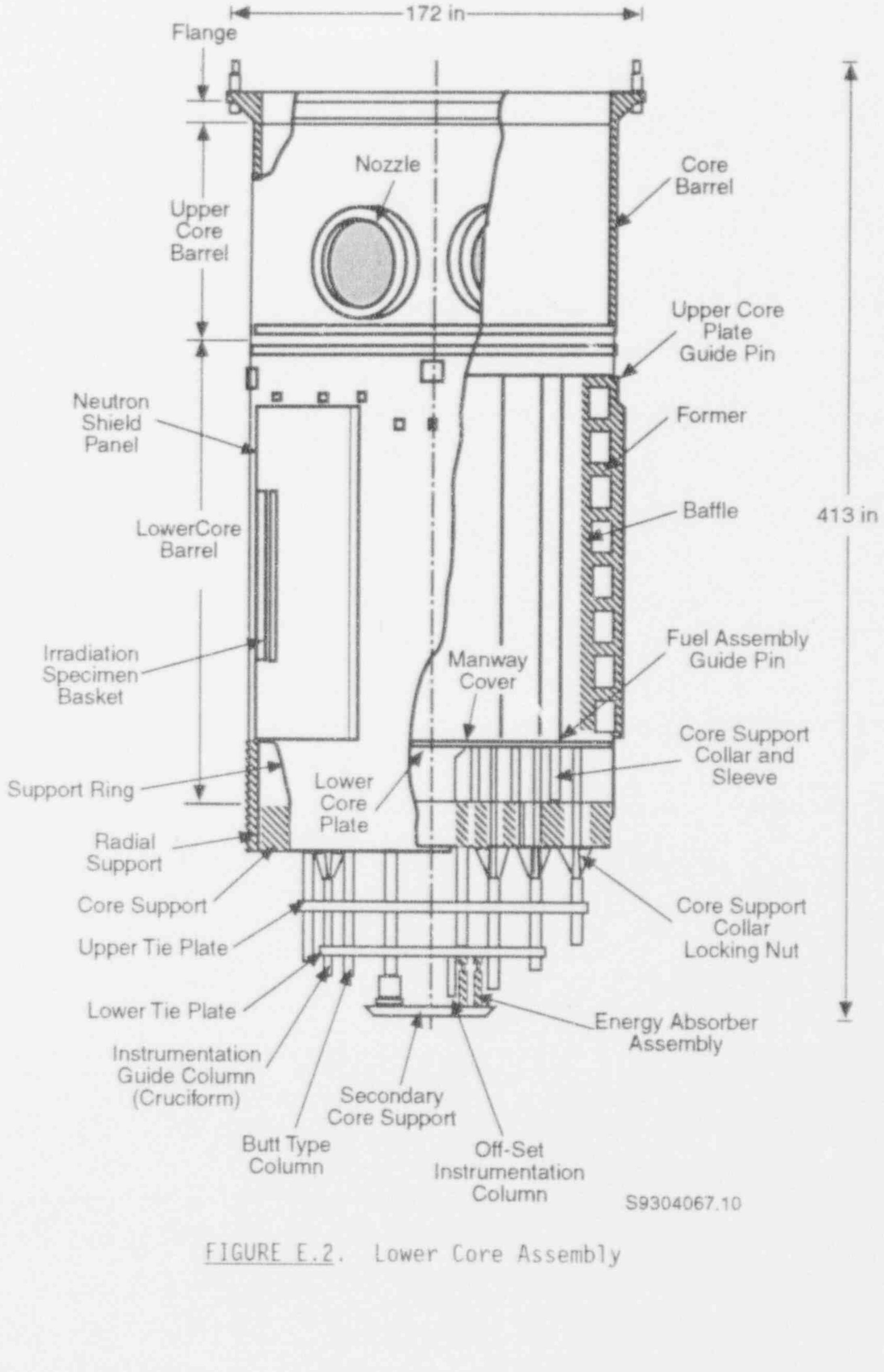

FIGURE E.2. Lower Core Assembly

E.3.2 Thermal Shields

The thermal shields consist of 4 segments of stainless steel attached to the outside of the lower core barrel to absorb neutrons and reduce the neutron dose to the pressure vessel wall in those locations closest to the corners of the fuel core. All of the shields are 148 in. in length and 2.8 in. thick. Two of the shields are 36 in. wide and two are 48 in. wide. The approximately 156 bolts attaching the thermal shields to the outside of the lower core barrel are removed and the shields removed to the cutting table for sectioning. The full-density volume is:

$$148 \text{ in.} \times 2.8 \text{ in.} \times 2\ (36 + 48) \text{ in.} = 69{,}619 \text{ in.}^3\text{, or } 1.141 \text{ m}^3$$

The weight of the thermal shields is:

$$69{,}619 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 20{,}190 \text{ lb, or } 9{,}158 \text{ kg}$$

The shields are cut into strips 8.5 in. wide, and assembled into strips 175 in. in length, for packaging as GTCC material:

[36/8.5 = 4 strips plus a 2-in. strip] x 2

[48/8.5 = 5 strips plus a 5.5-in. strip] x 2

The total number of strips is: 2 (4 + 5 + 1) = 20 strips that are 148 in. long. Assembling the strips into units 175 in. long yields:

$$20 \times 148/175 = 17 \text{ strips}$$

which can be loaded 3 strips per canister, for a total of 6 canisters (packaged volume of 1.4 m^3, rounded to the nearest whole canister). Thirty-four cuts, for 2,800 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canister are:

$$6 \text{ canisters } \times 0.24 \text{ m}^3 = 1.44 \text{ m}^3,$$

$$9{,}158 \text{ kg} / 6 \text{ canisters } = 1{,}526 \text{ kg/canister}, \text{ and}$$

$$9{,}158 \text{ kg} / [6 \text{ cans} \times 0.24 \text{ m}^3/\text{can}] = 6{,}360 \text{ kg/m}^3$$

E.3.3 Core Shroud Plates

These components consist of flat plates 160.5 in. long which enclose the fuel core vertically. Removal of the core shroud plates is accomplished by removing the approximately 900 bolts holding the plates to the shroud former plates. Disassembly of the shroud plates is accomplished by removing the approximately 17 bolts that hold each corner together and, if necessary, making a vertical cut in one of the wide plates to make enough space to permit removal of the plate assemblies from the vessel. The plate assemblies are moved to the refueling cavity cutting table for removal of the rest of the corner bolts and for sectioning.

The vertical plates are 0.75 in. in thickness and are in segments: 4 ea. 7.75 in. wide, 12 ea. 8.5 in. wide, 8 ea. 17 in. wide, and 4 ea. 61 in. wide. The full-density volume is:

$$[4(7.75) + 12(8.5) + 8(17) + 4(61)] \times 160.5 \times 0.75 = 61{,}752 \text{ in.}^3, \text{ or } 1.012 \text{ m}^3$$

The weight of the vertical plates is:

$$61{,}752 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 17{,}908 \text{ lb, or } 8{,}123 \text{ kg}$$

The vertical plates are cut into 8.5 in. (or less) wide strips for packaging as GTCC material. The strips, which are 160.5 in. long, when assembled into 175-in. strips yield an effective 56 strips. With 11 strips per canister, the number of 9-in.-square canisters is 56/11 = 5.1 canisters. Ninety-one cuts, for 6,246 linear inches, are required.

E.3.4 Shroud Former Plates

Eight shroud former plates surround the vertical plates and fit against the inside surface of the lower core barrel. The approximately 700 bolts attaching the shroud former plates to the lower core barrel are removed, and the shroud former plates are removed to the cutting table for sectioning.

The full-density volume of a former plate is found by computing the area of a disk whose diameter is that of the inside of the lower core barrel (148 in.), minus the area occupied by the fuel assemblies and the vertical shroud plates, and multiplying that area by the plate thickness (1.25 in.):

$$([\pi/4](148)^2 - 186(8.5)^2 - 513(0.75))\ \text{in.}^2 \times 1.25\ \text{in.} = 4225\ \text{in.}^3\text{, or } 0.069\ \text{m}^3$$

The weight of the eight shroud former plates is:

$$4225\ \text{in.}^3 \times 0.29\ \text{lb/in.}^3 \times 8 = 9802\ \text{lb, or } 4{,}446\ \text{kg}$$

The shroud former plates are less regular in shape but can be arranged into reasonably compact strips for packaging as GTCC material. The total length is about 2640 in., which, when cut into 175-in. lengths, will yield 15.1 strips. With a thickness of 1.25 in., 6 strips can be loaded per canister, for a total of 2.5 canisters. Twenty-six cuts, for 315 linear inches, are required.

The leftover pieces from the shroud vertical plates are loaded into the partially-loaded former plate canister, making a total of 5 + 3 = 8 canisters.

The total weight of the core shroud and former plates is:

$$17{,}908\ \text{lb} + 9{,}800\ \text{lb} = 27{,}708\ \text{lb, or } 12{,}568\ \text{kg,}$$

and the full-density volume is:

$$1.012\ m^3 + 8(0.069\ m^3) = 1.566\ m^3.$$

The packaged volume, weight per canister, and effective packaged density of the material are:

$$8 \text{ canisters} \times 0.24\ m^3/\text{can} = 1.92\ m^3,$$
$$12{,}568 \text{ kg} / 8 \text{ canisters} = 1{,}571 \text{ kg/canister, and}$$
$$12{,}568 \text{ kg}/[8 \text{ cans} \times 0.24\ m^3/\text{can}] = 6{,}546 \text{ kg}/m^3.$$

E.3.5 Lower Grid Plate

The lower grid plate is a disk 149.4 in. in diameter and 2 in. thick, with numerous holes of various sizes. The reference PWR report gives the weight of the lower grid plate as 3,946 kg, and the calculated volume of the plate (ignoring the holes) is:

$$[\pi/4](149.4)^2 \text{ in.}^2 \times 2 \text{ in.} = 35{,}061 \text{ in.}^3\text{, or } 0.575\ m^3.$$

The 384 bolts attaching the lower grid plate to the core support posts are removed, freeing the plate from the rest of the lower support assembly. The 60 bolts attaching the lower grid plate to the lower core barrel are removed or broken off, freeing the plate from the core barrel. The grid plate is removed to the cutting table for sectioning.

The grid plate is cut into strips 8.5 in. wide, and arranged into strips having a total length of 2042 inches, for packaging as GTCC material. Dividing this length into strips 175 in. long yields 11.7 strips, which are loaded 4 strips per canister. Thus, approximately 3 canisters are filled. The left-over space can be filled with the scraps from other packages. Thirty cuts, for 2,276 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

$$3 \text{ canisters} \times 0.24 \text{ m}^3/\text{can} = 0.72 \text{ m}^3,$$

$$3{,}946 \text{ kg} / 3 \text{ canisters} = 1{,}315 \text{ kg/can, and}$$

$$3{,}946 \text{ kg} / [3 \text{ cans} \times 0.24 \text{ m}^3/\text{can}] = 5{,}481 \text{ kg/m}^3.$$

E.3.6 Lower Core Barrel

This component is a cylindrical shell, 153 in. dia. which surrounds the core, extending the distance between the upper and lower core plates (160.5 in.), and is 2.5 in. in thickness. The full-density volume is given by:

$$\{\pi/4[(153)^2 - (148)^2]\} \text{ in.}^2 \times 203 \text{ in.} = 239{,}951 \text{ in.}^3, \text{ or } 3.932 \text{ m}^3.$$

The weight of the core barrel is:

$$239{,}951 \text{ in.}^3 \times 0.29 \text{ lb/in.}^3 = 69{,}586 \text{ lb, or } 31{,}563 \text{ kg.}$$

A circumferential cut is made in the lower core barrel just above the core support forging, making a section approximately 203 in. high. The barrel section is removed to the cutting table for sectioning.

The core barrel is cut into long strips that are 8.5 in. wide for packaging as GTCC material. The circumference of the core barrel is 153π or 480.7 in., which when divided by 8.5 in. yields 56.5 strips, 203 in. in length. To package in the space available in the canister, the total length of the strips is computed and divided by 175 in., to obtain the effective number of full-length strips to package.

57 strips x 203 in / 175 in. = 66.1, or 66 strips, plus an 18-in piece.

With the thickness of 2.5 in., only 3 strips can be placed into a 9-in.-square canister, yielding 22 canisters (rounded to the nearest whole canister). One hundred and twenty-three cuts, for 12,272 linear inches, are required.

The packaged volume, weight per canister, and effective packaged density of the material within the canisters are:

22 cans x 0.24 m^3 = 5.28 m^3,

31,563 kg / 22 cans = 1,435 kg/can, and

31,563 kg /[22 cans x 0.24 m^3/can] = 5,977.8 kg/m3.

E.3.7 Lower Core Support Structure

This assembly, illustrated in Figure E.3, is comprised of the core support forging, tie plates, support posts and instrument guides, and the secondary support plate. Those portions of the 96 support posts (about 3 in. dia.), and the 25 instrument guides (about 2 in. dia.), which protrude above the core support forging about 24 in., are cut off flush with the upper face of the forging, and packaged in 2 canisters as GTCC material. The remainder

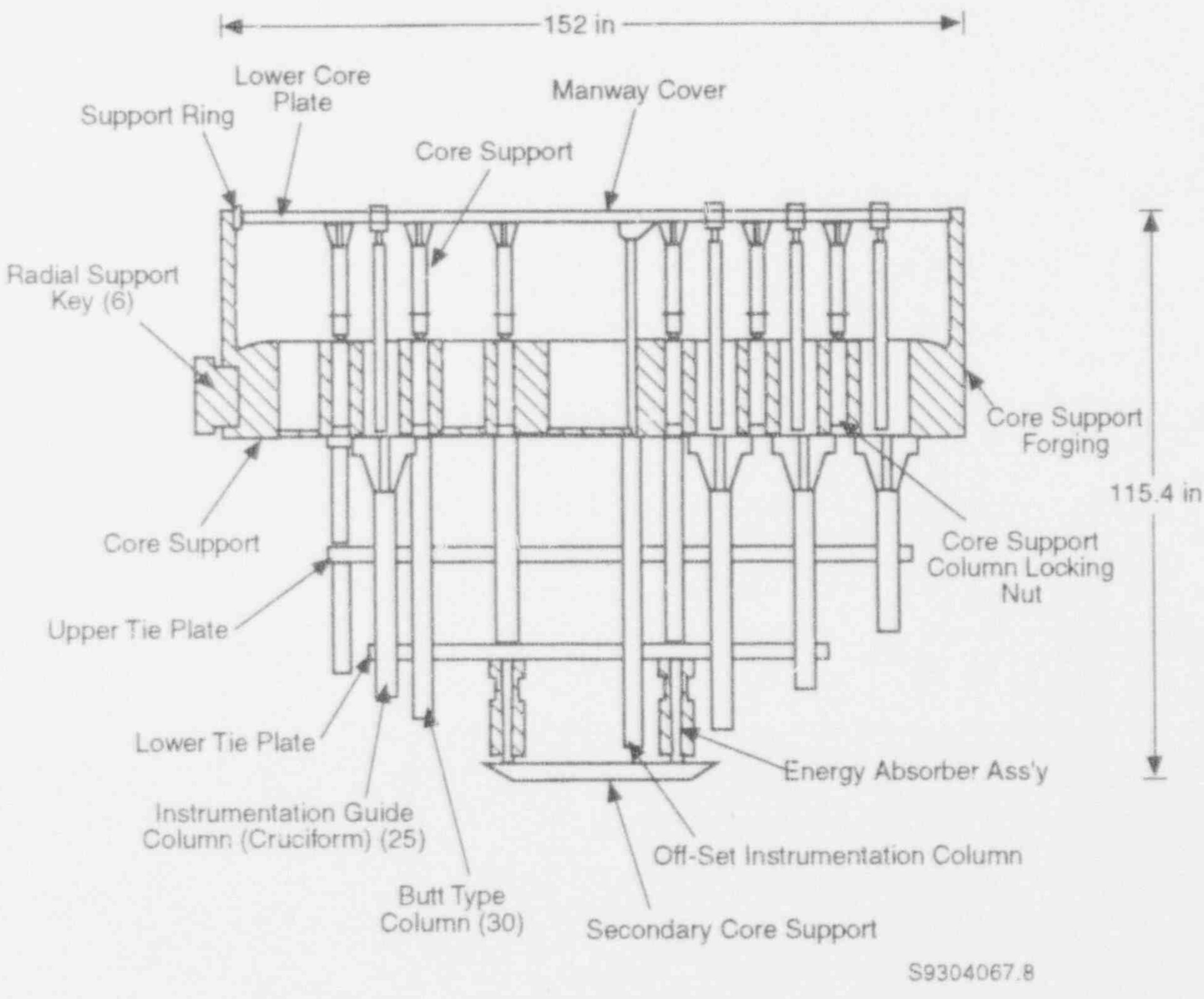

FIGURE E.3. Lower Core Support Structure of the support posts and instrument guides are handled as described below. One hundred and twenty-one cuts, for 336 linear inches, are required.

The core support forging, which is about 152 in. dia. and 20 in. in thickness, is turned face down and the approximately 236 bolts that attach the support posts and instrument guides to the forging are removed. The remainder of the lower core support assembly is lifted off, turned over, and placed face up to permit removal of the approximately 236 bolts attaching the posts and guides to the upper and lower tie plates. The posts and guides are removed for packaging. The bolts attaching the lower support posts to the lower tie plate and the secondary support plate are removed and packaged. The tieplates are removed to the cutting table for sectioning. The lower forging is removed to the cutting table for sectioning. All of the lower core support structure is packaged in six 8-120B cask liners (packaged volume of 22 m^3) for shielded shipment. Eighty-three cuts, for 1,660 linear inches, are required.

E.4 REACTOR PRESSURE VESSEL

The RPV, illustrated in Figure E.4, is a right circular cylinder with an outside diameter of 190 inches and hemispheric ends, with 8 RCS pipes attached to the 8 nozzles. The seal between the RPV and the surrounding biological shield is removed, to permit separating the RPV from the RCS piping, and to permit removal and packaging of the insulation surrounding the RPV. With the insulation and the RCS pipes removed, access to the outside of the RPV is available for sectioning the RPV using the oxy-acetylene torches. Disassembly and packaging of the RPV is described in the following subsections.

E.4.1 Insulation

The vessel insulation is comprised of packages of multiple layers of thin stainless steel which are contoured to surround the entire vessel, top and bottom heads and the cylindrical side wall. These packages are approximately 4 in. thick and are of various sizes to facilitate installation and removal. The packages are removed, flattened to reduce their volume, and cut into sizes for packaging. The lower 200 inches of the side wall insulation is packaged in an 8-120B cask liner (packaged volume of 3.6 m^3) for shielded

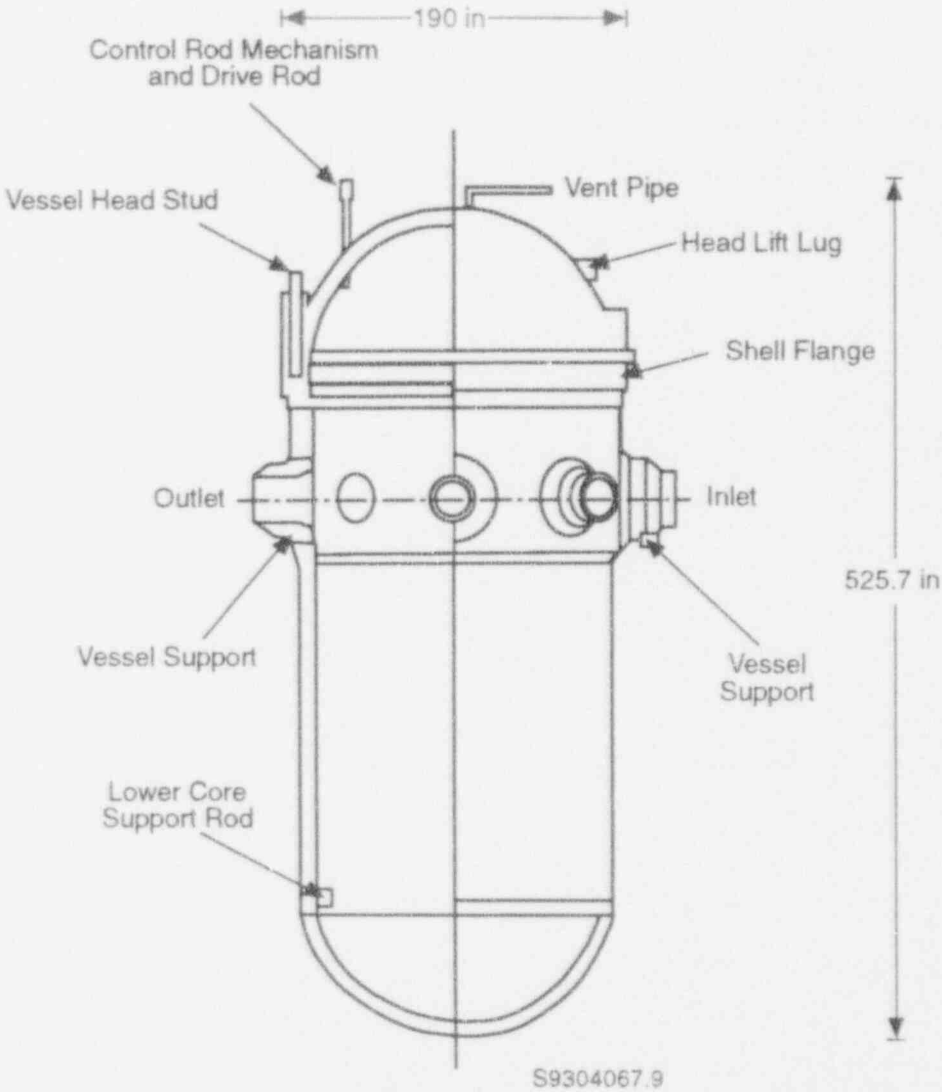

FIGURE E.4. Reactor Pressure Vessel

shipment. The remainder of the insulation is packaged in two 4 ft x 4 ft x 6 ft steel boxes (packaged volume of 5.4 m^3) for unshielded shipment. One hundred and thirteen cuts, for 9,300 linear inches, are required.

E.4.2 RPV Upper Head and Flange

The 61 CRD guides, which are about 3.8 in. dia., and assorted instrumentation penetrations on the RPV upper head are cut off flush with the hemispheric surface, and are packaged in a 4 ft x 4 ft x 6 ft steel box for unshielded shipment. About 63 cuts, for 240 linear inches are required.

A circumferential cut is made just above the upper head flange. The flange is cut into 14 segments and packaged 4 segments/per box in 4 ft x 4 ft x 6 ft steel boxes. The remainder of the upper head is cut into 22 segments approximating 46 in. x 46 in. in area and packaged 6 segments/box. One hundred cuts, for 2,689 linear inches, are required.

E.4.3 RPV Lower Flange and RCS Piping

The RCS piping is cut at the vessel nozzles. A circumferential cut is made about 27 in. below the surface of the RPV lower flange. The flange is cut into 14 segments and packaged 4 segments/box in 4 ft x 4 ft x 6 ft steel boxes. The combined packaging for the upper and lower vessel flanges is 7 boxes (packaged volume of 19 m^3). Fifteen cuts, for 975 linear inches, are required. The cutting of the RCS piping is accounted for in Section 3.4.4 of Chapter 3.

E.4.4 RPV Nozzles

A circumferential cut is made about 131 in. below the surface of the RPV lower flange just below the RPV nozzles. This ring is cut into 8 segments, 1 segment/nozzle. These segments are packaged by placing each piece in a form-fitting box which covers the inside surface of the piece and welding the box to the piece. The nozzle is capped and welded. The 8 pieces (packaged volume of 14.2 m^3) are shipped unshielded. Nine cuts, for 1,429 linear inches, are required.

E.4.5 RPV Wall

Four circumferential cuts are made every 50 in. down the length of the remaining RPV wall. The rings are cut into 11 segments. These segments are packaged in special cask liners for the 8-120B cask. The liners are fitted to contain 2 segments/liner, for a total of 22 shielded shipments (packaged volume of 22.5 m^3). Forty-eight cuts, for 4,588 linear inches, are required.

E.4.6 RPV Lower Head

The 58 instrument guide penetrations are cut off flush on the inside and outside of the RPV lower head, and the head is sectioned into 35 segments which are packaged in 4 ft x 4 ft x 6 ft steel boxes. The combined packaging of the upper and lower heads is 7 boxes (packaged volume of 19 m^3). One hundred cuts, for 2,735 linear inches, are required.

E.5 SUMMARY OF CUTTING AND PACKAGING ANALYSES

The results of the analyses for cutting and packaging the RPV internals and the RPV itself are presented in this section.

E.5.1 Cutting Team Compositions

Removal of the RPV internals and the RPV requires a sequence of operations, repeated many times, to cut and package these activated materials. The equipment is set up to make the cut, the piece to be cut is grappled to support it during and after the cutting, the cut piece is removed from the cutting location to the packaging location, and the piece is placed into the appropriate container preparatory to shipment for disposal. All of the GTCC material is packaged in canisters (9 in. x 9 in. x 180 in.) which are compatible with storage in the spent fuel racks in the spent fuel pool and with spent fuel shipping cask baskets.

Removal and packaging of the RPV internals is postulated to require two manipulator systems with attached plasma arc cutting devices, one operating at the far end of the refueling cavity and one operating at the location of the stand for the core barrel assembly in the refueling cavity. During subsequent RPV sectioning, a manipulator system for carrying the oxy-acetylene cutting torch is required within the reactor vessel cavity.

One crew per shift operates the cutting systems. Each crew is postulated to consist of the staff listed in Table E.1.

In addition to the dedicated cutting crews, a non-dedicated crew for handling the packaged materials operates on the third shift, to deliver and remove the casks/containers to and from the work areas and to prepare the casks and containers for transport. This crew is comprised of a foreman, 2 equipment operators, 2 craftsmen, and 2 health physics technicians. During the cutting and packaging of the RPV internals, this crew is provided by the utility, at a daily cost of $1,546.40, and received an average radiation dose of about 35 mrem/crew-hr. During the cutting and packaging of the RPV, this

TABLE E.1. Staffing and Labor Rates Postulated for Cutting Crews

Person-hrs per crew/hr	Category	Labor Rate ($/hr)[a]	Labor Cost ($/crew-hr)	Dose-rate (mrem/crew-hr)
3	Craftsman	49.70	149.10	30
4	Laborer	26.37	105.48	40
1	H.P. Tech.	36.82	--[b]	5
1	Foreman	54.84	54.84	5
9			309.42	80
Average cost per crew-hour			324.89[c]	

(a) Labor rates are in 1993 dollars, and include 110% overhead, and 15% DOC profit.
(b) Part of utility/DOC overhead staff, included in undistributed costs.
(c) Includes a 10% shift differential for second shift work.

crew is provided by the DOC, at a daily cost of $2,500.48, and received an average radiation dose of 35 mrem/crew-hr. These costs are included in the non-dedicated labor costs.

E.5.2 Cutting Operation Time Estimates

It is estimated that about 2 weeks will be required for initial installation and checkout of the cutting and manipulator systems. Subsequent cutting operations are estimated to require about 20 minutes to set up for each cut, including attaching grapples to the piece to be cut. The cutting time will depend upon the type of cutting, the material thickness, and the length of cutting required. Following a cut, about 20 minutes is estimated to be required to remove the cut piece from the cutting location and place it in the appropriate package. These efforts can continue in parallel with the next setup/grappling operation, which begins about half-way through the moving/packaging operation.

Underwater plasma arc cutting rates are postulated to range from about 14 in./min. for 0.5-in. thick stainless steel to about 5 in./min. for 5-in.-thick stainless steel, based on information developed at TMI-2 [5] and European experience described in ECFOCUS.[6] Rates for oxy-acetylene cutting of carbon steel are postulated to range from about 13 in./min. for 1.5-in. thick carbon steel to about 3 in./min. for 14-in.-thick carbon steel, based on information presented in the Decommissioning Handbook.[7] For many of the cutting operations, the actual cutting time is a very small fraction of the total operating time for a cut.

The total operating time (in minutes) for cutting the j^{th} component can be expressed by:

$$T_j = 30\ N_j + \sum (L_{ij}/R_{ij})$$

where N_j is the number of cuts, L_{ij} is the length of the i^{th} cut, and R_{ij} is the cutting rate for the i^{th} cut in the j^{th} component.

The effective time, TE_j, required to segment a component is greater than the total operating time described above. The effective time also includes the amount of time the crew spends in radiation protection/ALARA activities, in dressing and undressing with anti-contamination clothing, and on work breaks. The cutting equipment is basically automated and controlled remotely underwater. The gases evolved during cutting are filtered through the pool water and are captured and removed using ventilation hoods placed just above the pool surface over the cutting areas. As a result, respiratory protection should not be required for the crew during underwater cutting.

An additional factor associated with the plasma arc cutting is the time required to change the torch when it fails to function. Experience at TMI-2[5] suggests that a torch fails about every 7.5 cuts. Assuming the change-out time is 2 hours each occurrence, and the 890 plasma arc cuts made in stainless steel from Table E.2, the torch change-out factor is about 46%. Thus, the work difficulty factors appropriate for the underwater cutting are:

Non-productive-Time Adjustments

- Protective Clothing (8 x 15 min./shift) 39.4%
- Break Time (2 x 15 min./shift) 9.8%
- ALARA Activities (25 min./shift) 8.2%

Work Difficulty Adjustments

- Torch Change-out (1 every 7.5 cuts) 46%

TABLE E.2. Reactor Pressure Vessel and Internals Cutting Details

Component	Thickness (inches)	No. of Cuts	Total Length (inches)	Cutting Rate (inches/min.)	Cutting Time (minutes)	Operating Time (minutes)	Effective Time (minutes)	Labor Costs (1993 $)	Dose (man-rem)
Upper Core Assembly									
Top Plate	2.5 - 5	7	353	7 - 5.5	64	274	630	3,815	
CRD Guides	0.5	122	2,928	14	209	3,869	8,890	53,864	
Support Columns	0.5	79	1,896	14	135	2,505	5,756	34,876	
Upper Grid Plate	3.0	18	2,115	7	302	842	1,935	11,723	
Lower Core Assembly									
Upper Barrel	2.5	23	2,090	7	298	989	2,272	13,769	
Lower Barrel	2.5	123	12,272	7	1,596	5,443	12,506	75,779	
Shroud Plates	0.75	91	6,246	12	520	3,251	7,470	45,260	
Former Plates	1.25	26	315	10	31	812	1,866	11,306	
Lower Grid Plate	2.0	30	2,276	8	284	1,185	2,723	16,497	
Thermal Shields	2.8	34	2,800	7	400	1,420	3,263	19,770	
Lower Forging	2 - 6	83	1,660	8 - 5	332	2,822	6,484	39,288	
Tie Plates	3	20	80	7	11	611	1,404	8,507	
Support Columns	3.5	121	336	6	56	3,686	8,469	51,318	
Insulation	0.5	113	9,301	14	664	4,054	9,315	56,441	
Subtotal		890			5,102 (85 hrs)		72,982 (1,216 hrs)	$442,213	61.83
Reactor Pressure Vessel									
Top Penetrations	3.5	63	240	9	27	1,917	3,620	21,936	
Top Flange	9 - 14	14	399	3	133	553	1,044	6,327	
Top Dome	6.5	24	2,050	5.5	373	1,093	2,064	12,507	
Lower Flange	9 - 15	14	378	3	126	546	1,031	6,249	
Nozzles	8.5	8	832	4.5	185	425	803	4,863	
Vertical Wall	8.5	50	5,782	4.5	1,285	2,785	5,260	31,869	
Lower Dome	5.5	42	2,648	6.5	407	1,667	3,148	19,076	
Lower Penetrations	1.5	58	87	13	7	1,747	3,299	19 [illegible]91	
Subtotal		273			2,543 (42.4 hrs)		20,270 (338 hrs)	$122,[illegible]9	16.24[a]
Totals								$565,030	78.07

(a) Does NOT include a 25% contingency.
(b) Includes radioactive decay for 7 years since reactor shutdown.

Thus, the effective time for underwater cutting is given by:

$$TE_j = T_j\ (1 + 0.394 + 0.098 + 0.082)(\ 1.46) = 2.30\ T_j$$

For the in-air oxy-acetylene cutting of the RPV, and the in-air plasma arc cutting of the insulation and RPV piping, respiratory protection is assumed to be required for the crew, with a work difficulty factor of 20%. The torch change-out problems anticipated with the underwater plasma arc torch should not occur with the in-air plasma arc torch or the oxy-acetylene torch. For in-air cutting, the effective cutting time per component is given by:

$$TE_j = T_j\ (1.574)(1.20) = 1.88\ T_j$$

The exposure hours for the cutting crews are given by $TE_j/1.574$, since only actual contact hours apply.

The cost of the cutting operation for the j^{th} component is calculated as the product of the effective crew-time for that component, TE_j, and the cost per crew-hour, as displayed in the next-to-last column of Table E.2.

E.5.3 Cutting Analyses Details

The details of the analyses for cutting the RPV internals and the RPV into pieces suitable for packaging for disposal are presented in Table E.2, where each component is identified, and the number of cuts needed to section that component, the cutting thickness of the component, the total length of cut, the cutting rate for that material thickness, the cutting time and total elapsed time, and the labor costs for that component are listed.

E.5.4 GTCC Cutting and Packaging

The details of the cutting and packaging of material postulated to be activated levels to greater than Class C are presented in Table E.3. These materials are postulated to be packaged in 9-in. x 9-in. x 180-in.-square canisters whose envelope approximates that of a PWR fuel assembly and are compatible with PWR spent fuel racks and spent fuel cask baskets. The components are listed in column 1, and the component weights calculated from the

TABLE E.3. Calculated Weights, Full-Density Volumes, Packaged Volumes, and Numbers of Canisters of GTCC LLW Generated During the Decommissioning of the Reference PWR

Reactor Core Components	Component Weight (kilograms)	Full-Density Volume (m^3)	Packaged Volumes (m^3)[a]	No. of Canisters
Lower Core Barrel	31,563	3.932	5.28	22
Shroud and Former Plates	12,568	1.556	1.92	8
Thermal Shields	9,158	1.141	1.44	6
Lower Grid Plate	3,946	0.575	0.72	3
Upper Grid Plate[b]	3,973	0.495	1.20	5
Lower Support Columns[b]	2,922	0.363	0.48	2
Totals	64,130	8.062	11.04	46

(a) 9-in.-sq. by 180-in.-high canisters, disposal volume of 0.24 m^3 each.
(b) These items were not classified as GTCC LLW in the NUREG/CR classification reports[2, 3] but are included here as potential candidates.

reference PWR report[2] (and from Reactor Safety Analysis Reports and other supporting information) are given in column 2. Dividing those values by the theoretical density of the metal yields the full-density volumes given in column 3. The volumes of the component material, when packaged using the high-density approach developed in this appendix, are given in column 4. The numbers of 9-in.-square canisters that would arise from the high-density packaging approach are given in column 5.

E.5.5 Packages for Disposal

The number, type, and weight of packages, volume per package, number of shipments, weight per shipment, and disposal volume per shipment resulting from the cutting and packaging of the RPV and its internals are summarized in Table E.4.

E.5.6 Estimated Costs

The costs of removing, cutting, packaging, transport, and disposal are summarized in Table E.5. The removal/cutting labor costs are derived from Table E.2. The cost of disposal containers, transport cost (including cask rental), and disposal costs are derived from information listed in Table E.4 and Appendix B.

TABLE E.4. Summary of Information on RPV and Internals Packaged for Disposal

	Containers							
Component	Number	Ci/ea.	Liner Dose-rate (R/hr)	Weight[g] (lb)	Volume (ft^3)	Weight/ Shipment	Number of Shipments	Disposal Volume (ft^3)
Insulation	2[a]	<1	<2	1,730	96	3,460	1	192
Upper Core Assembly								
Top Plate	1[c]	<10		52,740	470	52,740	1	470
Upper Part of CRD Guide	2[a]	<50		12,465	96	24,930	1	192
Upper Part of Posts and Columns	4[a]	<50		4,957	96	19,826	1	384
Lower Part of Posts, Columns, CRD Guides	2[b]	<22,000	30	10,850	126	70,170	2	252
Lower Core Assembly								
Upper Barrel	2[a]	<1000	5	11,645	96	23,290	1	192
	3[b]	<1,000	5	9,250	126	68,570	3	378
Thermal Shields	6[d]	130,000		3,665[h]	8.4	54,865	6[i]	50.4
Shroud Plates and Formers	8[d]	3.065 M		3,764[h]	8.4	54,964	8[i]	67.2
Upper/Lower Grid Plates, Upper Part of Support Posts	10[d]	505,000		2,044[h]	8.4	83,288	5[j]	84.0
Lower Barrel	22[d]	586,000		3,463[h]	8.4	54,663	22[i]	184.8
Forging, and Tie Plates	6[b]	<2500	10	12,700	126	72,020	6	756
Lower Posts, Inst. Guides	1[b]	<300	5	12,400	126	71,720	1	126
Reactor Vessel								
Upper/Lower Heads	7[a]	<5		25,100	96	50,200	3.5	672
Upper and Lower Head Flanges	7[a]	<10		24,030	96	48,060	3.5	672
Nozzle Sections	8[e]	<20		22,260	62.5	44,520	4	500
Lower Wall	22[f]	<17,000	2	15,234	36	74,000	22	792
Studs and Nuts	2[a]	<10		18,400	96	36,800	1	192

(contd on next page)

TABLE E.4. (contd)

Component	Containers Number	Ci/ea.	Liner Dose-rate (R/hr)	Weight[g] (lb)	Volume (ft^3)	Weight/ Shipment	Number of Shipments	Disposal Volume (ft^3)
CRD and Instrument Guide Penetrations	1[a]	<1		1,600	96	1,600	1	96

(a) Standard Box, 4 ft x 4 ft x 6 ft, (600 lb empty) ($645 ea.).
(b) Cask Liner for 8-120B cask, 62 in. OD x 72 in. high, (2,000 lb empty) ($4,565 ea.). Empty cask wt. 59,320 lb.
(c) Special Container, U-shaped steel box (174 in. dia. x 210 in. long x 45 in. high), (1,500 lb empty) ($1,565 ea.).
(d) 9 in. x 9 in. x 180 in canister for GTCC material, (300 lb empty) ($520 ea.).
(e) Special Container, Fitted to inner wall shape, welded to wall, nozzle capped, (300 lb empty) ($470 ea.).
(f) Cask Liner for 8-120B cask, Oval-shaped, 16.5 in. x 60 in. x 52 in., (1,200 lb empty) ($4,695 ea.).
(g) Includes Container Weight.
(h) Averaged over all canisters of this set.
(i) NAC-LWT cask carrying 1 canister per shipment. Empty cask wt. 51,200 lb.
(j) TN-8 cask carrying 2 canisters per shipment. Empty cask wt. 79,200 lb.

E.5.7 Postulated Schedule for Cutting and Packaging the RPV and Its Internals

For this schedule analysis, it is assumed that the cutting and packaging activities occur on 2 shifts per day, with movement of casks and boxes into and out of the containment building occurring on the third shift. This latter activity is performed by the handling/shipping crew, not by the cutting crews.

The initial 2 weeks (20 shifts) of the RPV internals cutting operations are devoted to installing and testing the plasma arc torches and the manipulator systems in the refueling cavity area. The core assembly is removed from the RPV and placed in its stand in the refueling cavity during this period. Cutting and packaging of the RPV internals proceeds in the sequence shown in Figure E.5. Upon completion of the cutting and packaging operations, a final week is devoted to removal of the cutting systems and to final packaging and shipping from the refueling cavity. At that time, the remaining water in the refueling cavity is drained and the cavity is available for decontamination. The elapsed calendar time for the cutting and packaging of the RPV internals is estimated to be about 3½ months.

The initial week (10 shifts) of the RPV sectioning is devoted to installing and testing the plasma arc and oxyacetylene torches and the manipulator

TABLE E.5. Summary of Costs for Cutting, Packaging, Transport, and Disposal of the Reactor Pressure Vessel and Its Internal Structures[a]

Components	Costs in 1993 Dollars				
	Cutting[b]	Containers[c]	Transport[d]	Disposal[e]	Total
Insulation	50,439	1,290	1,332	9,311	108,600
		4,695	33,189	8,345	
Top Plate	3,409	1,565	1,332	34,508	40,813
Upper Portion, CRD Guides	79,304	1,290	1,332	11,441	212,155
Upper Portion, Posts & Columns		2,580	1,332	18,622	
Lower Portion, Posts, Columns, CRD Guides		9,390	39,852	47,013	
Upper Core Barrel	12,305	1,290	1,332	13,780	127,028
		14,085	47,396	36,840	
Thermal Shields	17,667	3,120	127,994	327,600	476,382
Shroud Plates and Formers	50,551	4,160	162,241	436,800	653,751
Upper/Lower Grid Plates	25,219	4,160	129,310	436,800	595,489
Upper Portion of Support Posts & Inst. Guides	22,930	1,040	61,446	109,200	194,616
Lower Core Barrel	76,720	11,440	401,358	1,201,200	1,681,718
Support Forging and Tie Plates	42,712	28,170	68,537	84,170	223,589
Lower Posts and Instrument Guides	22,930	4,695	33,449	11,643	72,717
Upper/Lower RPV Heads	28,224	4,515	4,661	107,139	144,539
Upper/Lower RPV Flanges	11,238	4,515	4,661	69,864	90,278
Nozzle Sections	4,346	3,760	5,327	66,847	80,281
Lower Wall	28,480	103,290	184,231	257,783	573,784
Studs & Nuts	---	1,290	1,332	14,636	17,258
CRD & Instrument Penetrations	37,468	645	1,332	4,656	44,101
Totals	504,943	210,985	1,312,975	3,308,196	5,337,100

(a) Costs do NOT include a 25% contingency.
(b) Data from Table E.2, rearranged to correspond to the packaging arrangements in Table E.4.
(c) Calculated using data from Table E.4
(d) Calculated by Cost Estimating Computer Program, using data from Table E.4.
(e) Calculated by Cost Estimating Computer Program, using data from Table E.4.

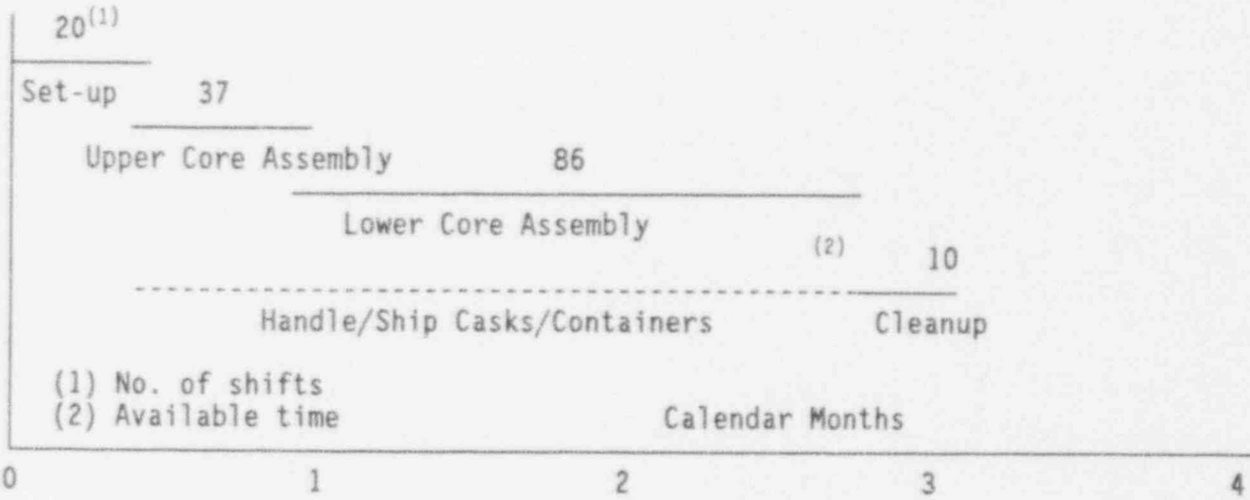

FIGURE E.5. Postulated Schedule for Cutting/Packaging the RPV and Internals

system in the reactor vessel, and to installing the RPV support structure beneath the RPV. Cutting and packaging of the RPV proceeds in the sequence shown in Figure E.6. Upon completion of the cutting and packaging operations, a final week is devoted to removal of the cutting systems and to final packaging, shipping, and cleanup. Thus, the elapsed calendar time for the cutting and packaging of the RPV is estimated to be about 1½ months.

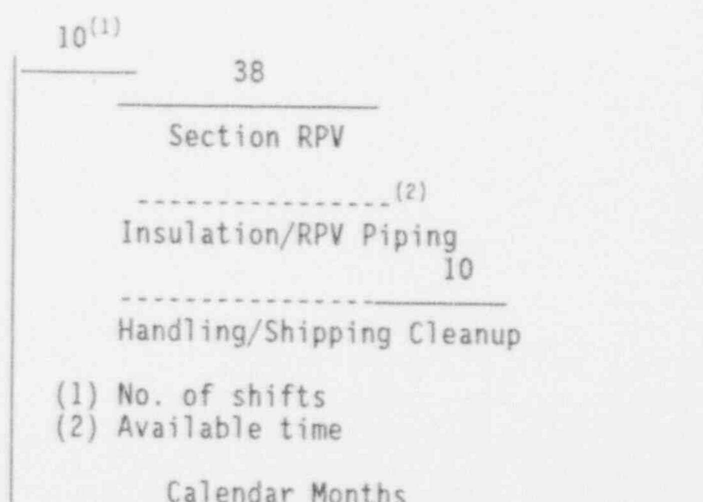

FIGURE E.6. Postulated Schedule for Cutting/Packaging the RPV

E.5.8 Impacts on Transport and Disposal Costs of Disposal at Barnwell

The transport and disposal costs for low-level radioactive wastes are sensitive to the distance between the reactor site and the disposal facility, and to the charge schedule at the disposal site. The analyses presented previously in this appendix are based on transport of the LLW portion of the sectioned and packaged segments of the reactor pressure vessel and the vessel internal from the Trojan site to and disposal at the U.S. Ecology facility at Hanford, Washington. All of these materials are assumed to be transported by truck. These same analyses were repeated for transport from the Trojan site to and disposal at the Chem-Nuclear facility at Barnwell, South Carolina. The results of these analyses are presented in Table E.6. The estimated transport cost to Barnwell is about a factor of 3 larger than the transport cost to Hanford, reflecting the much greater distance traveled. Similarly, the disposal cost at Barnwell is nearly a factor of 6 larger than the disposal cost at Hanford, reflecting the much higher disposal rate structure at Barnwell.

TABLE E.6. Sensitivity of Transport and Disposal Costs for the LLW Portions of the Reactor Vessel and Vessel Internals to Disposal Facility Location and Rates[a]

Location	Transport Costs (1993 $)	Disposal Costs (1993 $)
Hanford LLW	430,626	796,596
Barnwell LLW	1,330,489	4,585,646

(a) Costs do NOT include a 25% contingency.

E.6 REFERENCES

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4. R. A. Lundgren. Reactor Vessel Sectioning Demonstration. PNL-3687, (Revision 1), U.S. Department of Energy Report by Pacific Northwest Laboratory, Richland, Washington. September 1981.

5. M. S. McGough, W. E. Austin, and G. J. Knetl, "Performance of the Automated Cutting Equipment System During the Plasma Cutting of the Three Mile Island Unit 2 Lower Core Support Assembly," Nuclear Technology, Vol. 87, pp. 648-659, November 1989.

6. ECFOCUS, No. 11, Commission of the European Communities, DG XII - Science, Research and Development - Joint Research Centre, December 1989.

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

APPENDIX F

STEAM GENERATORS DISMANTLEMENT AND DISPOSAL ACTIVITIES, MANPOWER, AND COSTS

APPENDIX F

STEAM GENERATORS DISMANTLEMENT AND DISPOSAL ACTIVITIES, MANPOWER, AND COSTS

The postulated dismantlement and disposal activities for the steam generators, together with estimated manpower, costs, and schedule, are presented in this appendix. It should be recognized that most dismantlement costs can be estimated using standard costs per unit of removed quantity. After construction of the plant, quantities of material and equipment required in the plant can be estimated. These quantities can then be multiplied by a standard removal cost per unit, which includes the values of any work-related adjustment factors, to obtain total removal costs. This is not generally true, however, in the case of extra-large components such as the steam generators, which are more complex and reactor-specific in nature. Therefore, such items are estimated separately (as in this appendix) and are presented in cost summaries, elsewhere in this study, as an aggregate cost line item, with reference to this appendix for details.

Because of the many variables involved, the analysis presented in this appendix is not intended to result in an "exact" solution concerning costs or occupational doses for steam generator removal during decommissioning. The resultant cost and dose values are intended as reliable updated estimates (based on the key assumptions given in Section F.1) for the removal of steam generators from the reference pressurized water reactor (PWR) during decommissioning and their subsequent disposal. Consequently, the results of this analysis make a useful addition to the already existing decommissioning data base and increase its general applicability.

Following the assumptions, the methodology used in this analysis is presented in Section F.2, followed by a brief description of the steam generators in Section F.3. The steam generators removal and disposal activities are described in Section F.4. Section F.5 covers the radwaste handling and processing associated with the steam generator removal project. The results of a reevaluation of the anticipated occupational radiation dose for the project are discussed in Section F.6. Estimated costs and schedules and a discussion of important considerations associated with recent steam generator removal projects are presented in Sections F.7 and F.8, respectively. The references for the appendix are given in Section F.9.

F.1 ASSUMPTIONS

In developing scenarios and the subsequent analyses, the following assumptions were used:

- The removal of the reference plant's steam generators is based, in part, upon a reassessment of cost and dose estimates for removal of steam generators during decommissioning presented in Reference 1, which included a comprehensive review of recent steam generator changeout programs.

- One-piece steam generator removal is postulated, based upon three of the most important considerations - adequacy of plant equipment hatch egress, reduced radiation exposure, and a shorter overall schedule duration.

- The radiation dose rates used in the analyses remain essentially unchanged from those estimated in the original study, NUREG/CR-0130,[2] which, in turn, were based on conservative estimates of the effectiveness of the chemical decontamination of the plant systems. The rate at which radiation levels diminish with time during the decommissioning efforts is assumed to be controlled by the half-life of ^{60}Co.

- Steam generator exterior surfaces will be decontaminated, as required. Following injection of low-density cellular concrete to ensure encapsulation of the internal contaminants, all openings will be seal-welded, since the steam generators are anticipated to serve as their own burial containers. It is further assumed that the NRC issues Certificates of Compliance for shipments of the steam generators on an open waterway, as Type A LSA transport packages.

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

- The waste disposal costs presented in this study were specifically developed for the reference PWR, which is located within the Northwest Compact, assuming disposal at the U.S. Ecology site in Richland, Washington. Steam generators are removed sequentially and barged two at a time to U.S. Ecology, Inc. This scenario will consolidate shipping and reduce mobilization costs for the heavy haul vehicles used by the vendor mentioned above. To provide additional information, the costs also were estimated for shipping and disposal of the reference steam generators at the Barnwell site in Barnwell, South Carolina.

F.2 METHODOLOGY

Two removal scenarios were considered: 1) sectioning each steam generator into two or more pieces for subsequent transport by rail as delineated in NUREG/CR-0130[2] and 2) removing them intact for subsequent transport by barge. The one-piece removal scenario appeared to have the greatest estimated potential for minimizing cost and occupational radiation exposure (ORE) and was analyzed in this study.

F.3 STEAM GENERATORS (4 EACH)

The approximate weight of each of the reference steam generators is 312 Mg (688,000 lb), and about 321 Mg (about 708,000 lb) with shipping saddle and lifting beams. The steam generator shown in Figure F.1 is a vertical shell and U-tube unit with integral moisture separating equipment. The present steam generators at the reference plant are Westinghouse Series 51 models.

Each steam generator is supported on four hinged columns. Lateral resistance is provided by two ring girders. The lower girder is designed to permit the thermal movements of the support columns, vessel and primary piping in the horizontal and vertical directions. The upper girder is located close to the center of gravity of the steam generator. Lateral resistance at this level is provided by four bumper stops and two hydraulic suppressors (snubbers), as shown in Figure F.2.

The pertinent features of the reference plant's steam generators used in this analysis are given in Table F.1.

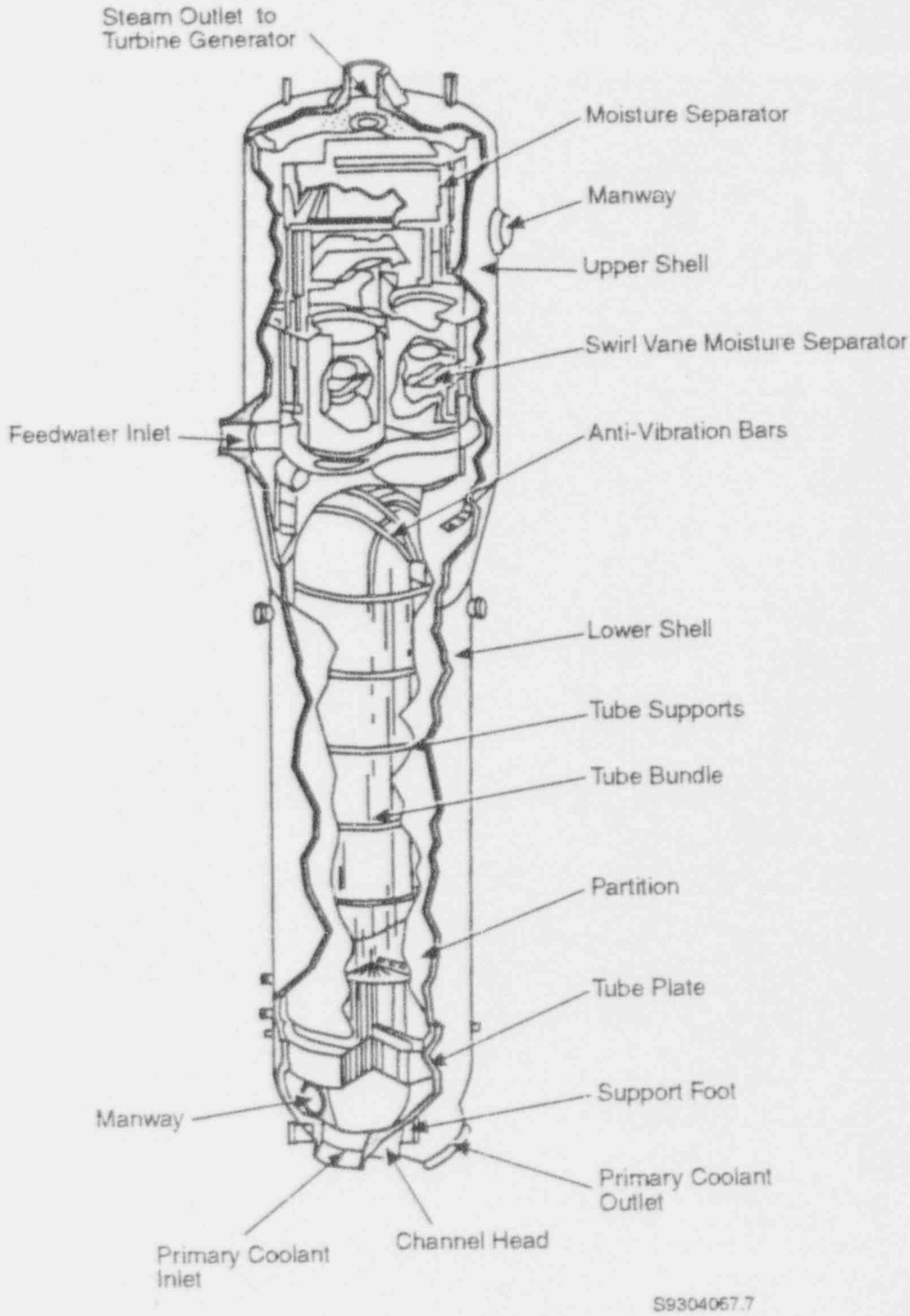

FIGURE F.1. Steam Generator

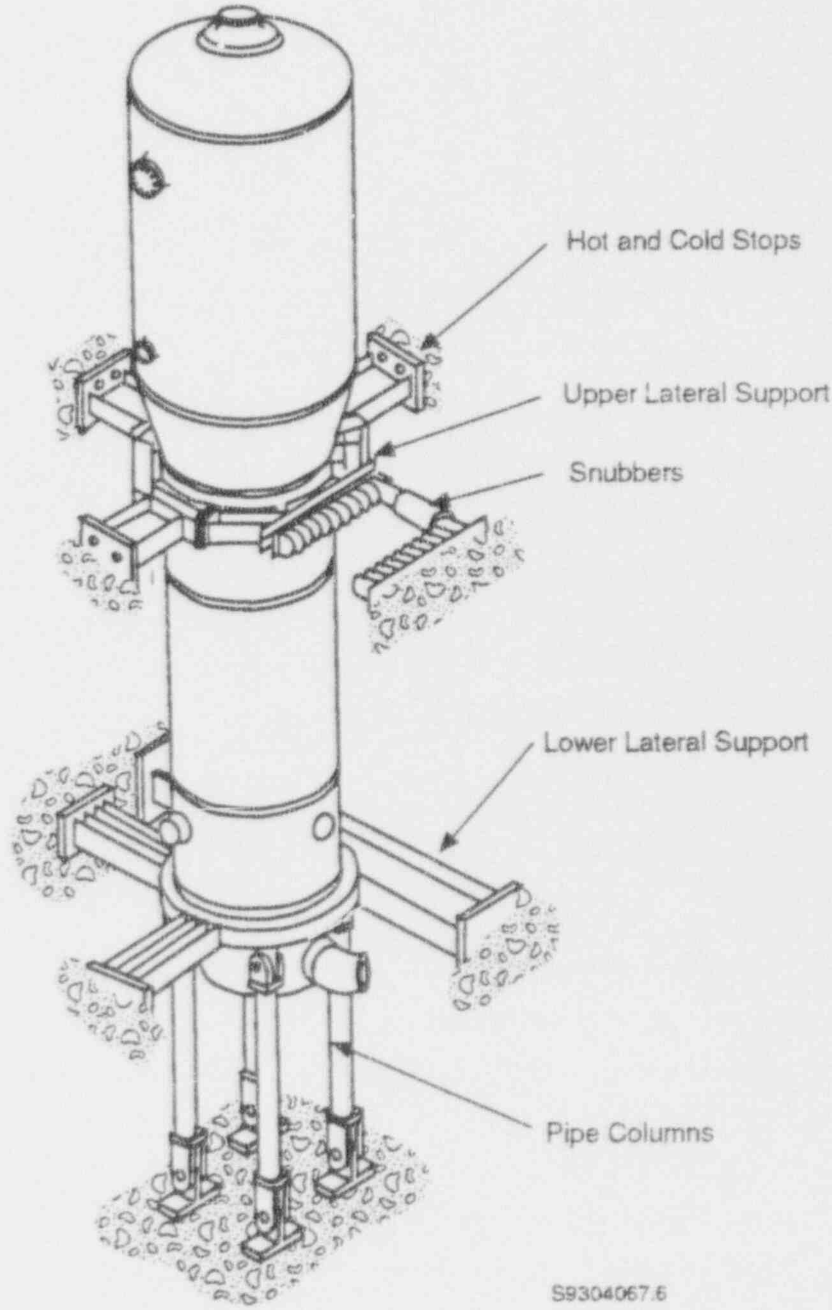

FIGURE F.2. Steam Generator Supports

TABLE F.1. Steam Generator Data

Total Heat Transfer Surface Area	4786 m^2	(51,500 ft^2)
Overall Height	20.63 m	(67.67 ft)
Diameter, Upper Portion	4.47 m	(14.67 ft)
Lower Portion	3.43 m	(11.25 ft)
Number of U-tubes	3388	
U-tube outer diameter	22.2 mm	(0.875 in.)
Tube wall thickness, nominal	1.27 mm	(0.050 in.)
Number of manways	4	
Estimated volume	230.2 m^3	(8130 ft^3)

F.4 STEAM GENERATORS REMOVAL AND DISPOSAL

For the purpose of this analysis, the steam generator removal and disposal operations were developed in four phases: Phase 1 - Precursor Tasks, Phase 2 - Preparatory Activities, Phase 3 - Removal Activities, and Phase 4 - Heavy-Lift Rigging, Transport, and Disposal Activities.

F.4.1 Phase 1 - Precursor Tasks

The selected Phase 1 precursor tasks (presented in Table F.2) are postulated as being completed before removing the steam generators.

F.4.2 Phase 2 - Preparatory Activities

The estimated labor hours for preparatory activities, per steam generator, from the Point Beach Nuclear Plant Number 1 (PBNP-1) two-piece removal program[1,3,4] were ratioed down to reflect actual hours as closely as possible for the one-piece removal scenario analyzed in this study. Those results, per steam generator, were compared to similar tasks for the Surry steam generator removal program.[5] Where both numbers were available, an average value per steam generator was computed and used in this analysis (see Table F.3).

TABLE F.2. Phase 1 - Precursor Tasks for Steam Generators Removal[a]

1. Chemical decontamination of the Reactor Coolant System (done within the first year after final reactor shutdown).

2. The transferring of the spent nuclear fuel from the fuel pool to an independent spent fuel storage installation (as discussed in Appendix D, the fuel pool could not be finally emptied until at least 7 years following reactor shutdown).

3. Disassembly, decontamination (as deemed appropriate), packaging, and disposal of all spent fuel storage racks.

4. Draining and decontamination of the spent fuel pool.

5. Decontamination of the 93-ft elevation in the Fuel Building.

6. Removal of appropriate sections of the Fuel Building roof to provide clearance for lifting the steam generators by a contractor. For the purpose of this analysis, the cost associated with this activity has been classified as a cascading cost[b] because no radioactively contaminated materials are anticipated to be involved.

7. Barge slip preparations (primarily dredging operations) - a cascading cost.[b]

8. Completion of a job training program for all staff participating directly in the steam generator removal operations.[c]

(a) Precursor tasks 1 through 5 are listed here for completeness. However, since they are accounted for elsewhere in this study, they are not costed in this appendix to avoid double-counting.

(b) Cascading costs are defined as those costs associated with the removal of noncontaminated and releasable material in support of the decommissioning process (e.g., if it is considered necessary to remove portions of the top floors or a roof to get at a bottom-floor nuclear component).

(c) It is assumed that existing, onsite training mockups and facilities will be used for this program. Recent steam generator removal project experience reveals the highly successful nature of such training programs in maximizing the productivity and reducing person-Rem exposure.

It is estimated that two dedicated 60-person crews, working one crew on each of two shifts, will be required to complete the Phase 2 activities in approximately 1.75 months. Each crew is assumed to consist of the staff listed in Table F.4. The work duration adjustment factors considered appropriate for the steam generator preparatory tasks given in Table F.3 and for

TABLE F.3. Phase 2 - Preparatory Activities

Task Description[a]	Estimated Labor (person-hours)
Polar Crane Modification	745
Install Steam Generator Transport System	3,446
Remove Containment Obstructions	513
Protection of Containment Components	769
Install Temporary Ventilation System	566
Temporary Scaffolding	5,795
Temporary Lighting and Power	680
Cleanup and Decontamination[b]	8,367
Polar Crane Operator	616
Health Physicist/Radiation Monitors[c]	3,080
Shielding	7,262
Install Service Air System	742
Work Platform Modification	2,312
Miscellaneous[c]	2,052
Subtotal Phase 2	36,945

(a) For the purpose of subsequent use in summary line-item cost presentations in this study, all tasks shown in the table are essentially associated with removal activities (as opposed to decontamination activities), unless indicated otherwise.

(b) This task has been designated a decontamination task; also see footnote (a).

(c) The subsequent calculated costs associated with this task have been evenly divided between removal and decontamination.

TABLE F.4. Staffing and Labor Rates Postulated for Removal Crews

Person-hrs/crew-hr	Category	Labor Rate($/hr) ($/labor-hr)	Cost[a] ($/crew-hr)
26.0	Craftsman	49.70	1,292.20
23.0	Laborer	26.37	606.51
5.0	Foreman	54.84	274.20
6.0	H. P. Tech.	36.82	220.92
60.0			2,393.83

Average labor cost per crew-hour, including shift differential[b] = $2,513.52

(a) Includes 110% overhead, 15% DOC profit.
(b) 10% shift differential for second shift.[5]

the steam generator removal tasks (presented in Table F.5 in Section F.4.3) are:

Duration Adjustment Factors

•	Radiation Protection/ALARA	10.0%
•	Respiratory Protection	20.0%
•	Height/Access Adjustment for Scaffold Work	10.0%

Lost-Time Adjustment Factors

•	Protective Clothing	36.4%
•	Break Time	9.1%

F.4.3 Phase 3 - Removal Activities

The estimated labor hours for removal activities, per steam generator, from the PBNP-1 removal program[1,3,4] were ratioed down to reflect actual hours as closely as possible for the one-piece removal scenario analyzed in this study. Those results, per steam generator, were compared to similar tasks for the Surry steam generator removal program.[5] Where both numbers were available, an average value per steam generator was computed and used in this analysis (see Table F.5).

It is estimated that two dedicated 60-person crews, working one crew on each of two shifts, will be required to complete the Phase 3 activities in

TABLE F.5. Phase 3 - Removal Activities

Task Description[a]	Estimated Labor (person-hours)
Removal of Insulation	2,594
Removal of Miscellaneous Piping	2,580
Cutting of Reactor Coolant Piping	-[b]
Cutting of Mainstream and Feedwater Piping	1,657
Disassembly of Steam Generator Supports	1,280
Removal of Steam Generator Level Instruments and Blowdown Piping	1,952
Temporary Scaffolding	13,296
Temporary Lighting and Power	4,548
Cleanup and Decontamination[c]	8,370
Polar Crane Operator	827
Health Physics Technicians[d]	4,136
Material Handling, Equipment Maintenance, and Miscellaneous Construction Activities[d]	8,372
Subtotal Phase 3	49,612

(a) For the purpose of subsequent use in summary line-item cost presentations in this study, all tasks shown in the table are essentially associated with removal activities (as opposed to decontamination activities), unless indicated otherwise.
(b) This task is listed here for completeness. However, since the cost of this task is accounted for elsewhere in this study, it is not costed in this table to avoid double-counting.
(c) This task has been designated a decontamination task; also see footnote (a).
(d) The subsequent calculated costs associated with this task have been evenly divided between removal and decontamination.

approximately 2.35 months. Each crew is assumed to consist of the staff listed in Table F.4.

Most of the steam generator insulation is comprised of packages of mineral fiber material, sandwiched between multiple layers of thin stainless steel, which are contoured to surround the entire generator, top and bottom heads and the cylindrical side wall. These packages are approximately 4 in. thick. The total volume of insulation for all 4 steam generators is estimated at about 11,028 cubic feet. Because the insulation package sizes are designed to facilitate installation and removal, very little, if any, cutting is anticipated before packaging. Using an estimated packing efficiency factor of 1.5, twelve 8-ft x 8-1/2-ft x 20 ft maritime containers (Sea-Vans) are packed with the insulation for unshielded shipment to Hanford. It is assumed that virtually all of the insulation is disposed of in this manner, since it could be argued that interior spaces between layers could not be proven to be contamination free without complete disassembly.

Once the insulation has been removed from a steam generator and packaged, the piping from the reactor coolant system (2 RCS cuts per generator), the feedwater system (1 cut per generator), the steam outlet to the turbine generator (2 cuts per generator), as well as the miscellaneous instrument and control lines are accessible for cutting. After cutting, the openings are seal-welded, since the steam generator is anticipated to serve as its own burial container. The steam generator is rigged and supported, as needed, in preparation for disengagement from the steam generator's support mechanisms (see Figure F.2). The lower support ring is cut as necessary, with oxy-acetylene torches, to allow clearance for RCS piping stubs when the steam generator is subsequently lifted. Similarly, the upper lateral support ring is cut as necessary to provide adequate clearance for lifting. With the insulation and the pipes removed, lifting of the steam generator can proceed.

F.4.4 Phase 4 - Heavy Lift Rigging, Tr: sport, and Disposal

This work is assumed to be done by a contractor (see footnote 1, Section F.1) and consists of rigging, handling, temporary storage, and placement of the steam generators on a barge, two to a barge, for hauling to the Hanford site for disposal. The contractor furnishes test equipment, test weights, test lifting equipment, and related items to be used in the performance of the work. The contractor is anticipated to use the polar bridge crane without charge. This crane is designed for both trolley and bridge travel under a 455-ton lifting capacity.

Inside the containment, the steam generator is raised by the polar bridge crane. It is placed in an upending device or skid (which is assumed to be furnished by the utility) and lowered to a horizontal position for extraction from the containment vessel - an auxiliary trolley placed on the Reactor Building bridge crane rail is used in conjunction with a runway and the Fuel Building crane, located outside the equipment hatch, to move the generator from the Reactor Building to the Fuel Building laydown storage area. In turn, each steam generator is placed in the laydown area at the 93-foot elevation in the Fuel Building in preparation for the 48-foot lift to grade level. It is estimated that this particular effort might amount to one work day for each generator. The generator is then lifted out of the Fuel Building, via an opening created in the building roof, and placed onto a cradle/trailer for movement to the barge slip and onto a barge for river shipment to the U.S. Ecology, Inc., commercial disposal site at Hanford.

F.5 RADWASTE HANDLING AND PROCESSING

The handling and processing of the steam generator removal project's radwaste is postulated to be accomplished as an integrated effort between the DOC and the licensee's personnel. It is assumed that limited storage facilities at the reference site require the continuous handling, processing, and shipping of radwaste. DOC personnel are responsible for the removal of waste as it is generated inside containment during steam generator removal. Waste is anticipated to be removed from containment and deposited at a temporary holding area. DOC personnel will prepare and package the waste for disposal.

Two drum compactors are assumed to be available during the steam generator removal project for the compaction of compressible waste. Noncompressible waste is packaged in B-25 metal containers (96 cubic feet disposal capacity). All of the waste is shipped from the site as the accumulated waste volume dictates optimal use of shipping vehicles.

The initial cleanliness of the Containment Building, and a continuing effort to control contamination, is anticipated to prevent the contamination of much of the equipment brought into containment. This effort is expected to result in a minimization of radwaste volumes.

The estimated radwaste volume for the reference PWR was ratioed from the PBNP-1 steam generator project radwaste volumes reported in Reference 4. Activities associated with the steam generator preparatory and removal phases for the reference PWR are estimated to generate a radwaste volume of 15,684 cubic feet, of which about 3,780 cubic feet are estimated to be compressible wastes and the remaining 11,904 cubic feet are estimated to be non-compressible wastes. These waste volumes do not include the steam generators (see Table F.1) or the insulation (discussed previously in Section F.4.3). The compressible wastes are shipped as LSA material to Hanford from the reference PWR in 55-gal drums. Approximately 504 drums are estimated to be utilized as shipping containers. Noncompressible wastes are shipped to Hanford using an estimated 124 B-25 containers.

F.6 OCCUPATIONAL RADIATION DOSE

The results of an analysis to evaluate and compare the occupational radiation doses of recent PWR steam generator changeout programs with the dose estimates previously developed for DECON of the reference PWR described in NUREG/CR-0130 are contained in Reference 1. For ease of reference and because they provide the bases for the steam generator removal scenario analyzed in this study, the principal results are given, in brief, in the following subsections.

The comparison of the reported exposures for the steam generator removal project at the Point Beach Nuclear Power Plant No. 1 (PBNP-1), which was selected for examination in Reference 1, considers in detail the tasks involved to determine their applicability to decommissioning under the DECON alternative. Data on the occupational exposure for that removal/replacement project were obtained from the literature as well as from personal communication with utility personnel. Analysis of those data involved assessing the reported doses concerning all specified tasks and then eliminating those doses associated with tasks determined to be unrelated to decommissioning. In addition, dose adjustments were made where it was determined that the task was performed in a different sequence or manner than envisaged during decommissioning. The adjusted doses were then compared to the doses previously estimated in NUREG/CR-0130. The comparison showed that the estimated total radiation dose to decommissioning workers for the removal of steam generators during DECON remained essentially unchanged from the total dose initially estimated in NUREG/CR-0130 for this task.

It should be emphasized that the dose consequences for any decommissioning alternative in which the steam generators are to be physically removed are quite different from the dose consequences associated with the replacement of steam generators during reactor outages. This is because, during a replacement effort, significant additional activities are necessary to assure continued operation, including preservation of building structures, concern for capital equipment, materials, continuing use of air, water, etc. On the other hand, large-component removal (such as steam generator removal) during decommissioning does not require any activities to assure future operability, and thus involves a much smaller commitment of resources than does removal and replacement of the steam generators.

Upon examination and discussion (with PBNP-1 staff) of the elemental constituents of each activity given in Table F.6, the occupational radiation dose was adjusted by PNL in Reference 1 for the "removal only" tasks concerning both PBNP-1 steam generators. The results are presented in Table F.7, together with the rationale for the adjustments used to derive the estimated occupational radiation doses for steam generator removal during DECON. The estimated dose resulting from the postulated removal of the four steam generators similar to the PBNP-1 units during DECON, but without the benefit of a

TABLE F.6. Summary of Occupational Radiation Doses from the Point Beach Steam Generator Replacement Project[a]

Task	Dose (rem)
Containment access building preparation	0.09
Equipment move-in/set-up in containment	7.09
Containment access modification	2.27
Temporary shielding - install/remove	44.52
Biological shield - install/remove	0.13
S/G supports - remove/refurbish[b]	6.83
S/G temporary supports and restraints - install/remove	7.26
Temporary power installation	5.98
Temporary power removal--restoration of permanent power	0.18
Protection of containment components	4.29
Interference removal	0.92
Foundation shoring of containment access	0.83
Communication system - install/remove	0.58
Tenting	14.42
Breathing air system install/remove	0.15
Polar crane modification	11.97
Load test	0.52
Equipment decontamination	6.63
Cleanup and decontamination of containment	62.97
Insulation removal	15.16
S/G girth cuts	3.82
Steam drum handling	0.45
S/G main steam and feedwater pipe cuts	1.62
S/G small bore piping and instrument line cuts	2.10
S/G reactor coolant pipe cuts	35.13
S/G lower assembly removal	22.19
S/G laydown stands	0.37
Steam drum modification	16.22
S/G lower assembly installation	12.45
Reactor coolant pipe weld	135.70
S/G girth weld	6.18
S/G main steam and feedwater pipe weld	4.27
S/G blowdown pipe and instrument line weld	12.18
Post weld heat treatment	0.18
Insulation installation	39.36
Containment restoration	17.49
System integrity	3.76
Primary side search and retrieval	5.62
Secondary side search and retrieval	0.83
General containment entry and miscellaneous work	75.60
Total Occupational Dose	589.65

(a) The information in this table is extracted from References 3 and 4.
(b) S/G = steam generator.

TABLE F.7. Estimated Occupational Dose for the Postulated Removal of Four Steam Generators Similar to PBNP-1 Units During Immediate Dismantlement With and Without Chemical Decontamination of the Reactor Coolant System[a]

	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem)			Rationale for Dose Reduction		Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)[d]	
Immediate Dismantlement Task	Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Cause	Effect	Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Containment access building (CAB) preparation	0.09	--[e]	0.09	Although a CAB is considered an optional structure at the reference PWR, it is included in this study for conservatism.	Negligible, no change in estimate.	0.090	0.090
Equipment move-in/set-up in containment	7.09	--	7.09	Includes the movement and set-up of numerous items and materials not related to decommissioning, including refurbishment/repair tasks as well as SG installation, post-installation and startup activities.	Examination of PBNP-1 data suggests that approximately 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	2.363	2.363
Temporary shielding install/remove*[f]	44.52	44.52	89.04	This activity is somewhat mislabeled since it also includes installing and removing scaffolding (which was done twice). The majority of these activities are required only once during immediate dismantlement.[g]	Therefore, the total dose for 4 SG's is estimated to be 44.52 rem without chemical decontamination.	44.520	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		8.904

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem): Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)[d]: Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
S/G supports remove/ refurbish*	6.83	6.83	13.66	Refurbishment is not necessary for decommissioning--simply remove and box for disposal.	Dose reduced by a factor of 10 due to severely reduced time and staff labor requirements.	1.366	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		0.273
Temporary power installation	5.98	--	5.98	Cable runs for 15 or more TV cameras and sound equipment, welding machines, etc. Much of the needed cutting equipment will already be inside the containment vessel (see schedule delineated in Figure G.2-2 of Reference 1). In addition, only 3 to 4 TV cameras are anticipated to be used during decommissioning. Power needs associated with SG installation, post-installation, and startup activities are not required.	It is estimated that approximately 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	1.993	1.993
Temporary power removal--restoration of permanent power	0.18	--	0.18	Restoration of permanent power is an unnecessary step for decommissioning.	It is estimated that approximately 1/2 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	0.090	0.090

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem)			Rationale for Dose Reduction		Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)[d]	
	Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Cause	Effect	Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Protection of containment components	4.29	--	4.29	An inventory is taken from prints and drawings to identify those components that must be protected for use during subsequent startup of the reactor. It is not known precisely how many of these components will be needed for decommissioning but according to the schedule presented in Figure G.2-2 of Reference 1, the reactor pressure vessel has already been removed and the RCS is empty.	It is estimated that approximately 1/2 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	2.145	2.145
Interference removal*	0.92	0.92	1.84	Conduits and minor piping which might interfere with the removal of the lower assemblies are identified, locations are precisely marked (for subsequent reinstallation), removed, and stored.	It is estimated that approximately 1/4 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 25%.	1.380	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		0.276
Foundation shoring of containment access	0.83	--	0.83	This task is included in this study for conservatism, because such shoring may be necessary at the reference PWR.	Negligible, no change in estimate.	0.830	0.830
Communication system install/remove	0.58	--	0.58	No dose reduction for this task is anticipated.	No change in estimate.	0.580	0.580

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem): Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)[d]: Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Tenting*	14.42	14.42	28.84	Tenting requirements inside the SG cubicles for removal and installation activities; tenting requirements for cutting and welding RCS piping; and staging associated with these tasks.		28.840	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		5.768
Breathing air system install/remove	0.15	--	0.15	Backup system to existing containment vessel system; includes laying down hoses from a compressor located outside of the containment vessel.	No change in estimate.	0.150	0.15
Polar crane modification	11.97	--	11.97	It should be recognized that many aspects of this task are unique to PBNP-1. This task includes erection of a reinforced steel structure over the reactor cavity that was used to support a center beam that extended from the structure to the polar crane bridge. This upgrade increased the lifting capacity of the polar crane from 100 to 230 tons. Additional, but smaller modifications were made during the upgrade as well.	Upgrading the polar crane for SG removal at the Trojan plant (the reference PWR) is a far less complex operation than the upgrade at the PBNP-1. It consists of the installation of a blocking arrangement located at the same height in the containment vessel as the polar crane itself. It is estimated that approximately 1/2 of the staff labor	5.985	5.985

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem): Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)(d): Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
					requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.		
Load test	0.52	--	0.52	During load testing, the crane load block bearings and a motor starter on the hoist failed and had to be replaced.	It is estimated that approximately 1/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 33%.	0.347	0.347
Equipment decontamination*	6.63	6.63	13.26	This task includes SG hose-down and waxing as well as attempts to decontaminate RCS pipe cuts in preparation for subsequent welding.	For the most part, the decontamination of RCS pipe cuts proved futile, but somewhat costly in terms of pers-rem. It is estimated that approximately 1/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 33%.	8.884	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		1.777

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem): Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)[d]: Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Cleanup and decontamination of containment	62.97		62.97	An ongoing (but not continuous) effort throughout the project at PBNP-1.	No change in cleanup procedure is anticipated at the reference PWR, except that the project starts in the 16th month after final reactor shutdown and after other major decommissioning tasks have been completed (e.g., reactor pressure vessel segmentation and removal). It is estimated that approximately 2/3 of these staff labor requirements are not necessary at this stage in the schedule; therefore, the dose is reduced by a factor of 3.	20.990	20.990
Insulation removal*	15.16	15.16	30.32	At PBNP-1, this task involved the removal of an older type of insulation; subsequently, it was replaced with the stainless steel strap-on type of insulation.	A reduction in staff labor of about 25% is anticipated at the reference plant because it uses the newer type of insulation.	22.740	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		4.548

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem): Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)(d): Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
S/G girth cuts*(i)	3.82	3.82	7.64	Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.	7.640	1.528
Steam drum handling(i)	0.45	0.45	0.90	This task included lifting the steam drums, placing them in storage stands inside the containment vessel and includes all refurbishment work that was subsequently done.	It is estimated that fully 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	0.300	0.300
S/G main steam and feedwater pipe cuts	1.62	1.62	3.24	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	1.620	1.620
S/G small-bore piping and instrument line cuts*	2.10	2.10	4.20	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	2.100	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		0.420
S/G reactor coolant pipe cuts*	35.13	35.13	70.26	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	35.130	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		7.026

TABLE F.7. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (pers-rem): Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (pers-rem)[d]: Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
S/G lower assembly removal*	22.19	22.19	44.38	A large number of preparations are required for this task.		44.380	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		8.876
S/G laydown stands[i]	0.37	--	0.37	This task included building the stands, inside containment, for holding the steam drums in upright positions. These were special stands for a special purpose.	Much simpler devices can be used for decommissioning; therefore, the task time/dose is reduced by at least a factor of 2.	0.185	0.185
General containment entry and miscellaneous work*[j]	75.60	--	75.60	This general category of activities is encompassed by the 170 man-rem originally estimated in Table G.3-1 of NUREG/CR-0130 for "miscellaneous activities" for the entire immediate dismantlement effort, including removal of the reference PWR's steam generators. Therefore, the category "General containment entry and miscellaneous work" is not included in the total for steam generator removal only.		0	0
Total dose	324.41	153.79	478.20			234.646	77.064

TABLE F.7. (contd)

(a) The information in this table is extracted from Table F.6 and modified for this study (see text for details).
(b) SG = steam generator.
(c) The information in this column is taken directly from Table F.6.
(d) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures. Immediate dismantlement values shown in the table were calculated based upon the steam generator removal program occurring about 18 months following final reactor shutdown.
(e) Dash indicates that the task is required to be done only once per plant.
(f) Events likely to be affected by chemical decontamination of the RCS are designated by an asterisk.
(g) Private communication with Douglas F. Johnson of Wisconsin Electric Power Company on September 24, 1987.
(h) Chemical decontamination of the RCS is the largest dose reduction factor of commonality used in this table. For the purpose of this study, it is conservatively estimated to reduce doses by a factor of five.
(i) Not applicable when a steam generator is removed in one piece.
(j) Table G.3-1 of NUREG/CR-0130 allows a total of 170 pers-rem for miscellaneous work during the entire immediate dismantlement effort.

chemical decontamination of the reactor coolant system (RCS), and the estimated dose resulting from the removal of four steam generators during DECON following a RCS chemical decontamination, are presented. Events likely to be affected by the chemical decontamination are identified in the table with an asterisk. Only those activities that would be performed during decommissioning, or would fall under the task description of steam generator removal in NUREG/CR-0130 are included. The adjusted total dose shown in the table (77.1 person-rem) is based on the conservative assumption that the chemical decontamination of the RCS results in a decontamination factor (DF) of 5. If a DF of 2 is assumed, the total occupational radiation dose is calculated to be about 136.2 person-rem.

The DECON values shown in Table F.7 were calculated for the reference PWR in Reference 1, based upon the steam generator removal program occurring at about 18 months following final reactor shutdown. However, for purposes of this analysis, the steam generator removal program is postulated to occur about 8 years following final shutdown, after the fuel pool is finally emptied (see Chapter 3 for details) and after the Fuel Building is decontaminated. Therefore, based on ^{60}Co decay, the applicable dose rates shown in Table F.7 can be expected to be further reduced by approximately a factor of two.

For the purpose of this study, the information shown in Table F.7 was adjusted to reflect the estimated labor hours given previously in Tables F.3 and F.5 for the preparatory activities and removal activities, respectively. In addition, as many as 13 subcontractor staff are estimated to be involved in the steam generator heavy-lift operations, including mobilization and demobilization activities. However, only about 9 of these workers are anticipated to be actually involved in working in radiation zones, near the steam generators. It is further anticipated that approximately 59,700 hours will be expended by all of the workers, in radiation zones that average about 1.0 mR/hr.

F.7 ESTIMATED COSTS AND SCHEDULES

The major contributors to the estimated total cost of steam generators removal, transport, and disposal at US Ecology and at Barnwell are summarized in Table F.8. The total cost for these activities i: timated at about $14.8

TABLE F.8. Summary of Estimated Costs for Steam Generators Dismantlement and Disposal Activities at US Ecology and at Barnwell

Cost Item	Estimated Cost ($)[a] US Ecology	Barnwell
Phase 1 - Precursor Tasks:[b]		
Items 1 through 5	-[c]	-[c]
Item 6 Fuel Bldg. Roof Preparations[d,e]	31,486	31,486
Item 7 Barge Slip Preparations[d]	110,250	110,250
Item 8 Job Training Program	208,885	208,885
Phase 2 - Preparatory Activities:[f]		
Labor	1,547,811	1,547,811
Phase 3 - Removal Activities:[g]		
Labor	2,078,495	2,078,495
Phase 4 - Heavy Lift Rigging, Transport, and Disposal Activities:		
Subcontractor Labor & Equipment	2,350,080[h]	2,624,703
Hanford Site Support Services:[i]	529,200	0
Disposal of Radioactive Materials:		
Steam Generators (4)	1,699,735	12,450,437
Compressible Dry Active Waste (DAW)	204,885	1,099,485
Non-Compressible DAW	745,023	3,508,804
Insulation[j]	875,177	4,646,119
Steam Generator Transport System:		
Upender	27,600	27,600
Low-Profile Saddle	55,100	55,100
Transfer Skid	198,500	198,500
Frame Trailer with Shipping Cradle (2)	496,200	496,200
Materials and Equipment[k]	469,535	469,535
Protective Clothing & Equipment Services[l]	227,212	227,212
Subtotal	11,855,174	29,780,622
Contingency (25%)	2,963,794	7,445,156
Total	14,818,968	37,225,778

TABLE F.8. (contd)

(a) Values are in constant 1993 dollars. The number of significant figures is for computational completeness and does not imply accuracy to that many significant figures.

(b) See Table F.2 for details concerning Items 1 through 8.

(c) Precursor Tasks 1 through 5 are accounted for elsewhere in this study and are not costed in this table to avoid double counting.

(d) For purposes of this study, this item is considered to be a cascading cost (see Table F.2, footnote (b) for additional details).

(e) Labor and materials associated with both the removal and the reinstallation of the Fuel Building roof are included in this cost estimate.

(f) See Table F.3 for itemized task descriptions and estimated labor hours.

(g) See Table F.5 for itemized task descriptions and estimated labor hours.

(h) See Table F.11 for itemized cost breakdown of subcontractor cost components.

(i) See text, Section F.7, for details concerning these costs.

(j) Assumes all insulation is contaminated and no compaction.

(k) Includes scaffolding, shielding, and $94,800 for the purchase of two drum compactors.

(l) Based upon discussions with industry personnel, these services are estimated to be approximately $21/day/person.

million at US Ecology and about $37.2 million at Barnwell, including a 25% contingency.

Phase 1, Item 6, Fuel Building Roof Preparations, shown in Table F.8, is estimated to cost approximately $31,500, based upon information contained in References 6 and 7. It is estimated that one large structural support beam and 5 smaller roof support beams as well as about 317 m^2 of roofing material must be removed (to allow room for the Phase 4 contractor to extract the steam generators) and replaced (to provide adequate weatherization for storage of the Fuel Building and/or subsequent re-use of the building by the utility). For purposes of this study, this cost is considered to be a cascading cost (see Table F.2, footnote (b) for details).

The dredging cost (Phase 1, Item 7 shown in the table) is a study estimate, based on discussions with industry personnel. The job training costs (Phase 1, Item 8 shown in the table) for the Phase 2 and 3 staff is based upon one week's training at the labor rates given in Table F.4. The literature review conducted as part of this reevaluation study indicates that training programs are highly successful in maximizing the productivity and reducing person-rem exposure. In addition to basic project introduction as well as security and health physics indoctrination, medical examination, whole body count, and respirator fit test, the training program is postulated to include detailed activity training, including mockup training for selected activities. Remote TV and video tapes of actual work may be used during the training to fine tune crew performance on special activities.

The decommissioning operations contractor (DOC) labor costs (Phases 2 and 3 in Table F.8), over the estimated 4.1-month removal period, are derived from the average cost per crew hour, based upon the crew compositions discussed previously in Section F.4, and include an additional 10% for second shift operations, where applicable.

On the Hanford site, which is controlled by the U.S. Department of Energy, contractors and subcontractors obtain services from the Operations and Maintenance contractors for the movement of large objects, such as the steam generators, to the low-level waste burial ground operated by US Ecology, Inc. Included in the cost of these services are road preparation and maintenance, utilities, fire protection, security, patrol, transportation, medical aid, etc. Based upon discussions with industry contacts, these services, including labor, equipment, and materials, are estimated to cost about $132,300 per trip, resulting in a total cost of $529,200 for these services for the four steam generators.

Three distinct waste forms require disposal during the steam generator removal project: 1) the steam generators themselves, which are shipped in one piece, two to a barge, 2) dry active waste (DAW), both compressible and non-compressible, and 3) the insulation that was removed from the steam generators. The steam generators and the dry active waste are anticipated to be shipped to the U.S. Ecology, Inc. commercial low-level waste burial ground at Hanford. The insulation is packaged in Sea-Vans for unshielded shipment to Hanford as discussed previously in Section F.4.3. As can be seen from Table F.8, disposal of radioactive materials at Hanford is estimated to cost approximately $3.5 million. The disposal costs shown in the table for DAW and insulation include the container, transportation, and burial costs. The costs for the four steam generators shown in the table represent only the burial costs. Transportation costs for the steam generators are accounted for in the total shown for Phase 4. The direct labor costs for removing and packaging these materials are accounted for in the Phase 2 and Phase 3 labor costs. A detailed breakdown of the disposal costs at US Ecology for these items is presented in Table F.9.

Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B) and upon vendor information concerning heavy-haul and barge transport, the total estimated cost for disposal at Barnwell for the aforementioned three distinct waste forms from the steam generator removal project is about $21.7 million (see Table F.10 for details).

The steam generator transport system (consisting of an upender, low-profile saddle, transfer skid, and frame trailer with shipping cradle) cost is a study estimate, based on discussions with industry personnel. The materials and equipment cost given in Table F.8 includes $94,800 (without contingency) for the purchase and installation of two drum compactors for the project. Protective clothing and equipment services are anticipated to be provided by an offsite subcontractor for the duration of the steam generator project, at an estimated cost of $21 per day per person, based on discussions with industry personnel.

A summary of the contractor costs (presented as Phase 4 costs in Table F.8) and schedule for removal, handling, and transport of the steam generators to the U.S. Ecology, Inc., commercial disposal site at Hanford is presented in Table F.11. It can be seen from the table that the contractor's total time onsite - including mobilization, removal of four steam generators, and demobilization - is estimated at 2 months, which is the basis for the equipment rental costs shown in the table. To scope the work, schedule the Lampson TransiLifts (LTLs), develop the plans, procedures, training requirements and calculations associated with the removal, handling, and transport of the steam generators is estimated to require a minimum 6-month lead time. Contractual

TABLE F.9. Estimated Costs for Disposal of Radioactive Materials at US Ecology from Steam Generator Removal Project

Component	No. of Disposal Containers	Container Costs ($)[a]	No. of Shipments	Transport Costs	Disposal Volume (ft^3)	Disposal Cost ($)[b]	Total Disposal Cost ($)
Steam Generators	4 [c]	- [d]	2 [e]	- [f]	32,520	1,699,735	1,699,735
DAW, Compressible	504 [g]	13,583	6	7,991	3,780	183,311	204,885
DAW, Non-Compressible	124 [h]	79,980	21	21,730	11,904	643,313	745,023
Insulation	12 [i]	43,800	6	7,991	16,320	823,386	875,177
Totals	644	137,363	35	37,712	64,524	3,349,745	3,524,820

(a) Based on information in Section B.4 of Appendix B.
(b) Based on information in Section B.7 of Appendix B; includes all surcharges, taxes, and fees, as applicable.
(c) Packaged as own container, openings welded closed, placed in shipping cradle.
(d) Not applicable.
(e) Shipped by barge, see text for details.
(f) Included with Phase 4 costs, see Table F.10 for details.
(g) Drums; see Section B.4 of Appendix B for details.
(h) B-25 containers; see Section B.4 of Appendix B for details.
(i) Sea-Vans; see Section B.4 of Appendix B for details.

TABLE F.10. Estimated Costs for Disposal of Radioactive Materials at Barnwell from Steam Generator Removal Project

Component	No. of Disposal Containers	Container Costs ($)[a]	No. of Shipments	Transport Costs	Disposal Volume (ft^3)	Disposal Cost ($)[b]	Total Disposal Cost ($)
Steam Generators	4 [c]	-[d]	2 [e]	3,255,000[f]	32,520	9,195,437	12,450,437
DAW, Compressible	504 [g]	13,583	6	25,929	3,780	1,059,973	1,099,485
DAW, Non-Compressible	124 [h]	79,980	21	90,752	11,904	3,338,072	3,508,804
Insulation	12 [i]	43,800	6	25,929	16,320	4,576,390	4,646,119
Totals	644	137,363	35	3,397,610	64,524	18,169,872	21,704,845

(a) Based on information in Section B.4 of Appendix B.
(b) Based on information in Section B.7 of Appendix B; includes all surcharges, taxes, and fees, as applicable.
(c) Packaged as own container, openings welded closed, placed in shipping cradle.
(d) Not applicable.
(e) Shipped by barge.
(f) Includes: $1.5 million barge costs; $0.6 million bridge ramp costs; $0.075 million Barnwell ramp costs; $0.11 million barge slip preparations at Savannah; $0.265 million Savannah site movement costs (assumed similar to Hanford site movement costs); $0.3 million offloading and transport to Barnwell costs; $0.4 million for NRC Certificate of Compliance for steam generators as Type A, LSA transport on open waterway; and about $5,000 in permit costs.
(g) Drums; see Section B.4 of Appendix B for details.
(h) B-25 containers; see Section B.4 of Appendix B for details.
(i) Sea-Vans; see Section B.4 of Appendix B for details.

TABLE F.11. Summary of Estimated Contractor Costs and Schedule for Removal, Handling, and Transport of the Steam Generators to Hanford[a]

Component	Estimated Cost (1993 $)	Estimated Time (as shown)
Mobilization for shipment to reference PWR:	-	2 weeks
Labor	65,070	-
Transportation Inbound	93,713	-
Mobilization of Equipment at reference PWR:	-	2 weeks
Labor	65,070	-
Remove 4 each Steam Generators/ Loadout Aboard Barge:	-	4 weeks
Labor	125,729	-
Mobilization for shipment to Hanford Burial Site:	-	2 weeks
Labor	65,070	-
Transportation Inbound	93,713	-
Mobilization of Equipment at Hanford:	-	2 weeks
Labor	65,070	-
Receive 4 each Steam Generators at Port of Benton/Transport to Hanford Burial Site and Offload:	-	2 weeks
Labor	65,070	-
Demobilize Equipment at Reference Plant:	-	2 weeks
Labor	65,070	-
Transportation Outbound	93,713	-
Demobilize Equipment at Hanford Burial Site:	-	2 weeks
Labor	65,070	-
Transportation Outbound	93,713	-
Major Equipment at Reference Plant:	-	(b)
1. 100-ton Truck Crane	18,743	-
2. 200-ton Crawler Crane	28,665	-
3. 550-ton Trailer System	79,380	-
4. 550-ton Prime Movers	37,485	-
5. LTL-900-ton Crane	275,625	-

TABLE F.11. (contd)

Component	Estimated Cost (1993 $)	Estimated Time (as shown)
Major Equipment at Hanford Burial Site:	-	(b)
1. 100-ton Truck Crane	18,743	-
2. 200-ton Crawler Crane	28,665	-
3. LTL-900-ton Crane	275,625	-
Major Equipment/Tidewater Barge Lines (50 ft x 200 ft Barge with Tug Boats):		(c)
1. Transportation Cost (Reference Plant to Port of Benton)	88,752	
	$1,807,754	
(30% Markup)	542,326	
Estimated Total Cost	$2,350,080	

(a) Based on letters: 1) William N. Lampson, Neil F. Lampson, Inc., to George J. Konzek, Battelle Northwest, transmitting rough-order-of-magnitude data on decommissioning costs for steam generators removal from the reference PWR, dated January 31, 1992; 2) Paul Parish, Neil F. Lampson, Inc., to George J. Konzek, Battelle Northwest, transmitting updated cost information on decommissioning costs for steam generators removal from the reference PWR, dated April 6, 1993.
(b) Based on 2 months rental cost for each piece of equipment.
(c) Based on travel times of about 39 hours upstream per trip and about 35 hours downstream per trip.

approval by the utility/DOC is assumed to be required for all contractor activities. Security measures required during the steam generator removal project are assumed to be the responsibility of the utility.

F.8 DISCUSSION

It was determined in Reference 1, and again in this analysis, that specific steam generator repair/replacement cost data were generally not available, due to the inherently proprietary nature of this highly competitive type of reactor outage work in the U.S. However, the estimated costs and conditions for removal of a steam generator during decommissioning can be much more sharply defined now than they could be in earlier studies. The activities associated with the removal process are no longer first-of-a-kind, but rather reflect direct applications of developed techniques and equipment. Recent learning experiences can be used to guide the industry in planning for future steam generator removal operations.

While relevant information on steam generator removal during reactor outages is now available, similar information from actual decommissioning experience is still largely unavailable. From the experience base reviewed in Reference 1 and again for purposes of this analysis, it is clear that 1) precise estimates of occupational doses for this type of large-component removal during decommissioning will probably remain uncertain because of the uncertainties in the exact procedures which could be utilized (e.g., harsher decontamination methods and more extensive dismantling operations could be used in decommissioning than would be allowed during a replacement project); and 2) the feasibility as well as the practicality of the reactor-specific procedures concerning steam generator removal will remain primary considerations for decommissioning planners, since the estimated occupational dose is highly dependent on the degree and manner of decommissioning envisioned.

In general, it is concluded that dose reduction during decommissioning, relative to recent steam generator repair/replacement projects at the U.S. operating power plants examined in this study, would be attributable to:

- Essentially no channel head or manway entries required for decommissioning.

- Chemical decontamination of the RCS, including the steam generators, which is anticipated to significantly reduce both contact and background radiation dose rates for decommissioning workers. Chemical decontamination processes for the RCS will be dictated by cost, decontamination effectiveness, and radioactive waste management considerations during decommissioning. However, if a significant reduction in worker dose is to be achieved, the value of chemical decontamination of the RCS cannot be overemphasized in the steam generator removal process during immediate dismantlement.

- Partially filling the steam generators with water for shielding after the chemical decontamination task, thus providing further reductions in background radiation during the initial preparatory and the actual removal cutting operations. This preparatory ALARA step also was done at Surry, Turkey Point, and H. B. Robinson.

- Removal of each steam generator in one piece (or in as few pieces as possible), thus minimizing the cutting and welding operations inside containment.

It is further concluded that, historically, it appears that a combination of poorly-defined data, controversial assumptions, and modeling difficulties for large-component removal projects have often resulted in significantly different occupational radiation doses than originally estimated. It seems reasonable, therefore, that the actual occupational radiation doses for steam generator changeout projects at operating PWRs in the future can probably be expected to continue to vary for a variety of reasons. It is anticipated that the occupational radiation dose during decommissioning will also vary considerably from plant to plant. In all cases, the total dose for this large-component removal operation is sensitive to 1) the amount of preparations required; 2) the quality and thoroughness of the preparations; 3) the degree of success of the chemical decontamination campaign; 4) the duration and working conditions; 5) the steam generator design and other plant-specific conditions; 6) the technology applied, involving to a large extent the need for and the successful use of purpose-built tools and equipment; 7) the removal methodology employed; 8) the skills of properly trained and qualified workers; 9) the degree of success of the management commitment to maintain the occupational doses within the 10 CFR Part 20 limits and as low as reasonably achievable (ALARA).

One potential change identified in Reference 1, and reaffirmed again in this analysis, is that fewer segmentation cuts per steam generator may be required for removal during decommissioning than were envisioned in NUREG/CR-0130. For decommissioning planners, additional emphasis is recommended on the initial general cleanup and decontamination of containment as well as on the periodic housekeeping and decontamination of walkways, platforms, tools, and equipment. All of these activities will be beneficial in reducing worker skin contamination, airborne radioactivity, and the need for respiratory-protection devices during steam generator removal projects.

In summary, there are definite advantages to removing and transporting steam generators in one piece, if possible, including reduced radiation exposure and a shorter overall schedule duration. Other factors include crane and crane support capacities, space limitations, architectural clearances, and transportation routing considerations.

F.9 REFERENCES

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

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3. Nuclear Engineering International. "Point Beach 1 Steam Generators Replaced Ahead of Schedule." pp. 38-42, January 1985.

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

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

APPENDIX G

DECOMMISSIONING METHODS

APPENDIX G

DECOMMISSIONING METHODS

Methods, equipment, and disassembly procedures postulated to be used to accomplish various decommissioning activities at nuclear facilities, such as the reference pressurized water reactor (PWR), were discussed in considerable detail in NUREG/CR-0130.[1] Some of those methods are no longer state-of-the-art, other methods/techniques have seen improvements, some never fully materialized for subsequent decommissioning applications as anticipated (e.g., the arc saw),[a] and some new decommissioning-related techniques, methods, and equipment have come on the scene. Information associated with this latter group is presented in Appendix K and is not repeated here. Decommissioning methods used in this reevaluation study are presented in this appendix, together with the development of selected cost estimates that are not presented elsewhere in this reevaluation study. The information is presented in the following order:

- system decontamination
- surface decontamination
- removal techniques and equipment
- water treatment and disposal.

G.1 SYSTEM DECONTAMINATION

For the purpose of this reevaluation study, the full-system chemical decontamination (recirculatory method) is used where dilute chemical decontamination solutions can be recirculated until the desired degree of decontamination is obtained. The dissolved radioactivity and chemicals are removed on ion exchange resin and the water is either reused for an additional decon-

(a) To date there is insufficient operating data to accurately compare arc saw cutting to other more conventional means. This technique could well provide a viable method for segmenting components; operating data from experimental or prototype units should be evaluated when available.[2]

tamination step or treated further for discharge. This technique was identified to reduce dose rates (and therefore exposures) incurred during the subsequent removal and disposition of the primary coolant system piping and associated equipment.

The information presented herein is based to a large extent on discussions between the authors and senior staff of Pacific Nuclear Services, who specialize in chemical decontamination services and are currently under contract to Consolidated Edison of New York to perform the first full-system decontamination of a commercial PWR in the U.S..

The major contributors to the estimated total cost and occupational radiation exposure (ORE) for full-system chemical decontamination at the reference PWR are summarized in Table G.1. The total cost for these activities is estimated at about $14 million, not including contingency. The total ORE is estimated to be about 46 person-rem.

The assumptions used in these reevaluation analyses are described below, followed by a general discussion of the estimated cost, ORE, volumes of radwastes, and schedule associated with the full-system chemical decontamination of the reference PWR.

G.1.1 Assumptions

In developing the chemical decontamination scenario and the subsequent analysis, the following assumptions were used:

- The PWR primary system components description and radioactive inventory were taken from NUREG/CR-0130.
- Full-system chemical decontamination of PWRs by a specialty contractor (vendor) is postulated to be routine work by the time this operation commences at the reference PWR (i.e., it is assumed that at least 3 such campaigns have been successfully completed prior to the reference PWR campaign).
- The full-system chemical decontamination will be completed during the first year following final shutdown, after defueling of the reactor and deborating of the primary coolant water (to less than 100 ppm) by the utility.

TABLE G.1. Summary of Estimated Costs and Radiation Dose for Full-System Chemical Decontamination of the Reference PWR

Cost Item	Estimated Cost (1993$)[a]	Estimated Dose (person-rem)[b]
1. Deboration of the primary coolant by the utility:[c,d]		
a. Labor	usc[e]	3.6
b. Energy (oil)	64,900[f]	-
2. Chemical Decontamination:		
a. Fixed-cost Contract (Specialty Contractor)[g]	12,500,000	12
b. Utility Support	usc	28
3. Disposal of Radioactive Materials from Item 2 Chem Decon:		
a. 18 High-Integrity Containers	404,498[h]	-[i]
4. Electricity[j]	238,000[f]	-
5. Water treatment/release[c]		
a. Fixed-cost Contract (Specialty Contractor)[g]	750,000	~2
b. Utility support	usc	-
6. Disposal of Radioactive Materials from Water Treatment:[c]		
a. 5 High-Integrity Containers	61,803[k]	<0.1
7. Protective clothing & equipment services (vendor only)[l]	22,176	-
Totals (w/o contingency)	14,041,377	~45.7

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) A dash means not applicable, unless indicated otherwise.
(c) A pretreatment conditional step considered necessary for optimal results from the subsequent chemical decontamination operations.
(d) Even without chemical decontamination, this step would be necessary during decommissioning.
(e) "usc" indicates that costs are included in the utility staff costs during this period.
(f) Undistributed cost.
(g) See text for details.
(h) Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B), the total estimated burial cost for the 18 HICs given in Step 3.a. is $1,731,780.
(i) Included in Utility Support.
(j) Assumes the use of various pumps, including the 4 primary pumps, for about 2 weeks consumes approximately 7 x 10^3 MWh of electricity as described in NUREG/CR-0130.[1]
(k) Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B), the total estimated burial cost for the 5 HICs given in Step 6 is $373,800.
(l) Based upon discussions with industry personnel, these services are estimated to be approximately $21/day/person for rad-zone workers only.

- No water rinses are needed following chemical decontamination; the solutions will be drained, treated, and released according to applicable release standards; the systems will be left dry.

- Decontamination does not permit release of the components for unrestricted use because of tightly adherent residual contamination; controlled removal and final disposition (either burial or shipment to a commercial decontamination/volume reduction facility) will be required.

- Removal of components after decontamination requires the same labor as without decontamination because the components are still contaminated. The same precautions and preparations, contamination controls and packaging would be required. However, significantly less ORE would be incurred and fewer personnel would be needed to accomplish the work.

- The postulated decontamination factor (DF) for the full-system chemical decontamination of the reference PWR is a DF of 10.

- Decontamination dose reductions are accounted for in subsequent removal of components after chemical decontamination for each of the three decommissioning alternatives, as applicable.

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

G.1.2 Discussion

Just as in NUREG/CR-0130,[1] the principal systems considered for chemical decontamination in this reevaluation study are the reactor coolant system (RCS), the chemical volume control system (CVCS), and inter-tied systems, i.e., those systems that contain deposited contamination representing a radiation dose rate hazard for further decommissioning effort once they are drained and dried.

In the opinion of the authors, chemical decontamination of the aforementioned systems is a necessary step even if the current decommissioning plan calls for placing the facility in safe storage for an extended period of time, since completing the decontamination step removes most of the internal radioactive contamination and leaves all options open for changing the decommissioning plan at a later date. It is unlikely that a chemical decontamination could be carried out without major equipment renovation after the facility has been in safe storage for a few years, due to equipment deterioration. If a decision were made to dismantle after 5 to 10 years of safe storage, significant radiation exposures would be encountered if the plant had not been previously decontaminated. It should be noted that even without chemical decontamination, the amounts given for Cost Items 1. and 5. (i.e., deboration and water cleanup prior to release) in Table G.1 would still be incurred.

The chemical decontamination project is postulated to be done by an experienced specialty contractor (vendor) well established in systems decontamination and associated integrated outage activities, under contract to the utility. During the planning and preparation stage, procedures and results from previous decontamination efforts will be reviewed to obtain maximum benefit from previous experience. Then, with the reactor completely defueled and the pressure vessel head reinstalled, the RCS and the CVCS will be isolated from the spent fuel pool system. All possible branches of the CVCS will be operated during the decontamination period, with heated solution circulating through pumps, heat exchangers, piping, and tanks, and returning to the RCS loop for reheat and cleanup.

Current information on chemical decontamination of light-water reactors was obtained from a comprehensive review of the literature and from discussions with senior staff of Pacific Nuclear Services (PNS), located in Richland, Washington. The PNS staff emphasized that it should be recognized that: 1) full-system chemical decontaminations of light-water reactors are very plant-specific; 2) the amount of radwastes depends on the solvent used for the job; and, 3) since no commercial PWR has yet undergone a full-system chemical decontamination in the United States, a first-of-a-kind (FOAK) full-system chemical decontamination of a PWR could cost in the range of $20 to $25 million. However, when such decontaminations of PWRs become "routine" (defined here as after at least 3 such campaigns have been successfully completed), a cost in the range of $10 to $15 million could be anticipated for a full-system chemical decontamination. This latter cost includes mobilization/demobilization costs, all contractor staff costs, the costs of chemicals, mobile equipment, hoses, etc., onsite radwaste processing, high-integrity containers for the resultant waste, and transportation costs, but not final burial costs of the high-integrity containers (HICs).

Based upon the information obtained from Pacific Nuclear staff, the following schedule, dose and cost values, and volumes of radwastes associated with a specialty contractor's effort are postulated to be reasonable estimates for use in this reevaluation study:

- About 4 months is estimated for the completion of the full-system chemical decontamination project at the reference PWR. About 2 months are estimated for mobilization, including reactor-specific indoctrination training, equipment installation, tie-ins, etc.; 1 week around-the-clock for decontamination process application; 1 month to process the waste onsite (outside the containment building such that these latter activities do not interfere with other decommissioning tasks) and for concurrent treatment and release of the water from the reactor systems; and 3 weeks for demobilization and shipment of the resultant wastes.

- A 3- to 5-step process will be required to obtain the desired results from the decontamination process.

- An occupational radiation exposure in the range of 30 to 50 person-rem could be expected for the decontamination effort. For purposes of this study, a mid-range value of 45.7 person-rem has been assigned to this work.[b]

- In consideration of the uncertainties associated with a full-system chemical decontamination to be done in the future, including the proprietary constraints and the highly competitive business climate for this type of work, and based upon an anticipated cost in the range of \$10 to \$15 million, a mid-range cost of about \$12.5 million has been assigned to the work.

- Somewhere between about 2,400 and 3,500 ft^3 of dewatered resin, Class A waste, containing about 5,000 curies of activity, could be expected to result from the full-system chemical decontamination job. A mid-range volume of about 3,000 ft^3 is used in this study.

The polyethylene HICs postulated to be used for the radioactive resins resulting from the chemical decontamination operations must be dewatered before burial. The HICs also are assumed to contain a nominal 15% void. For

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(b) It is postulated that the vendor's staff receive about 30% of the dose and the utility staff about 70%, based upon information contained in Reference 3.

the HICs postulated for use in this study (burial volume of 5.72 m^3 or about 200 ft^3/HIC), about 170 ft^3 of waste resin/HIC (assuming a 15% void) results in about 18 HICs requiring disposal at the low-level waste burial ground at Hanford. Nine of 18 HICs are postulated to require engineered concrete barriers for disposal, since they are assumed to contain 2% to 6% chelates. The remaining 9 HICs are assumed to contain <0.1% chelates. It is further assumed that the contact readings on the HICs are about 80 R/hr. Based upon the assumptions, it is calculated that each HIC contains approximately 278 curies.

Under the postulated conditions just described and based upon disposal cost information provided by U. S. Ecology for the Richland, WA, site (see Appendix B), the total estimated burial cost for the 18 HICs given in Step 3.a. of Table G.1 is $404,498. Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B), the total estimated burial cost for the 18 HICs given in Step 3.a. of Table G.1 is $1,731,780.

Upon completion of the chemical decontamination process, the solution remaining in the systems cannot be released without some form of additional treatment since the water is expected to still contain measurable radioactivity. Therefore, the water will be treated by batch process by a specialty contractor (sampled, analyzed and treated again, as necessary until release criteria are met) and released according to applicable release standards. The decontaminated systems will be left dry. As shown in Table G.1, Step 5, the cost for final water treatment is estimated at $750,000. It is further estimated to take 30 days, working 21 shifts per week. Since the waste activity concentration is not well known at this point, it is difficult to predict with confidence either the ORE or the volume of waste that will result from these activities. However, for the purpose of this study, 1) an occupational radiation exposure of approximately 2 person-rem is anticipated for these activities; and 2) it is roughly estimated that an additional five 5.72-m^3 high-integrity containers (HIC's) of spent ion exchange resin could be required. Based upon disposal cost information provided by U.S. Ecology for the Richland, WA, site (see Appendix B), the cost of subsequent disposal of the HIC's (Step 6 in Table G.1), estimated at $61,803,[c] is assumed to be the responsibility of the utility. Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B), the total estimated burial cost for the 5 HICs given in Step 6 of Table G.1 is $373,800.

The utility is responsible for the costs of indoctrination training for all non-utility staff coming onsite; energy; deborating the primary system water; protective clothing and equipment services; routine radwaste collection, processing, and disposition; and final disposal of the decontamination wastes. Also, security measures required during the chemical decontamination project are assumed to be the responsibility of the utility.

In addition to the specialty contractor's (vendor's) staff, which is assumed to be 18 people, the utility must provide technical support. A description of the optimum project staff is provided in Reference 4, based upon recent chemical decontaminations at boiling water reactors. However, the author states that the information presented is applicable to both BWRs and to PWRs. This study's approach is similar. Typical support staff for the reference PWR are assumed to include:

Position	Estimated Number Required
Station Project Manager (days) or Responsible Engineers (one/shift)	3
Plant technical support (one per shift)	3
Head liaison engineer (one per shift)	3
Consultant (one per shift)	3
Dedicated health physics support (2/shift)	6
One chemist plus one chemical technician per shift	6
Pipe fitters (two per shift on standby)	6
Instrument technician and electrician (1 each/shift on standby)	6
Laborers (two per shift on standby)	6

(c) Based upon disposal cost information for HICs provided by U.S. Ecology (see Appendix B); assumes < 0.1 % chelates, < 50 curies, and < 5 R/hr contact readings.

The aforementioned persons are part of the existing Period 2 utility staff.

In addition, Pacific Nuclear staff related that their experiences to date with chemical decontamination of drain systems indicates that it is probably not cost-effective, nor practical to chemically decontaminate reactor drain systems prior to disassembly. Therefore, the piping in the drain systems at the reference PWR is not postulated to be chemically decontaminated before disassembly.

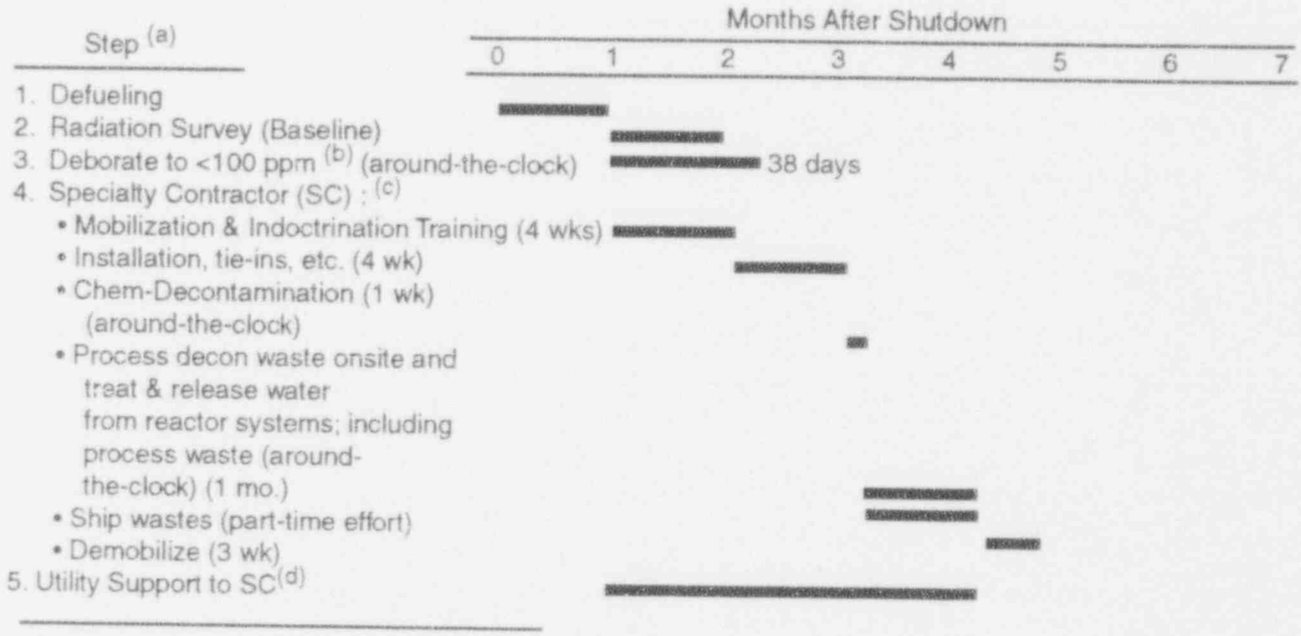
G.1.3 Estimated Task Schedule and Sequence

The overall task schedule and sequence of events for performing the chemical decontamination is given in Figure G.1. It can be seen from the figure that the contractor's total time onsite, including mobilization and demobilization, is estimated at 4 months. It is further estimated to require a 12-month lead time to scope and schedule the work, develop the plans, procedures, training requirements, and calculations associated with the chemical decontamination project.

G.2 SURFACE DECONTAMINATION

In this study, all contaminated horizontal surfaces are assumed to be washed using a manually operated cleaning system which washes the surface using high-pressure (250 psig) jets and collects the water and removed material simultaneously using a vacuum collection system. This system permits excellent cleaning while avoiding recontamination due to dispersion of the water. The same system, employing modified cleaning heads, is used to wash vertical or overhead surfaces. An additional 20% of labor time is postulated to be required for the vertical and overhead surfaces cleaning.

In general, the water-jet/vacuum decontamination activity can proceed independently of the recirculatory method. Only a brief discussion of the water-jet/vacuum decontamination activity is presented in this section, since the specifics associated with this activity are described in detail in Appendix C. Likewise, the costs per square foot of surface cleaned are developed in Appendix C and are not repeated here.



(a) Steps 1, 2, 3, and 5 are done by the utility.
(b) See text, Section G.4.1, for subsequent treatment and costs concerning the disposition of the condensate resulting from this step.
(c) Eighteen people are used for this work.
(d) Utility staff support of the specialty contractor (SC) minimizes costs.[3] See text for utility staffing details.

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FIGURE G.1. Estimated Task Schedule and Sequence for Chemical Decontamination

G.3 REMOVAL TECHNIQUES AND EQUIPMENT

The various removal techniques and equipment used in this study for the removal of contaminated and uncontaminated structural materials are discussed below.

G.3.1 Removal of Contaminated Concrete Surfaces

Those contaminated horizontal surfaces which are not sufficiently decontaminated using the high-pressure washing system (see Section 1.1.1) are removed using a commercially available pneumatically operated surface chipper removal system. Commercial systems which use very high pressure water jets for surface removal are also available. For this analysis, a specific commercial system manufactured by Pentex, Inc. is assumed (the Moose™ and associated smaller units) which chips off the surface and collects the dust and chips into a waste drum, and filters the air to prevent recontamination of the cleaned surfaces.

It is postulated that the depth of concrete to be removed will vary from location to location, but that on the average, removal of about 0.25 in. will be sufficient to remove the residual radioactive contamination. Because the removal system selected removes about 0.125 in. of material per pass, an average of 2 passes will be required over the contaminated areas. Because the Moose™ cannot get closer to walls than about 6 inches, smaller units of the same type are used to clean the perimeter areas of rooms. For this analysis, it is postulated that the perimeter areas comprise about 20% of the total surface area to be cleaned. For 1-pass removal operations, the Moose™ is assumed to clean at the rate of about 115 ft^2 per hour. Smaller units clean at the rate of about 30 ft^2 per hour. Combining these rates by weighting with the fractions of surface removed by each unit, the nominal removal rate becomes about 100 ft^2/hr. Assuming an average of 2 passes are required, the effective average cleaning rate becomes 50 ft^2/hr.

The smaller units (Squirrel III™ and Corner Cutter™) could also be utilized on vertical surfaces. The cost per square foot for vertical surfaces would be approximately four times the cost for horizontal surfaces, due to the lower removal rates of the smaller units. Staffing of the crews and unit cost factors are developed in Appendix C and are not repeated here.

G.3.2 Cutting Uncontaminated Concrete Walls and Floors

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

Material and labor costs for cutting uncontaminated concrete walls and floors are based on the length of cut, measured in inch-feet (i.e., a cut 1-inch deep, 1 foot long, equals 1 inch-foot). Based on discussions with an industry source, 60 inch-feet per hour is used in this study as a reasonable cutting rate.

Cutting of concrete walls is accomplished using a wall-saw on a mechanically driven track system. Cutting of concrete floors is done with a slab-saw. Scaffolding will be used as needed for installing and removing the track system when sawing openings in walls. The concrete pieces are cut into various shapes and sizes, depending upon the size of the openings desired. No packaging is contemplated, since the removed material is postulated to be uncontaminated. The removed pieces of concrete are transferred to nearby storage areas. The basic operations for cutting concrete walls and concrete floors, together with the estimated clock times required to accomplish each operation, the staffing, and the unit costs are developed in Appendix C and are not repeated here.

G.3.3 Removal of Cranes

The Containment Building polar crane and the Fuel Building crane are anticipated to be disengaged from their moorings by a vendor, lowered to the operating floor, decontaminated, surveyed, and, except for the trolley drums and associated cables, abandoned in place. The trolley drums and associated cables from each of the cranes will be packaged and shipped to the low-level waste disposal site at Hanford. In both buildings, these are the last scheduled decommissioning activities to occur before the license termination survey commences.

The major contributors to the estimated total cost of cranes removal, decontamination operations, and transport are summarized in Table G.2. The total cost of these activities is estimated at about $616,000, including a 25% contingency.

The estimated removal/labor costs and schedules for the removal of the Containment Building crane and the Fuel Building crane are discussed below. Two conceptual methods for the removal of the Containment Building crane are presented in Table G.3 (Method 1) and Table G.4 (Method 2), respectively, with the conceptual methods depicted in Figure G.2 (Method 1) and Figures G.3 and G.4 (Method 2), respectively. The postulated work plan associated with each method is included with the respective figures. For the purpose of this study, Method 2 at $237,020 is selected over Method 1 at $229,100 as the

TABLE G.2. Summary of Estimated Costs for Cranes Dismantlement and Disposal Activities

Cost Item	Estimated Cost (1993$)[a]
Removal of Reactor Bldg. Polar Crane using Method 2[b]	237,020
Removal of Fuel Bldg. Crane[c]	75,780
Decontamination/Survey of Cranes[d]	16,630
Disposal of Radioactive Materials:	
Maritime Containers (2)	7,300[e]
Transportation (2 OWT shipments)	2,837[f]
Disposal	153,206[g]
Subtotal	492,773
Contingency (25%)	123,193
Total	615,966

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) See Table G.4 and Figures G.2 and G.3 for details concerning Method 2 removal activities.
(c) See Table G.5 for details.
(d) Based on Table G.6 staffing and labor rates.
(e) Based on Table B.2 in Appendix B.
(f) Based on direct quote from Tri-State Motor Transport Co. for two OWT shipments from Trojan plant to the low-level waste burial ground at Hanford. With Barnwell as the disposal site destination, the transportation costs are estimated at $15,688, based on direct quote from Tri-State Motor Transport Co.
(g) Based upon disposal cost information provided by Chem-Nuclear Systems, Inc., the total estimated disposal cost for the waste at the Barnwell site is $770,102.

TABLE G.3. Summary of Estimated Contractor Costs, Manpower, and Schedule for Removal of the Containment Building Polar Crane Using Method 1[(a)]

Method 1 - Using Center Hole Jacks & Associated Equipment[(b)]

Component	Manpower	Estimated Cost (1993$)[(c)]	Estimated Time, days[(d)]
Equipment[(e)]	-	132,300	-
Labor:			
Jack Installation & Disassembly (2 each)	4 people	42,240	24
Remove Corbel	4 people	8,800	5
Lower Bridge Crane	4 people	1,760	1
Disassemble Bridge Crane[(f)]	8 people	35,200	10
Closure of Center Holes	5 people	8,800	4
Totals, Method 1		229,100	44

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.
(b) See Figure G.1 for postulated work plan.
(c) $55/person-hour is used in the calculations to estimate built-up job cost.
(d) Assumes 1-shift per day operations; 2-shifts per day would halve these values.
(e) Includes mobile crane and manbasket, center-hole jacks, and associated equipment.
(f) This step also includes removal and packaging of the trolley drum and cable (~40,000 lb) for subsequent shipment in a maritime container to the low-level waste disposal site at Hanford.

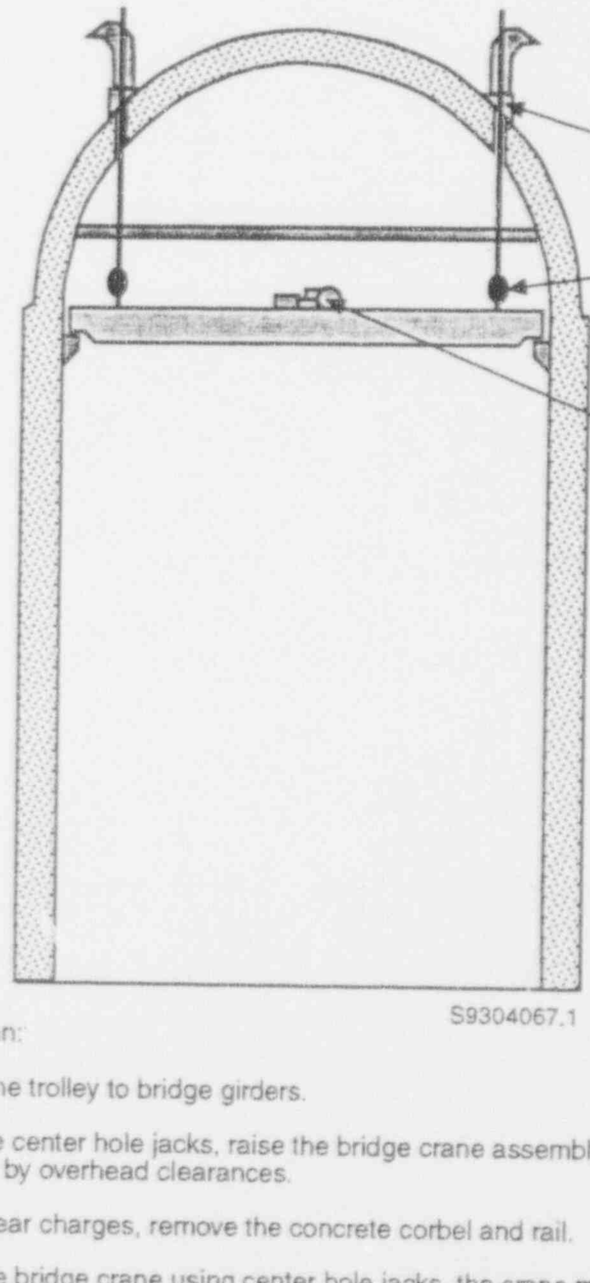
TABLE G.4. Summary of Estimated Contractor Costs, Manpower, and Schedule for Removal of the Containment Building Polar Crane Using Method 2[a]

Method 2 - Using Bar Climber & Associated Equipment[b]

Component	Manpower	Estimated Cost (1993$)[c]	Estimated Time days[d]
Equipment[e]	-	132,300	-
Labor:			
Tower Erection (4 each)	8 people	35,200	10
Lifting Bridge	5 people	1,650	0.75
Remove Corbel	4 people	8,800	5
Lower Bridge	5 people	2,750	1.25
Disassemble Bridge Crane[f]	8 people	35,200	10
Tower Disassembly (4 each)	8 people	21,120	6
Totals, Method 2		237,020	33

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.
(b) See Figures G.2 and G.3 for details.
(c) $55/person-hour is used in the calculations to estimate built-up job cost.
(d) Assumes 1-shift per day; 2-shifts per day would halve these values.
(e) Includes bar climber and associated equipment.
(f) This step also includes removal and packaging of the trolley drum and cable (~40,000 lb) for subsequent shipment in a maritime container to the low-level waste disposal site at Hanford.

Center Hole Jacking



Work Plan:

Secure the trolley to bridge girders.

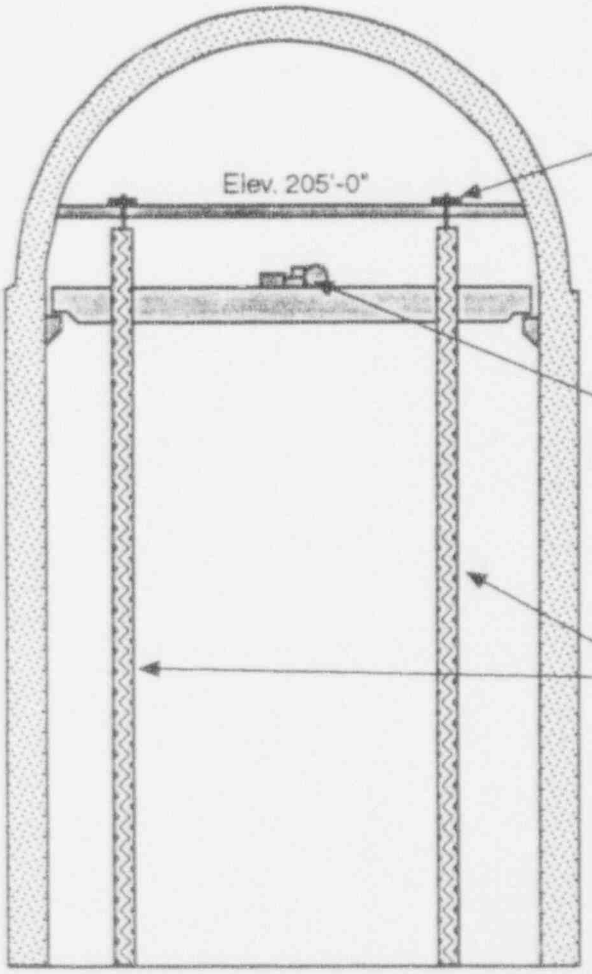
Using the center hole jacks, raise the bridge crane assembly to the limits allowed by overhead clearances.

Using linear charges, remove the concrete corbel and rail.

Lower the bridge crane using center hole jacks, the crane may act as a work platform to remove any remaining rebar, etc. to allow the crane to pass the corbel

Using the centerhole jacks, lower the bridge crane to grade.

FIGURE G.2. Conceptual Decommissioning Plan for the Polar Crane Using Method 1



Work Plan:

Using polar crane, assemble bar climbing towers to the upper hook limit.

Using air tuggers mounted at elevation 205'-0", set the top tower sections.

Using the polar crane, set a bar climber header beam between each of the two sets of towers at ground elevation.

Lash the trolley to the bridge girders.

Raise the bar climber/header assembly and lift the bridge girders.

Using linear shape charges, remove a section of the corbel and rail.

Using the bar climbers, lower the bridge girders to ground elevation.

FIGURE G.3. Conceptual Decommissioning Plan for the Polar Crane Using Method 2, Sheet 1 of 2

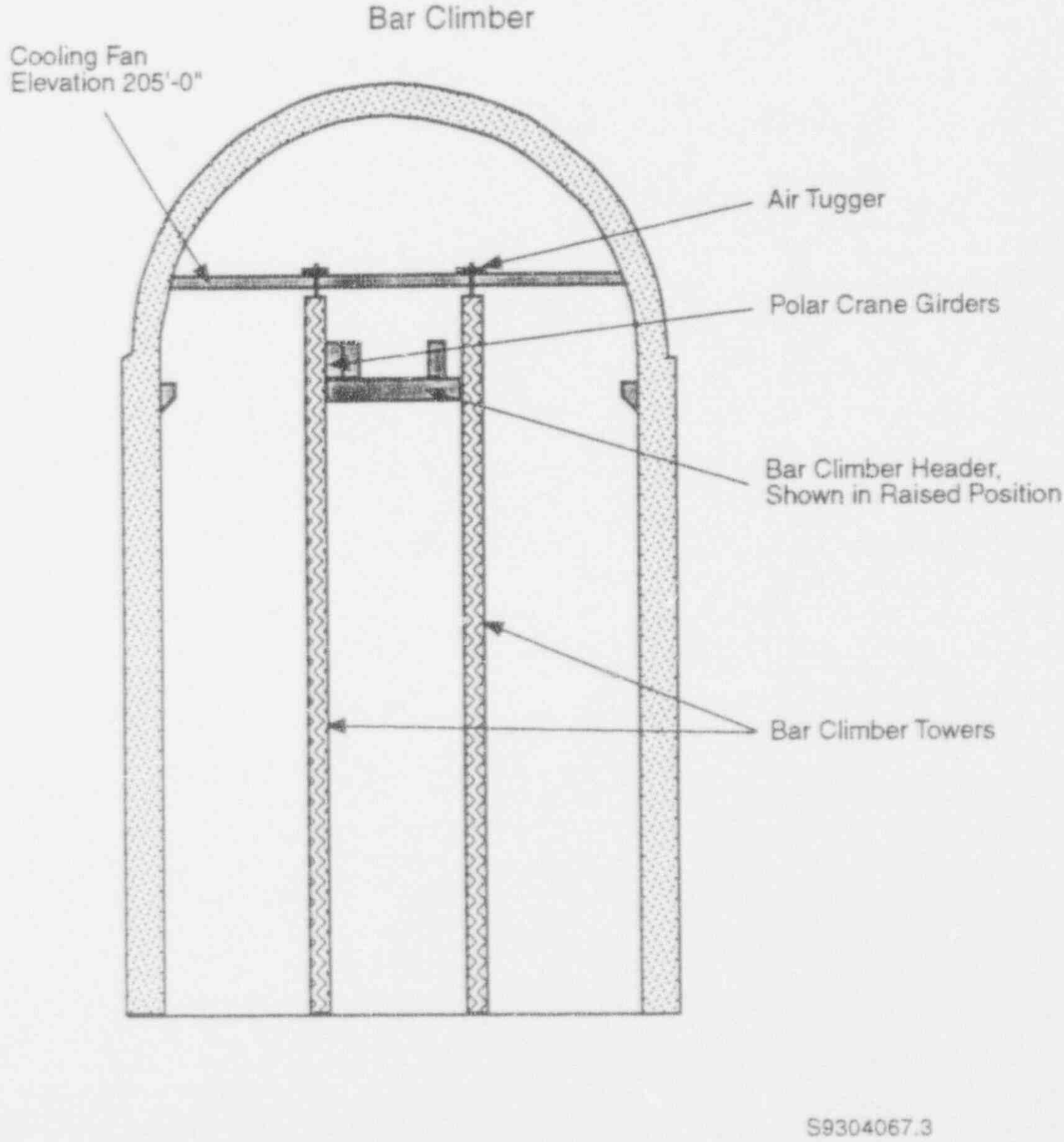


FIGURE G.4. Conceptual Decommissioning Plan for the Polar Crane Using Method 2, Sheet 2 of 2 preferred choice because of the lesser manpower commitment, better schedule (i.e., fewer days to do the project), and because the Containment Building roof is not violated and thus subsequent repair costs are avoided.

The estimated removal/labor costs and schedule for the removal of the Fuel Building crane are given in Table G.5. The postulated method used for the removal of the crane is illustrated in Figure G.5. The estimates presented in the tables are based upon information provided by Advanced Engineering Services.[d]

After removal of the trolley drums and associated cables, the decontamination process is estimated to require one week for each of the cranes. It is estimated that two dedicated 5-person crews, working one crew on each of two shifts, will be required to complete these activities at a total cost of $15,802. Very little, if any, occupational radiation exposure is anticipated from these activities. Each crew is assumed to consist of the DOC staff listed in Table G.6.

G.4 WATER TREATMENT AND DISPOSAL

Selected water treatment and disposal operations associated with decommissioning the reference PWR are described in this section.

G.4.1 Treatment and Disposal of the Concentrated Boron Solution

The deboration process (Cost Item 1. in Table G.1) is estimated to have resulted in the temporary storage of approximately 179,100 gallons of reactor grade boric acid solution. Pacific Nuclear's Radioactive Waste Volume Reduction System (RVR-800)™ or equivalent is presumed to be used by a vendor for the disposition of this borated water at an estimated cost of $6 per gallon, resulting in a total cost of $1,074,600.[e] The end-product, a pelletized powder, will be packaged in sixty-four 55-gallon drums for subsequent transport to the low-level waste disposal facility at Hanford.

(d) Letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.

(e) Subsequent transportation costs for the resultant radioactive wastes are included in this unit cost estimate, but radwaste burial costs are the responsibility of the utility.

TABLE G.5. Summary of Estimated Contractor Costs, Manpower, and Schedule for Removal of the Fuel Building Crane[a]

Component	Manpower	Estimated Cost (1993$)[b]	Estimated Time, days[c]
Equipment	-	22,050	-
Mobilization & Demobilization	5 people	22,050	10
Labor:			
Crane & Rigging Operations	8 people	14,080	4
Mechanical Demo[d]	5 people	17,600	8
Totals		75,780	22

(a) Based on letter, Chris Alexander, Advanced Engineering Services, to George J. Konzek, Pacific Northwest Laboratory, transmitting reference plant decommissioning cost projections, dated July 21, 1992.
(b) $55/person-hour is used in the calculations to estimate built up job cost.
(c) Assumes 1-shift per day operations; 2-shifts per day would halve these values.
(d) This step also includes removal and packaging of the trolley drum and cable (~40,000 lb) for subsequent shipment in a maritime container to the low-level waste disposal site at Hanford.

Based upon information contained in Appendix B, the cost for in-compact burial of these drums at U.S. Ecology is estimated at $23,278. Based upon information contained in Appendix B, the cost for out-of-compact burial of these drums at Barnwell is estimated at $134,600.

Assuming 10% equipment downtime, it is calculated that approximately 164 consecutive working days will be required to complete this task. Two 12-hour shifts, with three people per shift, are involved in these operations. A cumulative ORE of about 3 person-rem is anticipated.

G.4.2 Spent Fuel Pool Water Treatment and Disposal

Upon reduction of the spent nuclear fuel inventory to zero, approximately 7 years after final shutdown (see Chapter 6 for details), the spent fuel pool (SFP) water cannot be released without some form of additional

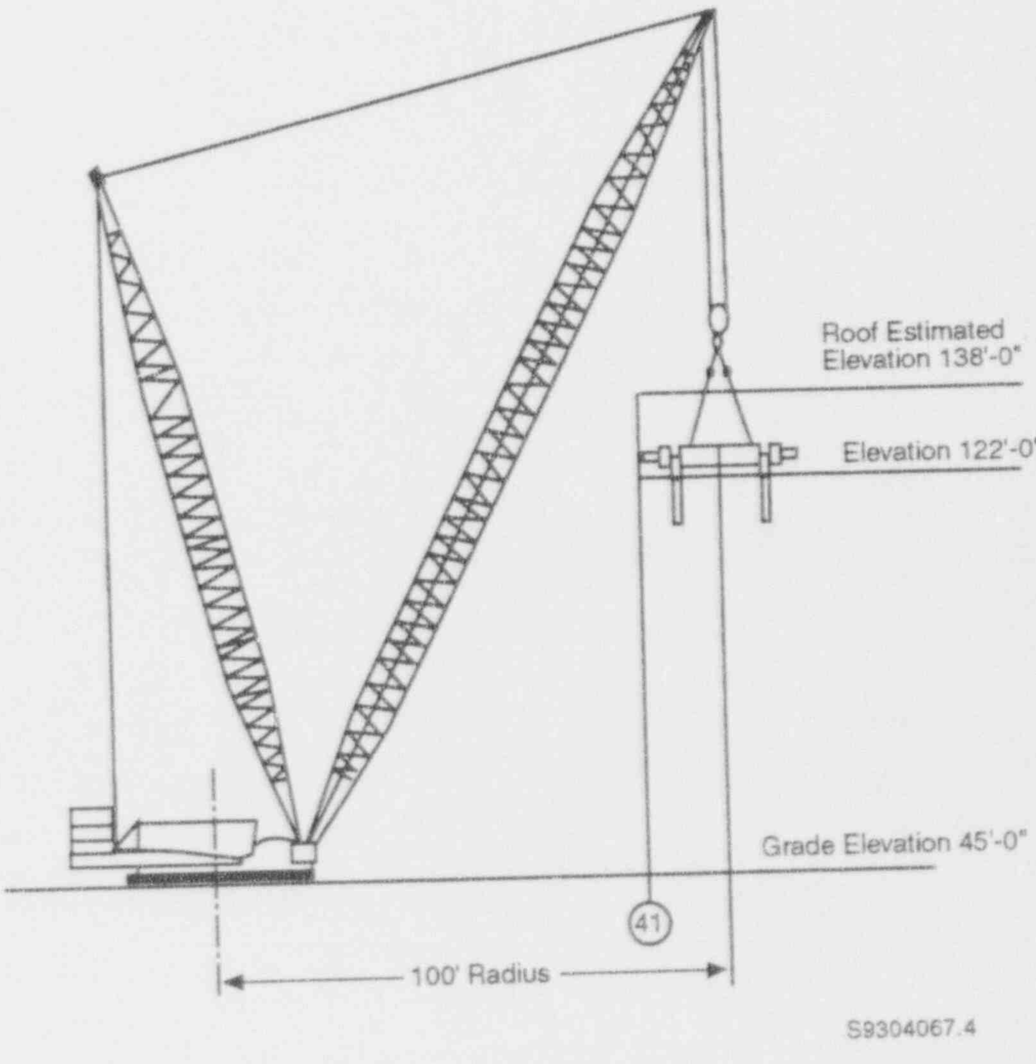


FIGURE G.5. Conceptual Decommissioning Plan for the Fuel Building Crane

TABLE G.6. Crew Composition and Exposure Rates Postulated for Crane Cleanup Crews

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

Average cost per crew-hour, including shift differential[c] $197.52

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

treatment since the water will contain measurable radioactivity. Therefore, the water will be treated by batch process by a specialty contractor (sampled, analyzed and treated again, as necessary until release criteria are met) and released according to applicable release standards. The SFP and associated systems will be left dry.

This task is very similar in nature to Task 5, shown in Table G.1. Discussions with a qualified vendor have suggested that the estimated vendor's cost for this task would be about $750,000. Subsequent transportation costs for the resultant radioactive wastes are included in this cost estimate, but radwaste burial costs are the responsibility of the utility. It is further estimated to take 30 consecutive days, working 21 shifts per week (6 people per shift). Protective clothing and equipment for vendor's staff are expected to cost the utility about $11,340.

Since the spent fuel pool water quality and extent of deposit accumulation from the fuel assemblies are not well known at this point, it is difficult to predict with confidence either the occupational radiation exposure or the volume of waste that will result from these activities. However, for the purpose of this study, 1) an ORE of approximately 2 person-rem is anticipated for these activities; and, 2) it is roughly estimated that about five 5.72 m^3 HIC's could be required.

Based on information contained in Appendix B, the cost of five HICs is estimated at $39,125. The transportation cost for the HICs from the manufacturer to the plant site is estimated at $4,210, based on a direct quote from the Tri-State Motor Transport Company. Twenty-one days of cask rental charges come to an estimated $26,250. Burial costs at U.S. Ecology are estimated at $67,590. Burial costs at Barnwell are estimated at $373,800. The burial cost estimates are based on the assumptions that individual HICs contain less than 50 curies of activity each and have surface contact readings of less than 20 R/hr.

A summary of the total estimated costs and ORE for this activity is presented in Table G.7.

G.4.3 Temporary Waste Solidification System

The specifics associated with the decontamination of surfaces using high pressure water wash/vacuuming are described in detail in Appendix C and are not repeated here. However, the water usage, and hence liquid radwaste generation, treatment, transport and disposal is addressed here.

At the calculated generation rate of 1 gallon per minute of system operation (see Appendix C for details), it is estimated that approximately 27,330 gallons of high solids, low activity waste solutions will result from the surface cleaning tasks at the reference PWR. It is postulated that a transportable evaporator-solidification system, together with specialty contractor operating personnel, will be used to provide this additional liquid radioactive waste handling capability and final cleanup capability at the reference PWR. Based upon discussions with senior staff at Pacific Nuclear Services, the waste solutions are estimated to be processed for disposal (i.e., evaporated/solidified in seven 5.72 m^3 HIC) at a unit cost of about $10/gallon. Mobilization/demobilization costs add another $20,000, resulting in a total cost of $293,300 for this fixed-price contract. Overall, about 36 days are required to complete the task, including mobilization/demobilization. Occupational radiation exposure is anticipated to be less than 0.7 person-rem.

TABLE G.7. Summary of Estimated Costs and Radiation Dose for Spent Fuel Pool Water Treatment and Subsequent Waste Disposal

Cost Item	Estimated Cost (1993$)[a]	Estimated Dose (person-rem)
Fixed-cost Contract, Specialty Contractor[b]	750,000	~2
Transportation of HICs to Plant Site from Mfgr.[c]	4,211	--[d]
High-Integrity Containers[e]	39,125	--
Cask Rental[f]	26,250	--
Transportation	--[g]	--
Burial[h]	67,590	--
Totals	887,176	~2
Protective Clothing & Equipment Services (vendor only)	11,340[i]	--

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) See text for details.
(c) Based on quote from Tri-State Motor Transport Company.
(d) Dashes mean no dose associated with this item.
(e) Based on Table B.2.
(f) Based on Table B.3.
(g) Included in $750,000 Fixed-Cost Contract.
(h) Derived from information provided by U.S. Ecology. Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B), the total estimated burial cost for the 5 HICs is $373,800.
(i) Included in Period undistributed costs.

The cost of the HICs, cask rental, transportation and final disposal of the HICs are the responsibility of the licensee. Based on information contained in Appendix B, the HICs are estimated to cost $54,775; 25 days of cask rental come to $31,250; total transportation costs are estimated at about $24,350; and disposal costs at U.S. Ecology are estimated at $86,525. Burial costs at Barnwell are estimated at $513,275. The burial cost estimates are based on the assumptions that individual HICs contain less than 5 curies of activity each and have surface contact readings of less than 5 R/hr. A summary of the total estimated costs and occupational radiation exposure for this activity is presented in Table G.8.

TABLE G.8. Summary of Estimated Costs and Radiation Dose for Temporary Waste Solidification System Operation and Subsequent Waste Disposal

Cost Item	Cost (1993$)[a]	Estimated (person-rem)	Estimated Dose
Fixed-cost Contract, Specialty Contractor[b]		293,300	<0.7
Disposal of Radioactive Materials:			<0.1
High-Integrity Container[c]		54,775	
Cask Rental[d]		31,250	
Transportation[e]		24,343	
Burial[f]		86,525	
		196,893	
Totals		490,193	~0.8

(a) The number of significant figures is for computational accuracy and does not imply precision to that many significant figures.
(b) See text for details.
(c) Based on Table B.2.
(d) Based on Table B.3.
(e) Based on direct quote from Tri-State Motor Transport Company. Includes transportation charges for the empty cask from Barnwell, SC to Trojan, the loaded casks from Trojan to Hanford, and the empty cask back to Barnwell, SC.
(f) Derived from information provided by U.S. Ecology. Based upon disposal cost information provided by Chem-Nuclear Systems, Inc. for the Barnwell site (see Appendix B), the total estimated burial cost for the 7 HICs is $513,275.

G.5 REFERENCES

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

2. T. S. LaGuardia, and J. F. Risely. 1986. Identification and Evaluation of Facilitation Techniques for Decommissioning Light Water Power Reactors. NUREG/CR-3587, U.S. Nuclear Regulatory Commission Report by TLG Engineering, Inc., Brookfield, Connecticut.

3. EPRI NP-6023, Project 1329-3. 1988. Chemical Decontamination Experience at Commonwealth Edison Nuclear Power Plants. Electric Power Research Institute Final Report by Niagara Technical Consultants, Niagara Falls, New York.

4. D. M. Vandergriff. August 1987. Evaluation of Recent Utility Experience With BWR Chemical Decontamination Technology. EPRI Report NP-5515.

APPENDIX H

MIXED WASTES

APPENDIX H

MIXED WASTES

The estimated volume of mixed radioactive/hazardous waste (i.e., mixed waste)[a] and the costs associated with its removal, packaging, and either storage or disposal were not considered in the original decommissioning study on the reference pressurized water reactor (PWR).[1] Disposal of mixed wastes, especially solid mixed waste, generated by the commercial nuclear power industry in the United States is presently very difficult, if not impossible, since there are no disposal sites licensed for radioactive wastes and permitted for hazardous wastes. Consequently, licensees must store mixed wastes until a disposal site becomes available. The statutory and regulatory requirements, current NRC guidance on the management of mixed waste, what is currently being done to deal with the problem of mixed wastes, estimated production of mixed wastes during operation at selected light water reactors, the postulated production of mixed wastes during decommissioning at the reference PWR, and the estimated costs for storage and disposal of mixed wastes are discussed in this appendix. The conclusions of this appendix are presented in Section H.7.

H.1 STATUTORY AND REGULATORY REQUIREMENTS

The U.S. Environmental Protection Agency (EPA) has authority under the Resource Conservation and Recovery Act (RCRA)[b] over the management of hazardous wastes. Radioactive material, as defined in the Atomic Energy Act (AEA), is excluded from the definition of solid waste in the RCRA. Accord-

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(a) Mixed low-level radioactive and hazardous waste (mixed LLW) is defined as waste that satisfies the definition of low-level radioactive waste (LLW) in the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) and contains hazardous waste that either 1) is listed as a hazardous waste in Subpart D of 40 CFR Part 261, Identification and Listing of Hazardous Waste or 2) causes the LLW to exhibit any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261.

(b) RCRA means the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976 (Public Law 94-580, as amended by Public Law 95-609 and Public Law 96-482, 42 U.S.C. 6901 et seq.)

ingly, commercial use and disposal of source, byproduct and special nuclear materials, and wastes are regulated by the NRC to meet the environmental standards developed by EPA. Low-level radioactive wastes (LLW) containing source, byproduct, or special nuclear material that also contain chemical constituents which are hazardous under EPA regulations in 40 CFR Part 261, Identification and Listing of Hazardous Waste are referred to as Mixed Waste (mixed LLW).

The Low-Level Radioactive Waste Policy Amendments Act of 1985 defines LLW as radioactive material that (A) is not high-level radioactive waste, spent nuclear fuel, or byproduct material as defined in section 11e(2) of the AEA (i.e., uranium or thorium mill tailings) and (B) the NRC classifies as LLW consistent with existing law and in accordance with (A). Listed hazardous wastes include hazardous waste streams from specific and non-specific sources listed in 40 CFR Parts 261.31 and 261.32 and discarded commercial chemical products listed in 40 CFR Part 261.33. If LLW contains a listed hazardous waste or non-AEA regulated materials that cause the LLW to exhibit any of the hazardous waste characteristics - ignitability (Section 261.21), corrosivity (Section 261.22), reactivity (Section 261.23), and toxicity, as determined using the Toxicity Characteristic Leaching Procedure (Section 261.24) - the waste is mixed LLW. The waste must be managed and disposed of in compliance with EPA's Subtitle C hazardous waste regulations in 40 CFR Parts 124, and 260 through 270, and NRC's regulations in 10 CFR Parts 20, 30, 40, 61, and 70. The generator is responsible for determining whether LLW contains listed or characteristic hazardous wastes. Furthermore, management and disposal of mixed LLW must be conducted in compliance with state requirements in states with EPA-authorized regulatory programs for the hazardous components of such waste and NRC agreement state radiation control programs for LLW.[2]

In summary, NRC regulations exist to control the byproduct, source, and special nuclear material components of commercial mixed LLW; EPA has the authority to control the non-radioactive component of the mixed LLW. Thus, the individual constituents of commercial mixed LLW are subject to either NRC or EPA regulations. When the components are combined to become mixed LLW, neither statute has exclusive jurisdiction; however, RCRA Section 1006(a) states that the AEA requirements have precedence in the event an inconsistency is found between the requirements of the two statutes. This has resulted in a situation of joint regulation where both NRC and EPA regulations may apply to the same waste. To aid commercial LLW generators in assessing whether they are currently generating mixed LLW, the NRC and the EPA jointly developed a revised guidance document entitled, "Joint EPA/NRC Guidance on the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste," Directive No. 9432-00-2, October 4, 1989. It is based on NRC and EPA regulations in effect on December 31, 1988. Application of the methodology to identify mixed LLW, as delineated in this document, will reveal the complexities of the definition of mixed LLW. Generators with specific questions about whether LLW is mixed LLW can call NRC and EPA contacts given in the document.

States are authorized to promulgate mixed waste regulations under the RCRA as long as their regulations are no less stringent than applicable federal regulations. States, however, have been slow to receive authorization to regulate mixed waste under their approved RCRA programs. Mixed waste is regulated as a RCRA hazardous waste in those states where EPA implements the entire RCRA Subtitle C program (i.e., unauthorized states) as well as in authorized states which have obtained specific authorization from EPA to implement a mixed waste program. Currently, there are five unauthorized states (Alaska, California, Hawaii, Iowa, and Wyoming) and, as of January 31, 1992, 29 additional states and territories with mixed waste authorization.

In any state previously authorized by EPA to regulate hazardous waste, but not mixed waste, the generation, transport, treatment, storage or disposal of mixed waste is not regulated under the federal RCRA program until the state's mixed waste authorization is approved. But in states not authorized to run their own RCRA program, federal RCRA mixed waste regulations become effective upon promulgation. A further complication comes about since no one, not even the federal government, has reliable data on the number of facilities producing mixed waste or the volumes produced annually. EPA estimates that 2 to 30% of all low-level radioactive waste contains RCRA-hazardous components. There is also a recognized absence of treatment and disposal facilities. In addition, complications attending mixed waste disposal are expected to yield massive disposal costs, which are likely to rise still further as generators, seeking to avoid costs as high as $20,000 per cubic foot, cut their mixed waste output drastically, thereby pushing up costs for the remaining waste.[3,4]

The NRC and the EPA have been working together for several years to resolve the issues associated with mixed waste. The agencies conducted a survey of generators of commercial mixed radioactive/hazardous waste and are completing two joint technical guidances on testing and storage of such wastes. Oak Ridge National Laboratory, which conducted the voluntary generator survey for the two agencies, sent out questionnaires to over 1,300 potential mixed waste generators in November 1991. The results of the survey, presented in NUREG/CR-5938,[5] have been used to develop a national profile that is expected to provide needed information to states and compact officials, private developers, and federal agencies to assist in planning and developing adequate disposal capacity for low-level radioactive waste, including mixed waste, as mandated by the LLRWPAA of 1985. The report also contains information on existing and potential commercial waste treatment facilities that may provide treatment for specific waste streams identified in the national survey. The report provides a reliable national database on the volumes, characteristics and treatability of commercial mixed waste in the United States. Data from the survey also may serve as a basis for possible federal actions to effectively manage and regulate the treatment and disposal of mixed waste.

NRC and EPA also are developing a joint guidance on safe storage of mixed waste. Given the current lack of treatment and disposal capacity for most mixed wastes, both agencies are concerned with problems that could arise from long-term storage of such wastes. The joint guidance will address issues associated with onsite storage, including inspection and surveillance of waste, waste compatibility and segregation, storage container requirements, and time limitations on storage of untreated waste. For each issue, the agencies are attempting to identify acceptable practices.[4]

In instances where regulatory authority can be delegated, the EPA may delegate regulatory authority to the state for state programs that meet or exceed EPA requirements. Where regulatory authority is not delegated, EPA is responsible for reviewing and evaluating compliance with the EPA regulations. This includes interpreting regulations and consulting with reactor owners and their contractors to aid regulation implementation and inspection of facilities at the sites.

H.2 NRC GUIDANCE ON THE MANAGEMENT OF MIXED WASTE

Guidance on storage and disposal of mixed wastes at nuclear power plants is provided in Draft Regulatory Guide DG-1005.[6] The draft guide describes elements to be included in the radioactive waste management plan, which is part of the final decommissioning plan submitted by the licensee to the NRC. The radioactive waste management plan should contain a description of the procedures, processes, and systems used for disposing of all radioactive wastes as well as a detailed characterization of the wastes to be generated with projected volumes, radionuclide concentrations, waste forms and classification, and information on any significant quantities of special wastes such as mixed wastes and chelating agents. Expected dispositions of these materials should also be identified with respect to treatment, packaging, interim storage, transportation, and disposal. The need for changes to the site radwaste process control plan and transportation plan should be addressed.

If radioactive wastes are to be stored onsite, the quantities of waste, the expected length of storage, the location of storage areas, radiation levels at access points, and the manner in which positive control will be maintained should be described. The plan should indicate the extent to which the site has been previously used to dispose of low-level radioactive wastes by land burial and indicate the remedial measures that are appropriate before the site can be released for unrestricted use and the license terminated.

In addition, the NRC has published a draft guidance document intended for use by NRC licensees entitled, "Clarification of RCRA Hazardous Waste Testing Requirements for Mixed Waste," March 1992. Described in the guidance are: 1) the current regulatory requirements for determining if a waste is a RCRA hazardous waste; 2) the waste analysis information necessary for proper treatment, storage, and disposal of mixed waste;[c] and 3) the implications of the RCRA land disposal restrictions (LDRs) on the waste characterization and analysis requirements. This information will be useful for radioactive mixed waste generators, who must determine if their waste is a mixed waste; for those generators storing mixed waste onsite in tanks or containers for longer than 90 days, who consequently become responsible for meeting RCRA and NRC storage requirements; and for those facilities who accept mixed waste for offsite treatment, storage, or disposal.

H.3 WHAT IS CURRENTLY BEING DONE TO DEAL WITH THE PROBLEM OF MIXED WASTES

Although primary responsibility for the development of treatment and disposal technologies rests with the nuclear industry and the Department of Energy, NRC is currently conducting several activities that should facilitate development by clarifying the regulatory framework for mixed waste management. NRC and EPA are jointly developing guidance documents on waste characterization, inspection, and storage of mixed waste. The waste characterization guidance will address occupational exposures during testing. The inspection guidance will provide NRC Regional, Agreement State, EPA Regional, and Authorized State inspectors with background information on mixed waste licensing and permitting, inspection planning and coordination, cross-training, and conduct of mixed waste inspections. The storage guidance will combine the NRC radioactive waste storage recommendations with EPA storage requirements. In addition, NRC is providing assistance to EPA in the permit writers' workshop on mixed waste regulation.[7]

EPA has set some treatment standards for mixed waste. Incineration is an applicable technology for low-level waste combined with organic compounds in wastewater and non-wastewater, as well as ignitable liquids (listed waste number D001 under RCRA). With the exception of scintillation fluids contain-

(c) The requirements and frequency of waste analysis for a given facility will be spelled out in the facility's waste analysis plan (WAP). The WAP specifies the parameters for which each hazardous waste will be analyzed, the rationale for selecting these parameters (i.e., how analysis for these parameters will provide sufficient information on the waste's properties), and the test methods that will be used to test for these parameters. The WAP also will specify the sampling method to be analyzed and the frequency with which the initial analysis of the waste will be reviewed or repeated to ensure that the analysis is accurate and up to date. The appropriate parameters for each WAP are determined on an individual basis as part of the permit application review process.

ing low levels of carbon-14 and mercury, DOE has the exclusive franchise on mixed-waste incineration in the United States. Incineration of mixed wastes destroys organic chemicals and reduces volume. An experimental DOE reactor at the Idaho National Engineering Laboratory, for example, is getting a 250-to-1 reduction rate; thus, substantial savings could be realized from commercial application of this technique, if it were available.[d] But at the Rocky Flats Plant, near Denver, Colorado, DOE abandoned plans to start an incinerator for mixed hazardous and radioactive wastes when public opposition combined with problems during the plant's testing phase.[8]

Diversified Scientific Services, Inc. (DSSI), Kingston, Tennessee, is the only commercial company in the United States currently licensed and permitted to treat/store selected liquid, mixed low-level wastes. In addition, the nation's largest low-level waste processor, Scientific Ecology Group, Inc. (SEG) in Oak Ridge, Tennessee, has applied for permits and a license to operate the first commercially available incinerator for solid and liquid mixed waste. The incinerator is currently licensed only for low-level radioactive waste. The company submitted an RCRA Part A permit application in March 1991.[3] The associated Part B permit application was submitted to the Tennessee Division of Solid Waste in early 1993. These permits, when granted, will allow SEG to store and treat characteristic hazardous wastes.

U.S. Ecology, Inc. is developing a new low-level waste burial ground at Ward Valley, California. The company has said that it expects ultimately to store mixed waste at Ward Valley; however, it prefers to develop the part of the site needed for the estimated 95% of the expected LLW that is not chemically hazardous.[9] As previously mentioned, EPA estimates that 2 to 30% of all low-level radioactive waste contains RCRA-hazardous components. At present, it appears that no one is exactly certain what percentage of low-level radioactive waste generated during the decommissioning process will contain RCRA-hazardous components. Additional LLW may be identified as mixed

(d) The DOE plant, part of the Waste Experimental Reduction Facility, has been processing low-level radioactive wastes since 1984. The facility is a pilot-scale plant, with a maximum capacity of burning 400 pounds of wastes per hour. By contrast, DOE's mixed waste incinerator in Oak Ridge, Tennessee, burns 3,000 pounds per hour. The Oak Ridge plant is the only full-scale incinerator for mixed wastes that is now licensed and operating in the U.S.[8]

LLW in the future, as generators implement the definition of mixed LLW and as EPA revises the definition of hazardous waste. At currently estimated costs as high as $20,000 per cubic foot for disposal of some mixed wastes, there exists strong incentive to implement mixed waste minimization techniques.[4]

In August 1991, EPA decided not to enforce RCRA land disposal restrictions (Section 3004) for mixed LLW for two years, since neither treatment nor disposal is available for such wastes. In effect, EPA outlined a policy that can be used on a site-specific basis to provide reduced enforcement priority to the storage of some mixed wastes. Thus, the new policy acknowledges the impossibility of enforcing the land-ban restrictions for these wastes. Generators of less than 1,000 cubic feet per year of mixed waste will not be interfered with so long as they are managing wastes in a responsible manner, as defined by EPA. This includes: 1) an inventory of stored mixed waste, 2) identification of such waste and good records, 3) a mixed waste minimization plan, 4) documentation of "good faith" efforts to ascertain availability of treatment and disposal, and 5) cooperation with EPA on a mixed waste survey it is conducting jointly with NRC (see Section H.1 for details). The policy will terminate December 31, 1993.[4] If sufficient lawful treatment or disposal capacity becomes available before then, it could be terminated early. On the other hand, it may be extended, although EPA is under no obligation to do so.

As reported in Reference 4, the so-called "land-ban" restrictions have placed some mixed waste generators in a "catch-22" situation. The Hazardous and Solid Waste Amendments Act of 1984 amended RCRA to, among other things, prohibit storage of hazardous waste subject to the Land Disposal Restrictions (LDRs) "unless such storage is solely for the purpose of accumulating necessary quantities of waste to facilitate proper recovery, treatment, or disposal." However, for radioactive mixed waste falling under LDR, neither treatment or disposal options exist, leaving generators unable to comply with the regulations.

H.4 ESTIMATED PRODUCTION OF MIXED WASTES DURING OPERATION OF SELECTED LIGHT-WATER REACTORS

The following information was extracted from Reference 10. In 1990, the Nuclear Management and Resources Council (NUMARC) completed a study of mixed wastes in the commercial nuclear power industry.[11] This investigation developed estimates of generation and disposal rates for mixed wastes from light-water reactor operations (summarized in Table H.1). Two case estimates were developed for the NUMARC study, one based on a set of conservative assumptions and the other based on reasonable changes made to those assumptions. The "reasonable assumptions" case indicates a lower bound LWR mixed waste generation rate of 82 m^3/year and a disposal rate of 21 m^3/year. These "reasonable assumptions" are based on the following:

- It is possible to segregate wastes containing certain hazardous (EPA Code F003) spent solvents from other spent solvents.
- Characteristically hazardous wastes can be processed to render them nonhazardous.
- Procedures can be implemented to minimize radiological contamination.
- Cadmium content in welds and weld rods may be shown to not exhibit the TCLP/EP toxicity characteristics.
- Explicit account can be made of the timing of mixed waste generated on an infrequent basis.
- Scintillation cocktails may be shown to not exhibit the ignitability characteristic.
- Chromate-bearing ion-exhange resins may be shown to not exhibit the TCLP/EP toxicity characteristics.
- Decontamination resins may be shown to not exhibit the corrosivity characteristic.
- Individual plants may have design and operating features which do not produce the mixed waste streams assumed in this estimate.

TABLE H.1. Summary of NUMARC-Estimated Characteristics of Mixed LLW from Commercial LWR Operations[a]

Source	Annual Waste Volume (m^3/year) Generated	Disposed
PWR Operations	102	42.5
BWR Operations	119	59.5
LWR Total, Conservative Base Case	221	102
LWR Total, Reasonable Assumptions Case	82.1	21.2

(a) Based on the NUMARC study, Reference 11.

H.5 ESTIMATED PRODUCTION OF MIXED WASTES DURING DECOMMISSIONING OF THE REFERENCE PWR

The implementation of waste minimization techniques at the reference PWR during the operating years is assumed to carry over into active decommissioning periods, resulting in relatively small volumes of generated mixed wastes (either liquid or solid). As used here, waste minimization refers to reducing the volume or toxicity of waste by using source-reduction techniques (e.g., chemical substitution, process modifications, or recycling). These techniques are not to be confused with the broader definition usually associated with waste reduction, which includes source reduction and recycling, but it also acknowledges various waste treatment options as useful to reducing the volume or toxicity of waste. Under these definitions, compaction to decrease waste volume would be considered waste reduction, but not waste minimization.

H.6 ESTIMATED COSTS FOR STORAGE AND DISPOSAL OF MIXED WASTES

If mixed wastes are required to be stored for a lengthy period at the reference PWR after final shutdown of the reactor, termination of the license would be delayed until the mixed waste inventory is reduced to zero, and DECON would not be possible. Similarly, ENTOMB would not be possible until the mixed waste inventory was reduced to zero, since entombment of mixed wastes is not covered by federal regulation. If either the hardened or passive SAFSTOR option is selected, the mixed waste inventory is anticipated to be added to the existing waste inventory that must be safely cared for. For the purpose of this study, it is assumed that: 1) if a RCRA permit existed during operation of the reference plant for the storage of mixed waste, the permit would be continued into the postulated decommissioning storage period, presumably until disposal of the mixed waste occurred; and 2) the RCRA-related costs (including liability requirements) and the ultimate disposal costs are considered to be operational costs.

A discussion with a representative of Diversified Scientific Services, Inc. (DSSI), Kingston, Tennessee, revealed that costs of about $35 per gallon (1991 dollars), not including transportation, for disposal of selected, liquid mixed wastes is a reasonable estimate to use.[e] Firm cost estimates for similar services concerning disposal of solid mixed LLW were not obtained, since such services are not currently available in the U.S.[12] However, joint regulation by both NRC and EPA is expected to make the unit cost of disposing of mixed waste much higher than the cost of disposing of other low-level wastes.[13]

H.7 CONCLUSIONS

Currently, mixed waste is estimated to account for less than 3% of the annual generation rate of LLW (by volume). No offsite disposal or treatment facility for mixed waste has been available since 1985. Utilities are finding ways to treat some of their mixed waste so that it is no longer a chemical hazard, thus making it possible to dispose of the radioactive component along with other LLW. The remainder of mixed waste, however, is currently stored onsite.[12, 14]

For purposes of this study, the ultimate cost of disposal of mixed wastes (either liquid or solid) expected to be present on the reference PWR site at final shutdown are considered to be operational costs, since they were incurred during operation of the plant. It should be recognized, however, that regardless of when solid mixed LLW is generated, commercial treatment,

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(e) Personal communications with L. Hembree, Customer Service Representative, October 9, 1991, Diversified Scientific Services, Inc., Kingston, Tennessee.

storage, and disposal services for the waste do not currently exist. Based on projected astronomical disposal costs and on the uncertainties surrounding the ultimate disposition of solid mixed LLW, it is assumed further that implementation of waste minimization techniques used during the operating years of the plant will also be used during decommissioning. Therefore, only a relatively small amount, if any, of additional solid mixed LLW is assumed to be generated during decommissioning of the reference PWR.

H.8 REFERENCES

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2. U.S. Nuclear Regulatory Commission. 1989. "Guidance on the Definition and Identification of Commercial Mixed Low-Level Radioactive and Hazardous Waste."

3. Hazardous Waste News, July 1, 1991, pp. 256-257.

4. Nuclear Waste News, August 29, 1991, pp. 342-344.

5. J. A. Klein, et al. December 1992. National Profile on Commercially Generated Low-Level Radioactive Mixed Waste. NUREG/CR-5938, U.S. Nuclear Regulatory Commission Report by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

6. U.S. Nuclear Regulatory Commission Draft Regulatory Guide DG-1005, "Standard Format and Content for Decommissioning Plans for Nuclear Reactors," September 1989.

7. Letter, The Honorable Kenneth M. Carr, Chairman, U.S. Nuclear Regulatory Commission, to The Honorable Morris K. Udall, Chairman Committee on Interior and Insular Affairs U.S. House of Representatives, transmitting information on issues related to the treatment and disposal of mixed wastes, dated January 10, 1990.

8. Tri-City Herald, October 6, 1991. "Company Heads for Uncharted Territory," p. A9.

9. Nuclear News. April 1989. "NRC Issues Guidance on 1990 Certifications," p. 114.

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11. Nuclear Management and Resources Council, The Management of Mixed Low-Level Radioactive Waste in the Nuclear Power Industry, NUMARC/NESP-006, prepared by Rogers and Associates Engineering Corporation with Nuclear Waste Management, Inc., Washington, D.C. (January 1990).

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13. GAO/RCED-92-61. January 1992. Nuclear Waste - Slow Progress Developing Low-Level Radioactive Waste Disposal Facilities. United States General Accounting Office Report to Congressional Requesters, Washington, D.C.

14. OTA-O-426. 1989. "Partnerships Under Pressure: Managing Commercial Low-Level Radioactive Waste," Office of Technology Assessment, U.S. Congress, Washington, D.C.

APPENDIX I

REGULATORY CONSIDERATIONS FOR DECOMMISSIONING

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REGULATORY CONSIDERATIONS FOR DECOMMISSIONING

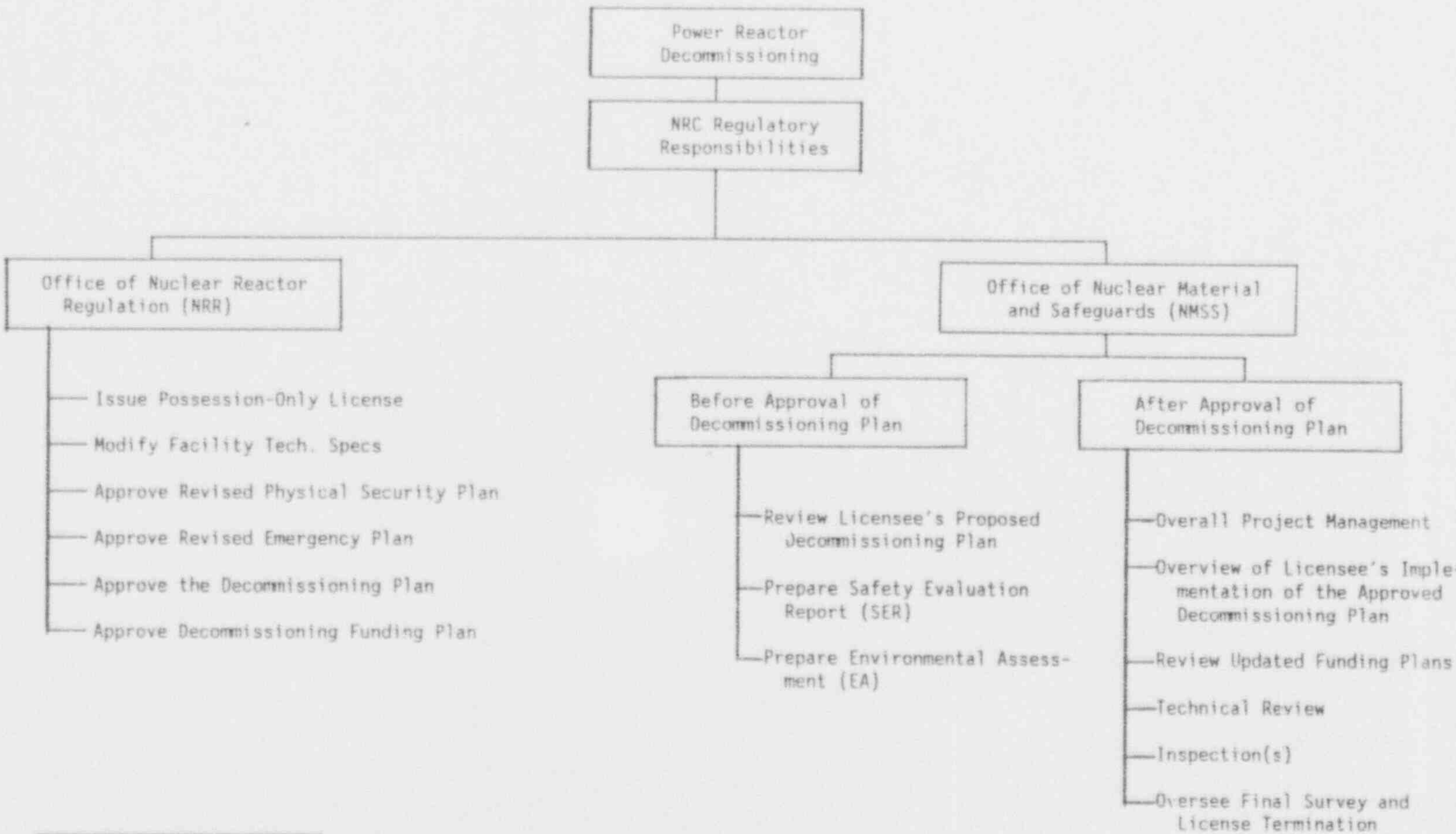
In decommissioning, the facility licensee must be aware of applicable regulatory requirements and regulatory guidance. The U.S. Nuclear Regulatory Commission (NRC) provides decommissioning guidelines in the rule "General Requirements for Decommissioning Nuclear Facilities."[1] In addition, Regulatory Guide 1.86[2] contains guidance on decommissioning procedures.

The licensee also should recognize that two offices within the NRC share the responsibilities in the decommissioning process for power reactors -- the Office of Nuclear Reactor Regulation (NRR) and the Office of Nuclear Material Safety and Safeguards (NMSS). An overview of their decommissioning regulatory responsibilities is illustrated in Figure I.1. NRC project management responsibility shifts from NRR to NMSS upon approval of the decommissioning plan. Upon transfer of project management responsibility, NMSS takes on the responsibility of overview of the licensee's implementation of the approved decommissioning plan.

This chapter identifies and discusses regulations, guides, standards, and changes in regulatory requirements from those delineated in NUREG/CR-0130, which was published in June 1978.[3] The chapter is organized according to the following phases of decommissioning: planning and preparation, active decommissioning, and, in the case of storage modes of decommissioning, continuing care. For completeness, selected regulatory aspects associated with decommissioning prematurely shutdown plants are discussed in Section I.4. Decommissioning after a 20-year license renewal period is discussed in Section I.5.

I.1 PLANNING AND PREPARATION

During the planning and preparation phase of decommissioning prior to final shutdown, the licensee, with NRC approval, decides on and plans how to



(a) Source: NRC Internal Realignment of Responsibilities, December 1988 (SECY-88-355).

FIGURE I.1. Power Reactor Decommissioning Regulatory Overview[a] accomplish the final disposition of the plant. The licensee's major preparatory effort is to 1) provide the necessary documentation for amending the facility operating license to a "possession-only" license (POL), 2) renewing the license if necessary, and 3) obtaining an NRC decommissioning order, if required.

This section discusses the regulations, regulatory guides, and other guides that pertain to the planning and preparation phase of decommissioning, in the following sequence: licensing, decommissioning plan, licensing costs, financial assurance, and Internal Revenue Service involvement in decommissioning funding.

I.1.1 Licensing Requirements

The facility operating license is regulated by 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities. In 10 CFR 50.51, "Duration of License, Renewal," the operating license is permitted to be valid for a maximum of 40 years. The decommissioning rule[1] requires submittal of a preliminary decommissioning plan about five years before permanent shutdown (10 CFR 50.75(f)) and submittal of a decommissioning plan at the time of permanent cessation of operations (10 CFR 50.82(a)). Both of these plans will contain a description of planned decommissioning activities and a description of methods used to ensure protection of workers and the environment against radiation hazards during decommissioning.

Upon expiration, the license may be either renewed or terminated. The requirements that must be met to terminate the operating license are presented in 10 CFR 50.82, "Application for Termination of License."

I.1.2 Decommissioning Plan Requirements

Requirements for applications for license termination and decommissioning nuclear reactors are contained in 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities, and specifically in Section 50.82, "Application for Termination of License." On June 27, 1988, the NRC published amendments to 10 CFR Part 50,[1] along with other parts of its regulations, concerning general requirements for decommissioning nuclear facilities. The revised Section 50.82 requires that an application for license termination be accompanied or preceded by a proposed decommissioning plan.

The following subsections discuss the regulations and regulatory guides that pertain to the documentation requirements of a license amendment request or a decommissioning plan in the following sequence: standard format and content, radioactive waste management plan, quality assurance plan, security and safeguards plan, and environmental plans.

I.1.2.1 Standard Format and Content for a Decommissioning Plan

Draft Regulatory Guide DG-1005, "Standard Format and Content for Decommissioning Plans for Nuclear Reactors," was issued for public comment in September 1989, in conjunction with publication of the decommissioning rule. The purpose of the guide is to identify the information needed and to present a format acceptable to the NRC staff for preparing and submitting a decommissioning plan. The NRC staff suggests the use of the standard format contained in the guide for decommissioning plans to facilitate preparation by licensees and timely and uniform review by the NRC staff and as guidance in use of the Standard Review Plan for decommissioning plans. Title 10 CFR Parts 20, 50, and 70 provide the regulatory basis for the guide.

A decommissioning plan should show that the facility can be decommissioned in a safe manner and describe the licensee's plans to demonstrate that the facility and site will meet criteria for release for unrestricted use.[a] This plan must be approved by the NRC staff. The decommissioning rule requires a licensee to submit a proposed decommissioning plan within two years after permanently ceasing operation and no later than one year prior to expiration of the operating license. In addition to the decommissioning plan, paragraph 51.53(b) requires each applicant for a license amendment authorizing the decommissioning of a production or utilization facility to submit with its application a separate document entitled "Supplement to the Applicant's

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(a) Unrestricted use refers to the fact that from a radiological standpoint, no hazards exist at the site, the license can be terminated, and the site can be considered an unrestricted area. This definition is consistent with the definition of an unrestricted area as it exists in 10 CFR 20.3 as being "any area access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials and any area used for residential quarters."[1]

Environmental Report--Postoperating License Stage." This supplement would reflect any new information or significant environmental change associated with the applicant's proposed decommissioning activities.

The requirements of 10 CFR 50.51(b) apply to a plant going into DECON, SAFSTOR, or ENTOMB. If either the SAFSTOR or ENTOMB decommissioning method is selected, a decommissioning plan would contain 1) the details for preparing the facility for safe storage or for entombment, 2) plans for monitoring and surveillance during the storage period, 3) plans for assuring funds for maintaining the facility and completing decommissioning, including the means of adjusting cost estimates and associated funding levels over the safe storage or surveillance period [guidance on funding is delineated in Regulatory Guide 1.159 (Task DG-1003), "Assuring the Availability of Funds for Decommissioning Nuclear Reactors"],[4] and 4) a commitment to submit an updated plan prior to starting final decommissioning activities.

It may take a year for a power reactor licensee to prepare a decommissioning plan for submittal and about a year for the NRC staff to review, evaluate, and approve the plan. Thus, preparation of a decommissioning plan should start as soon as practical after a licensee decides to permanently shut down a facility.

In some cases, the information requested - such as the 1) training program, 2) radiation protection provisions, 3) radioactive waste management plan, 4) updated cost estimate for decommissioning method chosen and plan for assuring availability of funds for completion of decommissioning, 5) quality assurance provisions in place during decommissioning, and 6) physical security plan provisions in place during decommissioning - may be the same or similar to information previously submitted. Information contained in previous submittals, statements, or reports may be incorporated by clear and specific references, and only changes need be submitted.

In order to terminate a license, the NRC must determine that release of the facility and site for unrestricted use will not constitute an unreasonable risk to the health and safety of the public. To make such a determination, there must be evidence to show that radiation levels of the facility, site, and adjacent environs permit release for unrestricted use. Residual radioactive contamination levels are the subject of interim guidance under preparation and in regulatory guides; present guidance is contained in Regulatory Guide 1.86.[2] In addition, the decommissioning rule requires submittal of a final radiation survey plan as part of the decommissioning plan.

The decommissioning plan and the associated approval process provide an adequate legal framework for the regulation of facilities undergoing decommissioning. Therefore, the licensee would submit, gain approval of, and carry out decommissioning plans in accordance with the requirements of 10 CFR 50.82 and the guidance of Regulatory Guide DG-1005. The NRC licensing offices evaluate the information contained in the plan on whether it is based on existing regulations applicable to reactors undergoing decommissioning. These regulations include applicable parts of Title 10 CFR Parts 20, 50, 61, 70, 71, and 73. NRC staff will also monitor the carrying out of the plans.

I.1.2.2 Radioactive Waste Management Plan

Regardless of the decommissioning mode, radioactive waste will be accumulated, treated, packaged, stored, and transported to a disposal site. Means for complying with the regulatory aspects of each of these areas must be defined in the decommissioning plan. Unless indicated otherwise, the following regulatory changes, since 1978, are taken from the Supplementary Information to the decommissioning rule.[1]

The DECON decommissioning alternative assumes availability of capacity to dispose of waste. Disposal capacity for Class A, Class B, and Class C wastes currently exists. The Low-Level Radioactive Waste Policy Amendments Act (LLRWPAA) of 1985 (Public Law 99-240, approved January 15, 1986, 99 Stat. 1842) provides that disposal of Greater-Than-Class C (GTCC) wastes is the responsibility of the Federal Government.

NRC staff expected that Congress would provide guidance for development of disposal capacity for wastes exceeding Class C concentrations. Those wastes whose radionuclides concentrations exceeded the maximum allowed for land disposal, GTCC, were required to be stored by licensees pending further determination. This determination was provided in an amendment to 10 CFR 61

(Part 61.55, "Waste Classification") published in the Federal Register dated May 25, 1989, wherein all GTCC wastes are to be disposed of in a geologic repository, or in an approved alternative. In the LLRWPAA legislation passed by Congress in 1985, the U.S. Department of Energy (DOE) was assigned the responsibility for the disposal of GTCC wastes. Under this legislation, DOE must provide the capability for disposal of the GTCC wastes, but the waste generator must pay for the service. Thus, the costs of disposal of GTCC wastes resulting from decommissioning activities are a legitimate decommissioning expense.

Decommissioning activities do not include the removal and disposal of spent fuel, which is considered to be an operational activity, or the removal and disposal of nonradioactive structures and materials beyond that necessary to terminate the NRC license. Spent fuel disposal, although not included as a decommissioning activity, could nevertheless have an impact on the decommissioning schedule (see discussion below). The detailed schedule for development of monitored retrievable storage and geologic disposal capacity provided in the Nuclear Waste Policy Act of 1982 (NWPA, Public Law 97-245, January 7, 1983) and in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, Public Law 100-203, December 22, 1987) has been slipping. Therefore, licensees will have to assess the situation with regard to spent fuel disposal when they prepare their decommissioning plans.

Appendix D contains the background information and the rationale for the derivation of the minimum length of the SAFSTOR period at the reference PWR resulting from DOE's intent to not accept standard spent nuclear fuel (SNF)[b] from reactors until that fuel is cooled at least five years or can meet shipping cask certification requirements. This regulatory action could also result in changes in the decommissioning planning bases for DECON and ENTOMB as well. This change in the planning base requires a reassessment of decommissioning activity schedules and sequences, staff loadings, and shift schedules, to minimize the cost and radiation dose over the different decom-

(b) As delineated in 10 CFR Part 961, Appendix E,[5] SNF is broadly classified into three categories - standard fuel, nonstandard fuel, and failed fuel. Most, if not all, SNF from the reference PWR is assumed to fall into the standard fuel category. One of the General Specifications for standard fuel is a minimum cooling time of five (5) years.

missioning periods. Thus, the results of the analysis presented in this study are realistically anticipated to significantly affect the available choices of decommissioning alternatives for the reference plant.

It should be recognized, however, that the situation described in Appendix D with regard to spent fuel storage and final disposition and its subsequent impact on choice of decommissioning alternative is predicated on the current regulatory environment and on site-specific information associated with the reference pressurized water reactor (PWR). Therefore, the conclusions reached in this study concerning decommissioning alternatives for the reference PWR may be different for other PWR power stations, depending upon the age and burnup of the fuel in the pool, and the availability of other pool storage within a given utility system.

The NWPA of 1982 assigns to the Federal Government responsibility to provide for the permanent disposal of SNF and high-level radioactive waste (HLW).[c] The Director of DOE's Office of Civilian Radioactive Waste Management (OCRWM) is responsible for carrying out the functions of the Secretary of Energy (Secretary) under NWPA. Section 302(a) of the NWPA authorizes the Secretary to enter into contracts[d] with owners or generators[e] of commercial SNF and/or HLW. The Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste[5] represents the sole contractual mechanism for DOE acceptance and disposal of SNF and HLW. It establishes the requirements and operational responsibilities of the parties to the Contract in the areas of administrative matters, fees, terms of payment for disposal services, waste acceptance criteria, and waste acceptance procedures. The Standard Disposal Contract provides for the acquisition of title

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

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

(e) Owners or generators of SNF and HLW who have entered into agreements with DOE and/or have paid fees for purchase of disposal services are referred to as "Purchasers."

to the SNF and/or HLW by DOE, its transportation to DOE facilities, and its subsequent disposal.

Concerning the issue of priority being afforded to permanently shutdown reactors, DOE has responded thusly:[6]

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

With regard to DOE's beginning operations in 1998, DOE's intention, consistent with the NWPA and the Contract, is to initiate acceptance of spent fuel from Purchasers as soon as a DOE facility commences operations. DOE anticipates that waste acceptance at a monitored retrievable storage (MRS) facility could begin in 1998 if the initiatives detailed in the November 1989 "Report to Congress on Reassessment of the Civilian Radioactive Waste Management Program"[7] are fully implemented. Until waste acceptance begins, the owners and generators of SNF/HLW will continue to be responsible for storing their spent fuel.

The decommissioning rule[1] requires that at or about five years prior to the projected end of operation, each reactor licensee submit a preliminary decommissioning plan containing a cost estimate for decommissioning and an up-to-date assessment of the actions necessary for decommissioning. This requirement would assure that consideration be given to relevant up-to-date information which could be important to adequate planning and funding for decommissioning well before decommissioning actually begins. These considerations include an assessment of the current waste disposal conditions. If, for any reason, disposal capacity for decommissioning wastes were unavailable, there are provisions in 10 CFR 50.82 that would allow delay in completion of decommissioning in order to permit temporary safe storage of decommissioning waste. In addition, Section 50.82 contains requirements to ensure that adequate funding is available for completion of delayed decommissioning. It should be noted, however, that delays would have to be based on safety considerations and not just on economic considerations.

Disposal of nonradioactive hazardous waste arising from decommissioning operations are not covered by the aforementioned regulations, but would be treated by other appropriate agencies having responsibility over these wastes.

I.1.2.3 Quality Assurance Plan

The NRC recognizes that quality assurance (QA) is important for decommissioning. The decommissioning rule[(1)] indicates that QA provisions during decommissioning are to be described, as appropriate, in the decommissioning plan. The decommissioning rule contains requirements that a decommissioning plan, regardless of the alternative chosen, contain a description of quality assurance provisions.

Quality assurance is enhanced and facilitated by good practices concerning record keeping by the licensee. Paragraph 50.75(g) of the decommissioning rule requires licensees to keep records of information important to safe and effective decommissioning until the license is terminated by the NRC. This section of the rule also identifies the kinds of information the NRC considers important to decommissioning. A draft regulatory guide (DG-1006)(8) has been developed in conjunction with the decommissioning rule and was published for public comment in September 1989. The purpose of the draft guide is to provide guidance concerning the specific information that should be kept and maintained in the decommissioning records required by the rule regarding the radiological conditions at the plant that could affect occupational and public health and safety during decommissioning. Knowledge of radiological conditions in and around the reactor will serve to facilitate decommissioning by minimizing occupational exposure and reducing the risk of any public exposure.

Currently, the NRC's regulatory position concerning records important for decommissioning of nuclear reactors is stated in DG-1006 as follows. The collection, safekeeping, retention, maintenance, and updating of decommissioning records should be included in the overall site quality assurance program, consistent with the coverage for other health and safety records systems. Regulatory Guide 1.88, Revision 2, "Collection, Storage, and Maintenance of Nuclear Power Plant Quality Assurance Records," should be used in particular for guidance on records administration, storage, preservation, safekeeping, and retrieval of the decommissioning records.

Draft Regulatory Guide DG-1005 provides the licensee guidance for QA program requirements to be established and executed during decommissioning. For example, the equipment, such as plasma torches, portable ventilation, and shielding, and the procedures that will be subject to the QA controls and audits should be listed. The QA program should be established at the earliest practical time consistent with the schedule for accomplishing an activity or task.[f] The staff positions and responsibilities for review and audit should be specified.

In addition, American Nuclear Insurers (ANI)[g] has established and applied a risk assessment program to decommissioning activities at a variety of insured nuclear facilities. This risk assessment begins at the planning stages and continues throughout the decommissioning effort. This program is primarily based on an engineering evaluation of the adequacy of performance in the major areas of nuclear safety, quality assurance (emphasis added), and documentation. The results of the engineering assessment and QA oversight can affect the level of premium assessed and the rate of change of premium during decommissioning.[9]

I.1.2.4 Security and Safeguards Plan

Security and safeguards plans should be part of the license amendment request or the decommissioning plan. Although security and safeguards during decommissioning are not specifically addressed in the regulations, the intent of the regulations for operating plants remains the same during decommissioning, insofar as they apply. These subjects are discussed in 10 CFR 50.34(c), "Physical Security Plan," Regulatory Guide 1.17, Protection of Nuclear Power Plants Against Industrial Sabotage, and 10 CFR Part 73, Physical Protection of Plants and Materials.

(f) DG-1005 defines an "activity" as an organized unit of work for performing a function and may consist of several tasks. A "task" is defined as a specific work assignment or job.

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

In addition, Supplementary Information supporting the rule states: "The existing regulations on safeguards for nuclear facilities are considered to contain criteria applicable to the decommissioning process. Therefore, it is not considered necessary to amend those regulations." However, the rule requires that safeguards provisions during decommissioning be described, as appropriate, in the decommissioning plan. Appropriate guidance documents have not yet been issued identifying which of the current operating requirements on safeguards are to apply during decommissioning.[1]

I.1.2.5 Environmental Plans

The environmental information that is supplied with the license amendment request or the decommissioning plan should satisfy the requirements of 10 CFR Part 51, Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions, and the intent of Section 51.53, "Supplement to Environmental Report." It states in Section 51.53(b) "Post Operating License Stage," that each applicant for a license amendment authorizing the decommissioning of a production or utilization facility covered by § 51.20 and each applicant for a license or license amendment to store spent fuel at a nuclear power reactor after expiration of the operating license for the nuclear power reactor shall submit with its application a separate document, entitled "Supplement to Applicant's Environmental Report - Post Operating License Stage," as appropriate, to reflect any new information or significant environmental change associated with the applicant's proposed decommissioning activities or with the applicant's proposed activities with respect to the planned storage of spent fuel. Unless otherwise required by the Commission, in accordance with the generic determination in § 51.23(a)[h] and the provisions of § 51.23(b), the applicant shall only address the environmental impact

(h) As stated in 10 CFR Part 51.23, Temporary Storage of Spent Fuel After Cessation of Reactor Operation - Generic Determination of No Significant Environmental Impact. Subsection (a): The Commission has made a generic determination that, if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impacts for at least 30 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor at its spent fuel storage basin or at either onsite or offsite independent spent fuel storage installations. Further, the Commission believes there is reasonable assurance that at least one mined geologic repository will be available within the first quarter of the twenty-first century, and sufficient repository capacity will be available within 30 years beyond the licensed life for operation of any reactor to dispose of the commercial high-level waste and spent fuel originating in such reactor and generated up to that time.

of spent fuel storage for the term of the license applied for. The Supplement may incorporate by reference any information contained in previously submitted records, which are delineated in Section 51.53(b).

Furthermore, in Section 51.95, "Supplement to Final Environmental Impact Statement," Subsection (b), "Post Operating License Stage," the following is stated: "In connection with the amendment of an operating license to authorize the decommissioning of a production or utilization facility covered by § 51.20 or with the issuance, amendment or renewal of a license to store spent fuel at a nuclear power reactor after expiration of the operating license for the nuclear power reactor, the NRC staff will prepare a supplemental environmental impact statement for the post operating license stage or an environmental assessment, as appropriate, which will update the prior environmental review. This document may incorporate by reference any information contained in previously submitted records, which are delineated in Section 51.95(b)."

In summary, the NRC has determined that if proper consideration and implementation is given to decommissioning, whatever alternative is chosen, in comparison with the impact expected from 40 years of licensed operation, the environmental impacts from decommissioning are expected to be small. Thus, the decommissioning rule[1] allows for reduction of 10 CFR Part 51 National Environmental Policy Act (NEPA) (42 USC 4321 et seq.) requirements through elimination of the mandatory requirement for an environmental impact statement (EIS) at the time of decommissioning for 10 CFR Part 50 and 72 licenses. Environmental assessments would still be required, but these would not necessarily lead to an EIS being issued.

I.1.3 Licensing Costs

The Omnibus Budget Reconciliation Act of 1990 (Public Law 101-508) was signed into law November 5, 1990. It requires that the NRC recover 100% of its budget authority from fees assessed against licensees for services rendered, except for the amount appropriated from the Department of Energy (DOE)-

administered Nuclear Waste Fund[i] to the NRC for FYs 1991 through 1995 for purposes of licensing support to the NWPA activities. Subsection (c) (3) directs the NRC to establish a schedule of annual charges that fairly and equitably allocates the aggregate amount of charges among licensees and, to the maximum extent practicable, reasonably reflects the cost of providing services to such licensees or classes of licensees. The schedule may assess different annual charges for different licensees or classes of licensees based on the allocation of the NRC's resources among licensees or classes of licensees, so that the licensees who require the greatest expenditures of the NRC's resources will pay the greatest annual charge.

With revision to 10 CFR Part 170, Fees for Facilities and Materials Licenses and Other Regulatory Services Under the Atomic Energy Act of 1954, as Amended, the NRC has established a policy of full-cost recovery for all NRC licensing services and inspections, including those activities associated with the renewal, dismantling/decommissioning, and termination of reactor licenses. NRC licensees are now expected to provide 100% of the agency's budget through user fees.

Title 10 CFR Part 171, Annual Fee for Power Reactor Operating Licenses, has been expanded to include additional regulatory costs that are attributable to power reactors other than those costs that have previously been included in the annual fee for operating power reactors. These additional costs include the costs of generic activities that provide a potential future benefit to utilities currently operating power reactors. These generic activities are associated with reactor decommissioning (emphasis added), license renewal, standardization, and Construction Permits and Operating License reviews. It should also be noted that if a facility has a POL at the beginning of the fiscal year, a licensee is no longer assessed annual fees. Hourly fees remain, however, for plant-specific licensing actions.

In addition, holders of licenses associated with the storage of spent fuel, including a general license to receive and store spent fuel at an inde-

(i) The Nuclear Waste Fund (NWF) was established by section 302(c) of the Nuclear Waste Policy Act of 1982, 42 U.S.C. 10222(c). In general, the NWF is for functions or activities necessary or incident to the disposal of high-level radioactive waste or spent nuclear fuel.

pendent spent fuel storage installation (ISFSI), and each holder of a Certificate of Compliance for a spent fuel storage cask, will be assessed an annual fee.

Thus, the NRC will charge fees in proportion to its costs (i.e., full-cost recovery) for providing individually identifiable services to specific applicants for, and holders of, NRC licenses and approvals. These fees are deposited into the U.S. Treasury and do not augment the NRC appropriation. Congress must still pass appropriations legislation for the NRC, but because the NRC is now obligated to raise the money from users, legislators will chiefly consider the funding authorization - that is, whether the amount of money the NRC proposes to raise is reasonable.[10, 11]

The financial protection requirements during plant operation are given in 10 CFR Part 140, Financial Protection Requirements and Indemnity Agreements. The levels of protection required during decommissioning are not specifically defined. However, the intent of the regulations for operating plants remains the same during decommissioning, insofar as they apply, as discussed in the following subsection.

I.1.4 Financial Assurance

As previously mentioned, on June 27, 1988, the NRC published amendments to 10 CFR Part 50 (53 FR 24018) concerning general requirements for decommissioning nuclear facilities. Amended 10 CFR 50.33(k), 50.75, and 50.82(b) require operating license applicants and existing licensees to submit information on how reasonable assurance will be provided that funds will be available to decommission their facilities. Amended Section 50.75 establishes requirements for indicating how this assurance will be provided, namely the amount of funds that must be provided, including updates, and the methods to be used for assuring funds for any of the decommissioning alternatives of DECON, SAFSTOR, or ENTOMB.

Title 10 CFR Part 50.75(c)(2) requires nuclear power reactor licensees to periodically adjust the estimate of the cost of decommissioning their plants, in dollars of the current year, as part of the process to provide reasonable assurance that adequate funds for decommissioning will be available when needed. NUREG-1307, "Report on Waste Burial Charges," which is scheduled to be revised approximately annually, contains information to be used in a formula for escalating decommissioning cost estimates that is acceptable to the NRC. The sources of information to be used in the escalation formula are identified, and the values developed for the escalation of radioactive waste burial costs, by site and by year, are given. The licensees may use the formula, the coefficients, and the burial escalation factors from NUREG-1307 in their escalation analyses, or they may use an escalation rate at least equal to the escalation approach presented therein.[12]

Regulatory Guide 1.159 (Task DG-1003), "Assuring the Availability of Funds for Decommissioning Nuclear Reactors," August 1990, was developed in conjunction with the rule amendments. Its purpose is to provide guidance to applicants and licensees of nuclear power reactors and research and test reactors concerning methods acceptable to the NRC staff for complying with requirements in the amended rule regarding the amount of funds for decommissioning. It also provides guidance on the content and form of the financial assurance mechanisms indicated in the rule amendments.

Under normal circumstances, decommissioning follows the orderly shutdown of the facility at the end of its planned life. However, as discussed in the Final Generic Environmental Impact Statement on Decommissioning Nuclear Facilities (commonly referred to as GEIS),[13] decommissioning at a reactor which has been involved in an accident could take place following stabilization and accident cleanup activities. Thus, the availability of funds for post-accident cleanup is also related to financial assurance for decommissioning. For example, an accident and the resulting accident cleanup activities have an effect on subsequent decommissioning activities, on the decommissioning alternatives, and on the cost, safety and environmental consequences of those alternatives.

The costs of post-accident cleanup can be substantially larger than the costs of decommissioning. Assurance of funds for post-accident cleanup activities is more properly covered by use of insurance. Post-accident cleanup activities are broader in scope than decommissioning, that is, they can lead ultimately to either reuse or decommissioning. Accordingly, the funding requirements for accident cleanup are not included in the GEIS or in the rule,[1] but are contained in 10 CFR 50.54(w), which requires that utility licensees for production and utilization facilities obtain insurance to cover decontamination and cleanup costs associated with onsite property damage resulting from an accident.[j]

With regard to the funding of decommissioning activities which would occur prematurely either following an accident or if an accident did not occur, NRC has had several studies done to address this issue, including NUREG/CR-1481,[14] NUREG/CR-3899,[15] NUREG/CR-3899 Supplement 1,[16] and NUREG/CR-2370.[17] These documents address the question of assurance provided by the various funding methods, including prepayment, external reserve, internal reserve, and insurance. In particular, as discussed in Section 2.6 of the GEIS and in more detail in NUREG-1221, Section D.3.2.1.1,[18] and as noted in NUREG/CR-3899, the market value of utilities, even those involved in the most extreme financial crises, is still far in excess of decommissioning costs and that the value of the assets of a utility (both tangible and intangible) is more than adequate to cover future projected decommissioning costs. These considerations must also be viewed within the context of the Commission requirements for onsite property damage insurance in 10 CFR 50.54(w), discussed above, the proceeds from which a utility could use to decontaminate its reactor after an accident. Although these insurance proceeds would not be used directly for decommissioning, they would go a long way toward reducing the risk of a utility being subject to a tremendous demand for funds after an accident. Because most utilities are now carrying insurance in excess of $1 billion and the Commission has implemented its requirement in 10 CFR 50.54(w) for insurance at this level, a major threat to long-term utility solvency has been substantially reduced.[13]

(j) As a result of the efforts during accident cleanup, decommissioning can be carried out in a more stable environment than the accident cleanup. Nevertheless, there would be certain impacts on the decommissioning from the accident and the accident cleanup activities, including increased levels and spread of contamination compared to normal decommissioning still remaining after the cleanup activities, the need to decommission systems and structures built and used during accident cleanup, and the potential need to store wastes generated by the accident and during the accident cleanup period, onsite on an interim basis for an extended time period.[13]

Thus, pursuant to 10 CFR 50.54(w), a licensee is required to carry a minimum coverage limit of onsite primary property damage insurance for a reactor station site of either $1.06 billion or whatever amount of insurance is generally available from private sources, whichever is less. However, under certain conditions (e.g., a permanently shutdown, defueled reactor), and with the proper justification, an NRC exemption to reduce the amount of primary property damage insurance from the full amount of $1.06 billion to a lesser amount (with correspondingly lesser premiums) is possible. For example, in its application for exemption, the licensee must provide justification that the lesser amount of insurance provides an adequate level of coverage to stabilize, clean up, or decontaminate the reactor facility based on limited and much less severe accidents that could occur, given the defueled condition.

At a licensee's request, the NRC has the prerogative to grant exemptions from the requirements of the regulations, which pursuant to 10 CFR 50.12(a) are 1) authorized by law, will not present an undue risk to the public health and safety, and are consistent with the common defense and security, and 2) present special circumstances. Pursuant to 10 CFR 50.12(a)(2)(ii), special circumstances exist when compliance with a rule would not serve the purpose of or is not necessary to achieve the underlying purpose of the rule. Pursuant to 10 CFR 50.12(a)(2)(iii), special circumstances exist if compliance would result in undue hardship or costs in excess of those contemplated when the regulation was adopted, or costs that are significantly in excess of those incurred by others similarly situated.

In addition, the Commission recognized the risk that, if some reactors did not operate for their entire operating lives, those licensees might have insufficient decommissioning funds at the time of permanent shutdown. After the NRC published the decommissioning rule in 1988,[1] four power reactor facilities shut down prematurely - the Fort St. Vrain Nuclear Generating Station, the Yankee Rowe Nuclear Power Station, the Rancho Seco Nuclear Generating Station, and the Shoreham Nuclear Power Station. As a result, the NRC had to consider whether the decommissioning funding provisions in the rules were appropriate in those cases. In August 1991, the NRC decided to propose a new special-case amendment.[19]

The decommissioning rule, as it stands now, allows a licensee to build up funding steadily over the duration of the license, but intends that enough money should be in place by the time plant operations end. For a facility which has permanently ceased operation before the expiration of its operating license, the collection period for any shortfall of funds will be determined, upon application by the licensee, on a case-by-case basis taking into account the specific safety and financial situation at each nuclear power plant.[20]

In addition, although not as directly related to decommissioning activities as to the potential impacts on the selection of decommissioning alternatives, the following statement is made in 10 CFR Part 50.54(bb) concerning how reasonable assurance will be provided that funds will be available to manage and provide funding for the spent fuel upon expiration of the reactor operating license. "For operating nuclear power reactors, the licensee shall, no later than 5 years before expiration of the reactor operating license, submit written notification to the Commission for its review and preliminary approval of the program by which the licensee intends to manage and provide funding for the management of all irradiated fuel at the reactor upon expiration of the reactor operating license until title to the irradiated fuel and possession of the fuel is transferred to the Secretary of Energy for its ultimate disposal. Final Commission review will be undertaken as part of any proceeding for continued licensing under Part 50 or Part 72. The licensee must demonstrate to NRC that the elected actions will be consistent with NRC requirements for licensed possession of irradiated nuclear fuel and that the actions will be implemented on a timely basis. Where implementation of such actions require NRC authorizations, the licensee shall verify in the notification that submittals for such actions have been or will be made to NRC and shall identify them. A copy of the notification shall be retained by the licensee as a record until expiration of the reactor operating license. The licensee shall notify the NRC of any significant changes in the proposed waste management program as described in the initial notification."

The number of reactors that have been shut down prematurely has increased over earlier expectations. Therefore, the NRC has recently proposed to amend its regulations concerning 10 CFR 50.54(bb) to clarify the timing of notification to the NRC of spent fuel management and funding plans by licensees of those nuclear power reactors that have been shut down before the expected end of their operating lives. The proposed rule, if adopted, would require that a licensee submit such notification either within 2 years after permanently ceasing operation of its licensed power reactor or no later than 5 years before the reactor operating license expires, whichever event occurs first.[21]

I.1.5 Internal Revenue Service Involvement in Decommissioning Funding

The Tax Reform Act of 1984 added section 468A, "Special Rules for Nuclear Decommissioning Costs," to the Internal Revenue Code, which sets out the rules for creating nuclear decommissioning funds by public utilities. This section defines the rate at which funds are taxed, restrictions on the funds, and types of investments that can be made by the fund. The cash contributed to these funds and the income accumulated by the funds will be used to pay future costs of decommissioning nuclear power plants and to pay the administrative costs of the funds each year. Funds are tax-deductible the year they are contributed to the fund, but the income on the investments of these funds is taxed at the highest tax rate that applies to corporations.

The Tax Reform Act of 1986 provides that nuclear decommissioning funds will be treated as corporations. This law also reduced the highest tax rate from 46% to 34% and became effective on July 1, 1987. Subsequently, the tax rate on decommissioning funds was lowered from 34% to 20% when the National Energy Policy Act (NEPA), Public Law 102-486, was signed into law on October 24, 1992.[22]

The Tax Reform Act of 1986 also requires nuclear decommissioning funds to pay estimated taxes. The method for determining estimated tax is explained in the General Instructions of Form 1120-ND (November 1986), which is used by nuclear decommissioning funds to report contributions received, income earned, the administrative expenses of operating the fund, and the tax on the income earned.

As part of the 1986 tax overhaul, the Internal Revenue Service, which must determine the "qualified" portion of every nuclear utility's decommissioning funds (i.e., the amount of the total decommissioning costs entitled to funding on a tax-deductible basis) was empowered to look at utilities' decommissioning fund contributions going back to 1984.[23]

An unqualified fund invested, for example, in stocks, could earn greater returns, but its principal is subject to risk and contributions are taxed. Contributions to a qualified fund are tax-deductible, but its earnings are taxed at the maximum federal corporate rate of 34%. The NRC decommissioning rule[1] required utilities to have external funds established by mid-1990 but does not require them to be qualified. An unqualified fund's earnings are added to the earnings of its corporate owner and taxed at the utility's overall rate.[23]

I.2 ACTIVE DECOMMISSIONING

Regulations, regulatory guides, and national standards that apply to the basic aspects of active decommissioning of the reference PWR are discussed in this section. Most of these basic aspects are similar in nature to many aspects of plant operation; and the regulatory controls and national standards that govern plant operation of these aspects also apply to active decommissioning, although some of them may not specifically mention decommissioning activities. The basic areas of active decommissioning are: licensing, occupational radiation safety, public radiation safety, special nuclear material management, radioactive waste management, industrial safety, and license termination and facility release.

I.2.1 Licensing

"Application for Termination of License" is regulated by 10 CFR Part 50.82. For a facility that permanently ceases operation after July 27, 1988, the application must be made within two years following permanent cessation of operations, and in no case later than one year prior to expiration of the operation license. Each application for termination of license must be accompanied, or preceded, by a proposed decommissioning plan (see previous discussion in Section I.1.2 for details).

Although a POL is not defined anywhere in the regulations, Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors,[k] contains the procedures that are acceptable to NRC in amending the facility operating license to a POL and for obtaining a dismantling order. A POL is essentially an amended operating license and is one way for a licensee to obtain relief from operating requirements. Regulatory Guide 1.86 delineates the applicability of the POL and the dismantling order to the various decommissioning modes, the surveillance and security requirements if the final decommissioning status requires a POL, and the procedures for terminating the license.

The POL allows the licensee to possess, but not to operate, the facility. It permits unloading, storing, and subsequent shipping of the spent reactor fuel, as well as the minor work associated with preparation for custodial safe storage or passive safe storage. In effect, the POL does not preclude the storage of spent fuel in the spent fuel pool, in an onsite independent spent fuel storage installation (ISFSI), shipment of spent fuel to another ISFSI offsite, or shipment to a U.S. Department of Energy facility for disposal. It is the governing license in all decommissioning modes, but a dismantling order is also required in the case of dismantlement or preparations for hardened safe storage or entombment. The POL remains in force during the continuing care period of safe storage or entombment, and must be renewed every 40 years. In addition, an updated decommissioning plan is required at the end of the SAFSTOR period when the licensee decides on how to dismantle the facility. All activities must be completed within 60 years of plant final shutdown.

The POL permits deletion of the technical specifications regarding plant operation (and associated surveillance requirements) that are not applicable

(k) It should be recognized that Regulatory Guide 1.86 is currently being revised to be fully consistent with the recent changes to 10 CFR 50.82.

to decommissioning, but maintains those that are necessary to ensure protection of the workers and the public during decommissioning. Thus, the POL would allow the licensee to immediately cut expenses by reducing testing requirements and staffing. It also contains the authority to possess and handle byproduct material, source material, and special nuclear material as governed by 10 CFR Part 30, Rules of General Applicability to Domestic Licensing of Byproduct Material, 10 CFR Part 40, Domestic Licensing of Source Material, and 10 CFR Part 70, Domestic Licensing of Special Nuclear Material.

Situations that exceed the limitations of the POL may arise during the course of active decommissioning. (Regulatory Guide 1.86 refers to these situations as "unrelated safety questions.") This type of situation is regulated by 10 CFR 50.59, "Changes, Tests and Experiments."

I.2.2 Occupational Radiation Safety

Because of the highly radioactive materials and contaminated work locations in the reference PWR during active decommissioning, occupational radiation exposure control is of major importance. Occupational radiation safety is regulated by 10 CFR Part 20, Standards for Protection Against Radiation. The maximum permissible limits for occupational radiation exposure are presented in 10 CFR 20.101, "Radiation Dose Standards for Individuals in Restricted Areas," and 10 CFR 20.103, "Exposure of Individuals to Concentrations of Radioactive Materials in Air in Restricted Areas." However, these limits are tempered by the operating philosophy of As Low As is Reasonably Achievable (ALARA) as explained in 10 CFR 20.1(c). This philosophy is described in Regulatory Guide 8.8, Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations will be As Low As Reasonably Achievable, and in Regulatory Guide 8.10, Operating Philosophy for Maintaining Occupational Radiation Exposures as Low As is Reasonably Achievable.

Additional information on how to comply with the ALARA concept can be found in the NRC Standard Review Plan, Section 12.1, "Assuring that Occupational Radiation Exposures Are As Low As is Reasonably Achievable."[24] Besides

10 CFR Part 20 and Regulatory Guide 8.8, some of the more relevant regulations and guidance cited in Section 12.1 are given below:

- 10 CFR Part 19, Notices, Instructions and Reports to Workers: Inspection and Investigations
- Regulatory Guide 1.8, Personnel Selection and Training/ Qualification and Training of Personnel for Nuclear Power Plants
- Regulatory Guide 1.33, Quality Assurance Program Requirements (Operations)
- NUREG-0761, Revision 2, July 1981, "Contents of Radiation Protection Plans for Nuclear Power Reactor Licensees."

As of January 1, 1994 (with earlier compliance encouraged), the maximum permissible limits for occupational radiation exposure delineated in 10 CFR 20, Subpart C, "Occupational Dose Limits," Section 20.1201 "Occupational Dose Limits for Adults" are to be implemented. The NRC listed several objectives in revising 10 CFR 20. A primary objective was to "implement the principal current dose-limiting recommendations of the International Commission on Radiological Protection (ICRP)" by incorporating the ICRP effective dose equivalent (EDE) concept and requiring programs for "keeping radiation exposures as low as reasonably achievable (ALARA)."[25]

The following brief discussion of the revised 10 CFR 20, as it relates to the radiological protection of workers, has been extracted from References 26 and 27. The ICRP EDE concept essentially says that one rem from external exposure is no different from one rem due to internal exposure. In addition, with the revision of 10 CFR 20, internal dose (committed effective dose equivalent) and external whole-body dose (deep dose equivalent) must be added to obtain the total effective dose equivalent (TEDE), which is limited to 5 rem (0.05 Sv) per year. There is no quarterly limit, although the NRC fully expects that licensees will prorate the 5 rem quarterly.

The revision of 10 CFR 20 is based on the 1977 recommendations of the ICRP - which the NRC began reviewing soon after - and is "generally consistent" with 1987 recommendations of the National Council on Radiation Protection and Measurements (NCRP). The changes reflect basic changes in the philosophy of protection and update scientific information on radionuclide uptake and metabolism and the biological effects of ionizing radiation. The revision implements the 1987 Presidential guidance on occupational radiation protection. The major changes to 10 CFR 20 include the following:

- greater emphasis on numerical risks
- control of dose by use of the sum of internal and external doses
- greater equality in treatment of external and internal doses
- use of the committed effective dose equivalent for internal exposures rather than the critical organ approach
- wider selection of methods for estimating radionuclide intakes and internal doses.

The revised rule also eliminates the use of the cumulative lifetime dose limit of 5(N-18), where N is the age of the worker in years. No lifetime dose is specified because if the magnitude of the annual dose is limited, there is a de facto limitation of the lifetime dose that can be received.

I.2.3 Public Radiation Safety

Public radiation exposure that results from decommissioning the reference PWR must also comply with 10 CFR Part 20. Currently, the maximum public exposure limits for external exposure are specified in 10 CFR 20.105, "Permissible Levels of Radiation in Unrestricted Areas." Limits for internal exposure pathways are given in 10 CFR 20.106, "Radioactivity in Effluents to Unrestricted Areas." As in the case of occupational exposure, 10 CFR 20.1(c) requires application of the ALARA principle to the control of public radiation exposures and releases of radioactive materials to the environs. In addition, a plant undergoing decommissioning must meet the design requirements of Appendix I to 10 CFR Part 50.

As of January 1, 1993 (with earlier compliance encouraged), the maximum permissible limits for public radiation exposure are delineated in 10 CFR 20, Subpart D, "Radiation Dose Limits for Individual Members of the Public," Section 20.1301 "Dose Limits for Individual Members of the Public" became effective. The major changes to 10 CFR 20 concern:

- Explicit limits on public doses - 0.1 rem (1 mSv) per year, [a temporary 0.5 (5 mSv) rem per year limit is available upon NRC approval]; the previous requirement was an implicit limit of 0.5 rem per year.
- The dose in any unrestricted area from external sources does not exceed 0.002 rem (0.02 mSv) in any one hour. (Note: This Part 20 dose requirement is separate from current decommissioning site release criteria discussed in Section I.1.2.1.)

The Environmental Protection Agency (EPA) public exposure limits are defined in Title 40 CFR Part 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes; specifically Subpart A, Environmental Standards for Management and Storage, July 1, 1990. Section 191.01 states that the EPA limits apply to the radiation doses received by members of the public as a result of the management (except transportation) and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at any facility regulated by the NRC or by Agreement States, to the extent that such management and storage operations are not subject to the provisions of Part 190 of Title 40.

It is further stated in Section 191.03, Standards, that management and storage of spent nuclear fuel or high-level or transuranic radioactive wastes at all facilities regulated by the Commission or by Agreement States shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public in the general environment resulting from: 1) discharges of radioactive material and direct radiation from such management and storage and 2) all operations covered by Part 190; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ.

I.2.4 Special Nuclear Materials Management

Safeguards and security precautions must continue after plant shutdown until all special nuclear materials that come under regulatory control are removed from the plant. Regulations defining the required precautions are found in 10 CFR Part 70, Domestic Licensing of Special Nuclear Materials and 10 CFR Part 73, Physical Protection of Plants and Materials. The principal concern is to protect against acts of industrial sabotage that could endanger the safety of the work force and the public.

I.2.5 Radioactive Waste Management

Regulations that govern the packaging and transport of radioactive materials are designed to prevent the dispersal of radioactivity to the environs and to protect the public and the transportation workers during shipment. There is some overlapping of federal responsibility for regulating the safe packaging and transport of radioactive materials. This responsibility lies primarily with the Department of Transportation (DOT) and secondarily with the NRC.

The following subsections describe packaging and transportation regulations and licensing requirements for land disposal of radioactive wastes associated with decommissioning radioactive waste management.

I.2.5.1 Packaging and Transport Regulations

The DOT is responsible for safety standards governing packaging and shipping containers and for their labeling, classification, and marking. The NRC develops performance standards and reviews designs for Type B, fissile, and large-quantity packages. The DOT requires NRC approval to use these packages. The DOT also implements safety standards for the mechanical condition of carrier equipment and for the qualifications of carrier personnel. The Federal Aviation Administration (FAA), the Interstate Commerce Commission (ICC), the U.S. Coast Guard, and the U.S. Postal Service also exercise some regulatory authority over the shipment of radioactive materials.

Shipments of radioactive material utilizing NRC-approved packages must be in accordance with the provisions of 49 CFR 173.471, "Requirements for U.S. Nuclear Regulatory Commission Approved Packages," and 10 CFR Part 71, Packaging and Transportation of Radioactive Material, as applicable. In satisfying the requirements of Section 71.12, "General License: NRC Approved Package," it is the responsibility of the licensees to insure themselves that they have a copy of the current approval and conduct their transportation activities in accordance with an NRC-approved quality assurance program. Note that the general license of 10 CFR 71.12 does not authorize the receipt, possession, use, or transfer of byproduct, source, or special nuclear materials; such authorization must be obtained pursuant to 10 CFR Parts 30 to 36, 40, 50, or 70.

By Federal Register notice dated December 21, 1990,[28] the DOT promulgated a final rule which comprehensively revises the Hazardous Materials Regulations (HMR; 49 CFR Parts 171-180) with respect to hazard communication, classification and packaging requirements. The changes are based on the United Nations Recommendations on the Transport of Dangerous Goods (U.N. Recommendations) and DOT's Research and Special Programs Administration's (RSPA) own initiative. They are made because the existing HMR are: 1) difficult to use because of their length and complexity; 2) relatively inflexible and outdated with regard to non-bulk packaging technology; 3) deficient in terms of safety with regard to the classification and packaging of certain categories of hazardous materials; and, 4) generally not in alignment with international regulations based on the U.N. Recommendations. The changes: 1) simplify and reduce the volume of the HMR; 2) enhance safety through better classification and packaging; 3) promote flexibility and technological innovation in packaging; 4) reduce the need for exemptions from the HMR; and 5) facilitate international commerce.

In addition to complying with NRC's requirements in 10 CFR Part 71, each licensee who transports licensed material outside of the confines of its plant or other place of use, or who delivers licensed material to a carrier for transport, shall comply with the applicable DOT requirements in 49 CFR Parts 170 through 189.

I.2.5.2 Land Disposal Regulations

By Federal Register notice dated December 27, 1982,[29] the NRC promulgated a regulation governing the land disposal of low-level radioactive waste (LLW): 10 CFR 61, Licensing Requirements for Land Disposal of Radioactive Waste. The new regulation established three classes of LLW, based on radiological hazard, and provides minimum waste form and stability requirements and near-surface disposal requirements for the land burial of these wastes. The categories were identified as Class A, Class B, Class C, and Greater-Than-

Class C (GTCC), depending upon the contained concentrations of specific short-lived and long-lived radionuclides. Class A waste contains the lowest radionuclide concentrations and must meet only minimum waste form requirements. Class B and C wastes contain higher radionuclide concentrations and must meet both the minimum waste form and the stability requirements of Section 61.56. Class C waste must be disposed of by use of methods that provide added protection against inadvertent intrusion into the burial ground. Categories A, B, and C are acceptable for land disposal.

Those wastes whose radionuclides concentrations exceeded the maximum allowed for land disposal, GTCC, were required to be stored pending further determination. This determination was provided in an amendment to 10 CFR 61 (Part 61.55, "Waste Classification") published in the Federal Register dated May 25, 1989, wherein all GTCC wastes are to be disposed of in a geologic repository, or in an approved alternative. In related legislation passed by Congress in 1985 (Low-Level Radioactive Waste Policy Amendments Act of 1985), the U.S. Department of Energy (DOE) was assigned the responsibility for the disposal of GTCC wastes. Under this legislation, DOE must provide the capability for disposal of the GTCC wastes, but the waste generator must pay for the service. Thus, the costs of disposal of GTCC wastes resulting from decommissioning activities are a legitimate decommissioning expense.

In effect, the amendments to 10 CFR 61 treat GTCC as if it were high-level waste, which is what the DOE intends to bury in its repository. However, the NRC has stated it does not consider this action to be a redefinition of GTCC as HLW. The supporting text to the most recent amendments to 10 CFR 61, published in the Federal Register on May 25, 1989, addresses the matter of considering GTCC as a separate class of intermediate-level waste as follows: "It is the Commission's view that intermediate disposal facilities may never be available....At the same time, the Commission wishes to avoid foreclosing possible use of intermediate disposal facilities," by the DOE.[30]

In the analysis of the decommissioning of the reference PWR reported previously in NUREG/CR-0130, it was assumed that the LLW from decommissioning could be disposed of by near-surface burial at a licensed shallow-land burial ground. This assumption was reevaluated by Murphy[31] in terms of the established requirements contained 10 CFR Part 61, which took effect on January 23, 1983. Based upon the 1983 regulation (10 CFR 61), Murphy's reevaluation concluded that the neutron-activated stainless steel core shroud and the lower grid plate have such high concentrations of Ni-59, Ni-63, and Nb-94 that they exceed the Class C limits of 10 CFR 61. The radioactivity of the lower core barrel and the thermal shields also exceeds Class C limits by a small amount. These materials are generally unacceptable for routine near-surface disposal. Therefore, this reevaluation of decommissioning the reference PWR now includes rough estimates for storage and geologic disposal of these materials.

Some additional requirements directed primarily at waste generators and handlers were concurrently published as a new Section 20.311, "Transfer for Disposal and Manifests," of Part 20, "Standards for Protection Against Radiation." The effective date of 10 CFR 20.311 was December 27, 1983. Subsequently, the NRC announced in January 1991, the availability of a revised Staff Technical Position entitled "Technical Position on Waste Form (Revision 1)." This technical position on waste form was initially developed in 1983 to provide guidance to both fuel-cycle and non-fuel-cycle waste generators on waste form test methods and results acceptable to the NRC staff for implementing the 10 CFR Part 61 waste form requirements. It has been used as an acceptable approach for demonstrating compliance with the 10 CFR Part 61 waste stability criteria. The Position (Revision 1) includes guidance on 1) the processing of wastes into an acceptable, stable waste form, 2) the design of acceptable high integrity containers, 3) the packaging of filter cartridges, and 4) minimization of radiation effects on organic ion-exchange resins. The regulation, 10 CFR 20.311, requires waste generators and processors to certify that their waste forms meet the requirements of Part 61 (including the requirements for structural stability). The recommendations and guidance provided in the Technical Position (Revision 1) are an acceptable method upon which to base such certification by waste generators.

Because of their subsequent potential impact on legally-disposable LLW from decommissioning, a brief historical review of U.S. LLW disposal facilities and selected regulations that impact their licensing and operation follows.

Six commercially operated LLW disposal facilities have been licensed and operated since the AEC's announcement in 1960 that regional land disposal sites for commercially generated LLW should be established and that the sites should be operated by the private sector, subject to government licensing authority. These facilities are located in Beatty, Nevada; Maxey Flats, Kentucky; West Valley, New York; Richland, Washington; Sheffield, Illinois; and Barnwell, South Carolina. The Beatty facility, which opened in 1962, was the first to begin commercial disposal operations; the Barnwell facility, which opened in 1971, was the last. Four of those facilities (Maxey Flats, West Valley, Sheffield, and Beatty) have since closed. The other two facilities (Richland and Barnwell) are still operating successfully and dispose of all the commercial LLW currently generated in the United States.

The problems experienced in the developmental years of commercial LLW disposal led to the recognition that the regulations controlling the licensing of radioactive materials did not contain sufficient technical standards or criteria for the disposal of radioactive waste.[1] More comprehensive standards, technical criteria, and licensing procedures were needed for the licensing of new disposal sites, the operation of the existing sites, and for the final closure and stabilization of all sites.

Title 10 Code of Federal Regulations, Part 61 also established a series of performance objectives and technical and financial requirements which a LLW disposal site and site operator must meet in order to ensure public health, safety, and long-term protection of the environment. The regulation established four performance objectives: a) to protect the general population from releases of radioactivity, b) to protect any individual who inadvertently

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(1) Inadequate waste form was one of the most significant factors leading to the difficulties experienced at the closed sites. Waste forms sent to the sites reflected general practices of the times. Licensees were encouraged to send all suspect wastes for disposal, and waste minimization and volume reduction were not required. Most of the waste that was disposed of at the sites is believed to have been either composed of very easily degradable material or packaged so that large void spaces existed within the waste or between the waste and the packaging. Some of the waste packages (such as cardboard and fiberboard boxes) were often easily degradable. Also, the wastes often contained chemical agents that enhanced waste degradation and leaching of radionuclides. Frequently, these easily degraded wastes contained little or no radioactivity. Early operating practices also contributed to rapid waste degradation, subsequent slumping of the trench covers, and influx of precipitation. Problems of this kind have not been experienced at the two sites still in operation.

enters a disposal site after the site is closed, c) to protect workers during site operations, and d) to ensure long-term stability at disposal sites to eliminate the need for ongoing active maintenance after closure.

Technical requirements were established for site selection, design, operation, and closure as well as for environmental monitoring, waste classification, and waste characteristics. Specifically, two of the technical requirements established during the regulatory reform years of 1980-1983 have the potential for impacting decommissioning costs. They are: a) sites must have characteristics which maximize long-term stability and isolation of waste and ensure that performance objectives are met (site characteristics and performance must be evaluated for at least a 500-year period) and b) to reduce subsidence or cracking of the caps or barriers covering the waste, all LLW must be placed in the disposal unit in a way that maintains the integrity of the waste package and permits voids to be filled.

Special technical requirements were also established for waste form. These requirements included: a) waste must not be packaged for disposal in cardboard or fiberboard boxes; b) liquid waste must be solidified or packaged in absorbent material; c) wastes that generate toxic fumes or are spontaneously flammable or explosive are prohibited; d) waste form or high integrity containers (HICs) used to provide structural stability must maintain gross physical properties and identity for 300 years, under the expected disposal conditions, and e) void spaces must be reduced to the extent practicable.

Nevada, South Carolina, and Washington passed additional regulations to ensure that the transportation and packaging problems they had experienced in the earlier years of operation would not be repeated. In general, these state regulations required radioactive waste shippers to: a) purchase transportation permits and liability insurance, b) certify that the shipment and transport vehicle have been inspected and comply with applicable state and federal laws, and c) notify the disposal facility prior to shipment of waste. In addition, the regulations impose penalties ranging from $1,000 to $25,000 in fines and possible suspension or revocation of the permit.

In summary, the current system for management of LLW evolved over a period of time when disposal capacity was available and costs were low. Disposal capacity currently exists at two sites: Barnwell, South Carolina and Hanford, Washington. South Carolina and Washington have decided to cut back on the amount of waste they will accept from other states. Furthermore, the volume of waste generated is on the rise despite improved volume-reduction techniques. Disposal costs have risen as well, as have costs for transporting the waste as much as 3,000 miles to accommodate current volume ceilings at the existing disposal sites.

When Congress enacted the Low-Level Radioactive Waste Policy Act of 1980 and subsequent amendments in 1985, it set in motion major changes in the national low-level waste disposal program:

- As of January 1, 1993, each state will be responsible for providing its own disposal facilities for low-level waste. That includes all 50 states and the District of Columbia.
- The most efficient method would be through regional compacts, which would provide a central disposal facility for several neighboring states. Congress must endorse the creation of each compact in advance and renew the approval every five years.
- After January 1, 1993, any state can refuse to accept low-level waste from other states that are not members of its regional compact. Essentially, this means that a state must enter into a regional agreement, establish its own disposal facility, or stop generating low-level waste.[32]

The lessons learned during the developmental years of commercial LLW disposal led to regulatory reform of the system under which disposal is conducted. Improvements in the form of waste that is disposed of, as well as in site selection, characterization, operations, monitoring and post-closure care, have significantly reduced the likelihood that a new LLW disposal facility will require costly remediation in the future.

In addition to the aforementioned technical improvements, many states and compacts have also imposed requirements for additional engineered barriers (generally concrete waste packages or disposal cells) to reinforce public confidence that the waste will be safely isolated from the environment while it decays to background levels. Although the long-term benefit of engineered barriers over carefully selected natural barriers is a topic of much discussion and technical analysis, the selection of multiple barrier systems illustrates the degree to which state and compact officials have responded to public concerns that disposal of LLW should pose as little risk to public health and safety as reasonably possible. However, it should be recognized that the costs of any changes/improvements will ultimately be paid for by the waste generators.

On April 30, 1991, the NRC renewed in its entirety Chem-Nuclear Systems Incorporated's license to receive, possess, store, and dispose of special nuclear material (SNM) at its commercial LLW disposal facility located near Barnwell, South Carolina. The license was renewed in its entirety for five years.[33]

I.2.6 Industrial Safety

During active decommissioning of a PWR, industrial safety and occupational work conditions are regulated by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor under 29 CFR Parts 1900 to end.

Hazardous waste operations are defined as any work within a facility, site, or area that has been deemed as a hazardous waste site. Work may include sampling, logging, drilling, excavating, monitoring, and remediation activities. Such work may be governed by a written, customized Health and Safety Plan (HSP) that meets the intent of the requirements established in 29 CFR 1910, Occupational Safety and Health Standards, and 29 CFR 1926, Construction Safety and Health Standards, with specific emphasis being applied to 29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response."

The OSHA requirements delineated in 29 CFR 1910.120 that dictate experience for team members are imposed to protect the worker. 29 CFR 1910.120 requires that all hazardous waste workers receive at least three days (24 hours) experience on a bona fide hazardous waste site under the direct supervision of an experienced hazardous waste worker with similar duties. Specific training and certification in such areas as radiological safety, asbestos removal and handling, and hearing protection may also be required.

For example, if an asbestos abatement worker is to be assigned work on a hazardous waste site, that worker must either verify that he/she has the necessary hazardous waste experience, or must be assigned to a worker who has been verified as an experienced hazardous waste worker. For decommissioning workers, applicable state, local, or licensee requirements may be imposed as well. A thorough prejob analysis will help determine the level of training required. In addition, it is expected that the onsite project manager or team leader have relevant work experience, e.g., mixed waste characterization, mixed waste remediation, or soil removal.

I.2.7 Other Statutory and Regulatory Requirements

The Environmental Protection Agency (EPA) develops, promulgates, and enforces environmental protection standards and regulations as directed by statutes passed by the U.S. Congress. Environmental regulations and standards of potential relevance to decommissioning the reference PWR are those promulgated by the EPA under the Atomic Energy Act (AEA), the Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

As reported in Reference 34, regulation of mixed radioactive/hazardous waste (i.e., mixed waste) by the EPA and the NRC is largely duplicative, and that situation is not likely to change in the near future. In fact, regulations are likely to become more complex and burdensome in the future. States are authorized to promulgate mixed waste regulations under the RCRA as long as their regulations are no less stringent than applicable federal regulations. States, however, have been slow to apply for and receive authorization to regulate mixed waste under their approved RCRA programs; in fact, as of January 24, 1991, only 24 states and territories had been authorized to regulate mixed waste.

The NRC and the EPA have been working together for several years to resolve the issues associated with mixed waste. The agencies conducted a survey of generators of commercial mixed radioactive/hazardous waste and are completing two joint technical guidances on testing and storage of such wastes. Oak Ridge National Laboratory, which conducted the voluntary generator survey for the two agencies, sent out questionnaires to over 1,300 potential mixed waste generators in November 1991. The results of the survey, presented in NUREG/CR-5938,[35] have been used to develop a national profile that is expected to provide needed information to states and compact officials, private developers, and federal agencies to assist in planning and developing adequate disposal capacity for LLW, including mixed waste, as mandated by the LLRWPAA of 1985. The report also contains information on existing and potential commercial waste treatment facilities that may provide treatment for specific waste streams identified in the national survey. The report provides a reliable national database on the volumes, characteristics and treatability of commercial mixed waste in the United States. Data from the survey also may serve as a basis for possible federal actions to effectively manage and regulate the treatment and disposal of mixed waste.

The NRC and the EPA also are developing a joint guidance on safe storage of mixed waste. Given the current lack of treatment and disposal capacity for most mixed wastes, both agencies are concerned with long-term problems that could arise from storage of such wastes. The joint guidance will address issues associated with onsite storage, including inspection and surveillance of waste, waste compatibility and segregation, storage container requirements, and time limitations on storage of untreated waste. For each issue, the agencies are attempting to identify acceptable practices.[36]

The EPA has set some treatment standards for mixed waste. Incineration is an applicable technology for LLW combined with organic compounds in wastewater and non-wastewater, as well as D001 ignitable liquids (listed waste under RCRA). Vitrification is specified as an acceptable technology for transuranic and high-level wastes containing both highly radioactive compounds and hazardous components.[34]

Scientific Ecology Group, Inc. (SEG) in Oak Ridge, Tennessee, is the nation's largest LLW processor. SEG has applied for permits and a license to operate the first commercially available incinerator for solid and liquid mixed waste. The incinerator is currently licensed only for LLW. The company submitted an RCRA Part A permit application in March 1991.[34] The associated

Part B permit application was submitted to the Tennessee Division of Solid Waste in early 1993. These permits, when granted, will allow SEG to store and treat characteristic hazardous wastes.

In instances where regulatory authority can be delegated, the EPA may delegate regulatory authority to the state for state programs that meet or exceed EPA requirements. Where regulatory authority is not delegated (e.g., CERCLA), the EPA is responsible for reviewing and evaluating compliance with the EPA regulations. This includes interpreting regulations and consulting with reactor owners and their contractors to aid regulation implementation and inspection of facilities at the sites.

I.2.8 License Termination and Facility Release

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

As discussed in the Supplementary Information contained in the decommissioning rule,[1] acceptable levels of residual radioactivity for release of property for unrestricted use were not proposed as part of the rulemaking. Criteria for residual radioactive contamination are being developed by the NRC as part of a major rulemaking effort currently underway.

I.3 CONTINUING CARE

Continuing care is a sub-category of SAFSTOR and deals with the surveillance and maintenance of the plant in a safe storage mode. The NRC staff reviews the decommissioning alternatives submitted by the licensee against the applicable regulations. Primary concerns during this period are for public and occupational safety and for licensing. Safeguards and security precautions as discussed in Section I.2.4 are required until the spent nuclear fuel inventory is reduced to zero.

I.3.1 Public and Occupational Safety

Requirements for public and occupational safety during the continuing care phase of decommissioning remain identical to those during active decommissioning (see Sections I.2.2 and I.2.3). The requirements in this area are specified by the possession-only license, which likely will not be changed for continuing care.

I.3.2 Licensing

The NRC possession-only license remains in force during SAFSTOR. Regulatory Guide 1.86 and 10 CFR 50.82, "Application for Termination of License," present the guidance and regulations, respectively, for terminating the license at the end of SAFSTOR. In most cases, some dismantlement will be required to ensure that the contamination levels in the plant are at or below acceptable residual contamination levels. The regulatory requirements discussed in Sections I.1.1 and I.2.8 of this chapter will apply in these cases.

I.4 SELECTED REGULATORY ASPECTS ASSOCIATED WITH DECOMMISSIONING PREMATURELY SHUTDOWN PLANTS

The following information concerning the regulatory process for decommissioning prematurely shutdown plants is extracted from NUMARC 92-02 (draft report).[37] The current regulations in 10 CFR 50 focus primarily on the design, construction, and operation of nuclear facilities. Although 10 CFR § 50.82 "Application for Termination of License" allows a licensee to apply to the NRC for the authority to surrender its license voluntarily and decommission its facility, there are a myriad of regulatory issues that become ambiguous, or are undefined, when a licensee decides to shut down its facility permanently.

With the recent premature closing of several nuclear power stations, licensees, NRC, and the Nuclear Management and Resources Council, Inc. (NUMARC) have recognized the need for a uniform nuclear plant closure and decommissioning policy. The NUMARC 92-02 draft report presents:

- guidance on activities that can be accomplished after premature plant closure;

- a discussion of the regulations applicable to a plant as it proceeds from cessation of operations through preparation for decommissioning activities, including issues utilities may face with regards to supporting their permanently shutdown nuclear facility;

- a review of the current regulatory process for decommissioning, including a regulatory summary;

- a review of a number of "case histories" of prematurely shutdown facilities, including a comparison of their decommissioning approaches and common features so that facilities can use this information for early decommissioning planning.

Prematurely shutdown plants have been submitting documents to gain regulatory and economic relief and to begin the decommissioning process. Because there is no defined set of documentation to achieve these objectives, each plant has submitted its own unique series of documents to the NRC for approval. Although each facility has experienced different circumstances leading to permanent shutdown, the post-shutdown status and condition of the plants were similar in many respects.

When a plant is shut down prematurely, it is likely that the licensee has not fully prepared for permanent plant closure or decommissioning. It is also likely that the licensee has not yet submitted its application to terminate the operating license or completed its proposed decommissioning plan. To minimize the cost of supporting a prematurely shutdown nuclear reactor, it is essential that a utility act quickly to reduce the number and scope of regulatory programs applicable to its prematurely shutdown facility that are no longer applicable or needed to protect public health and safety. NUMARC 92-02 discusses a plan to provide a smooth transition through these phases and considerations as to the most effective way to address these issues. In addition, a step-by-step licensee/NRC action plan for decommissioning is included in the report.

Currently, there is no definition or criteria for a possession-only license (POL) in the Code of Federal Regulations. However, as a result of recent closures, there has been much discussion concerning what a POL is and what its implications are. The NUMARC 92-02 draft report reviews the impact of the POL on plant closure and decommissioning, including the generic issues impacting decommissioning along with the regulatory basis for relief (e.g., § 50.59 evaluation process, National Environmental Policy Act, Decommissioning Funding, Annual Operating Fees). The report also identifies the 10 CFR sections for which an exemption should be submitted to the NRC relative to a POL.

The following selected conclusions are drawn from the NUMARC 92-02 draft report:

- Decommissioning a prematurely shutdown nuclear plant involves much more than decontaminating and dismantling the facility to permit its release for unrestricted use, and allow for termination of its license.
- Future rulemaking on decommissioning is needed because the present regulations and associated guidance do not address prematurely shutdown plants and all phases of the process once a plant is prematurely shutdown. Until such rulemaking is completed, utilities must be aware of, and plan for, the cost of maintaining their prematurely shutdown facilities until they are issued a POL and gain approval of their proposed decommissioning plan.

I.5 DECOMMISSIONING AFTER A 20-YEAR LICENSE RENEWAL PERIOD

The NRC is proposing to amend its regulations to establish new requirements for environmental review of applications to renew operating licenses for nuclear power plants. The proposed amendments would define the number and scope of environmental impacts that would need to be addressed as part of a license renewal application.

As reported in Reference 38, the physical requirements and attendant effects of decommissioning nuclear power plants after a 20-year license renewal period are not expected to be different from those at the end of the current 40-year license period. While license renewal would not be expected to change the ultimate cost of decommissioning, it would reduce the present value of the cost. The socioeconomic effects of decommissioning will depend on the magnitude of the decommissioning effort, the size of the community, and other economic activities at the time. However, the NRC does not expect that the impacts would be increased by decommissioning at the end of a 20-year license renewal period rather that at the end of the current license term. Because the NRC can reach a generic conclusion on the acceptability of the incremental impacts of decommissioning for all plants, impacts on decommissioning need not be evaluated for each plant license renewal application.[38]

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37. NUMARC 92-02 (Draft), July 1992. "Regulatory Process for Decommissioning Prematurely Shut Down Plants." Report by Nuclear Management and Resources Council, Inc., Washington, D.C.

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The NUREG reports and regulatory guides mentioned in this chapter are available for inspection and copying for a fee under the decommissioning file docket 43 FR 10370, at the Commission's Public Document Room, 2120 L Street NW, Washington, DC 20036. NUREG reports and final regulatory guides are available for purchase from the National Technical Information Service, Springfield, VA 22161; and from the Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7982. Free single copies of draft regulatory guides are available on request from the Division of Information Support Services, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

APPENDIX J

REVIEW OF DECOMMISSIONING EXPERIENCE SINCE 1978

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REVIEW OF DECOMMISSIONING EXPERIENCE SINCE 1978

A comprehensive review of the available experience in the decommissioning of nuclear facilities was presented in NUREG/CR-0130, published in 1978.[1] Since that time, additional decommissioning activities have occurred, including the total dismantlement of the Shippingport reactor. This chapter contains information on selected nuclear reactor decommissionings, both domestic and foreign, since 1978. Industrial activities with potential applications to decommissioning pressurized water reactors (PWRs) are described in Appendix K.

J.1 DOMESTIC EXPERIENCE IN DECOMMISSIONING NUCLEAR POWER STATIONS SINCE 1978

The decommissioning of nuclear reactor facilities is a relatively well-developed technology. In the United States, the term "decommission" means to remove (as a facility) from service and reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of license (10 CFR 50).[2] Historically, decommissioning activities at nuclear facilities have not necessarily resulted in complete dismantlement of plant facilities for unrestricted use. In fact, the safe storage (mothballing, layaway, and entombment) approaches that have been used are now recognized as only one stage in the decommissioning process, leading to dismantlement/unrestricted release. The current NRC decommissioning regulations require that all decommissioning activities be completed within 60 years after termination of licensed power operations. Consideration will be given to an alternative which provides for completion of decommissioning beyond 60 years, only when it is necessary to protect health and safety.[3]

Previously, conventional wisdom suggested that all decommissioning methods start with removing all fuel and source material from the site. Of course, the 1978 study (NUREG/CR-0130) could not foresee the future provision delineated in the 1983 U.S. Department of Energy (DOE) contracts with utilities (10 CFR Part 961)[4] that would require spent fuel to undergo at least 5 years of radioactive decay before DOE will take possession of spent fuel. This provision impacts decommissioning activities by delaying, for up to 5 years, removal of the last core loading of spent fuel from a site and subsequent decontamination and dismantlement of the spent fuel storage facility.[a]

J.1.1 Decommissioning Experiences at Nuclear Reactor Power Stations

Information on selected nuclear reactor power stations decommissionings and/or shutdowns since 1978 is presented in Table J.1. Discussions of some of the significant reactor decommissionings follow, based on information excerpted from a United States General Accounting Office report,[5] unless indicated otherwise.

J.1.1.1 Shippingport Reactor, Shippingport, Pennsylvania

Over its 25-year life, Shippingport operated for about 80,324 hours, produced about 7.4 billion kilowatt-hours of electricity, and operated at varying power levels of 68, 150, and 72 megawatts electric. The plant was shut down by its owner, Duquesne Light Company, in October 1982. In 1983, The Energy Daily reported that the \$60- to \$70-million job of decommissioning the reactor was expected to start in March 1984.[6] However, actual decommissioning activities began in September 1985. At the time of shutdown, the radioactivity in the pressure vessel was about 30,000 curies; at the outset of decommissioning, it was about 17,000 curies.

DOE generally met the goals it had established for Shippingport. It completed all decommissioning activities in December 1989 - 4 months ahead of schedule - at a cost of \$91.3 million, \$7 million under its 1986 estimated cost. The most significant benefit of Shippingport was that DOE demonstrated that technology existed to decommission a plant within the costs and time

(a) The impact of the temporary storage of spent fuel at the reference PWR, until DOE takes possession, is addressed in Appendix D. A small staff would be required to provide security operations, maintenance, and radiation protection support. Some low-level radioactive wastes would also be generated due to operation of the water purification system for the spent fuel storage facility. Storage operations would continue to be under an NRC license.

TABLE J.1. Information on Selected Nuclear Reactor Decommissionings and Shutdowns[a]

Facility Name and Location	Reactor Type	Power Rating, MWe	Type of Decommissioning	License Status	Monitoring System	Safe Storage Measures	Year Decommissioned	Other Information
Dresden 1, Morris, IL	BWR	200	SAFSTOR	POL[b]	-[c]	-	-	-
Fort St. Vrain, Platteville, CO	HTGR	330	DECON	POL	-	-	-	Onsite ISFSI Constructed
Hanford-N, Richland, WA	LGR	860	-	None; gov't owned	-	-	-	Defueled; dry lay-up since 1988
Humboldt Bay 3, Eureka, CA	BWR	63	SAFSTOR	POL	Continuous security force	Locked doors, security fence	-	Wet Storage of spent fuel onsite; Decommissioning Plan approved by NRC
Indian Point 1, Buchanan, NY	PWR	257	-	POL	-	-	-	Decommissioning Plan under review
LaCrosse, Genoa, WI	BWR	50	SAFSTOR	POL	-	-	-	Decommissioning Plan approved; SNF onsite
Pathfinder, Sioux Falls, SD	BWR	66	Dismantled[d]	Byproduct NRC	-	-	1992	Estimated dismantling cost $13 M
Rancho Seco, Clay Station, CA	PWR	913	TBD[e]	POL[f]	Continuous security force	Locked doors, security fence	-	Spent nuclear fuel stored on-site
Shippingport, Shippingport, PA	LWBR[g]	72	Dismantled	Not NRC licensed	-	-	1989	Decommissioning cost $91.3M; took 4 years
Shoreham, Brookhaven NY	BWR	809	DECON	POL[h]	-	-	-	See footnote (i)
Three Mile Island 2, Londonderry Twp., PA	PWR	792	-[j]	-	-	-	-	-

(a) With the exceptions of Pathfinder (closed in October 1967), Indian Point 1 (closed in October 1974), Humboldt Bay 3 (closed in July 1976), and Dresden 1 (closed in October 1978), the remaining reactors shown in the table were shut down permanently in the post-1978 time frame.
(b) POL = Possession-Only License (10 CFR Part 50).
(c) Dash indicates information is unavailable from the literature or is not applicable.
(d) The Pathfinder reactor was shut down in 1967 and placed in safe storage until dismantlement began in 1990.
(e) TBD = To Be Determined.
(f) In accordance with the results of a public referendum on June 6, 1989, the owner of the Rancho Seco unit decided to shut it down and notified the NRC of its intent to decommission the plant. A decommissioning plan was submitted to the NRC in May 1991.
(g) Converted to a light water breeder reactor on October 1, 1977.
(h) The POL was issued for Shoreham on June 14, 1991, but may not be effective because of possible lawsuits. The decommissioning plan is under review by the NRC.
(i) The Shoreham unit achieved criticality and produced power, but closed before it could begin commercial operation.
(j) The TMI-2 reactor is defueled and in a Post-Defueling Monitored Storage (PDMS) condition, similar to SAFSTOR. The licensee's application for a POL is currently under review.

frame established. One objective of the Shippingport project was to demonstrate that a nuclear power plant could be safely and economically decommissioned using existing technology, such as manually dismantling radioactive piping systems and components. Thus, DOE did not design the project to increase the basic research and development knowledge on methods or equipment needed to decommission a large plant. It relied on technology that the nuclear industry had used for the last 30 years to construct, maintain, or demolish plant systems and components. As a result, DOE did not need, nor was it required, to develop new technology, such as robotics, to decommission Shippingport.

Very few utilities will be able to decommission their plants the way DOE decommissioned Shippingport, and it is possible that newer technology may be available by the time utilities do so. To illustrate, Shippingport was much smaller and less radioactively contaminated than other plants, and DOE removed the most highly radioactive component, the reactor pressure vessel, in one piece. Utilities operating commercial plants will probably have to disassemble (cut-up) the reactor pressure vessels, because of their much larger sizes, in a manner similar to the disassembly procedure used for the Elk River Reactor pressure vessel in the early 1970s. For the Elk River Reactor disassembly, a full test development program was carried out on the cutting processes and a manipulator for remote handling of the cutting torches was developed. Also, DOE disposed of all the low-level radioactive waste from the Shippingport decommissioning activities at its Hanford, Washington, facility. Utilities will have to dispose of waste at commercial sites at substantially higher costs.

Because of the demonstration nature of the Shippingport decommissioning project, DOE used a relatively elaborate management structure. To extend decommissioning experience and knowledge to the private sector, DOE used over eight contractors to conduct the physical activities, and three management contractors to oversee those activities. Only about 30 percent of DOE's costs related to the actual physical decommissioning activities; the remaining 70 percent included engineering, oversight, management, and other activities, such as waste disposal (see Table J.2).

TABLE J.2. Summary of Shippingport Decommissioning Costs[a]

Cost Category	Approximate Cost ($ millions)		Approximate Percent of Total
Phase I Engineering	6.1		7
Operations Project Management (DOE)	10.5		11
		16.6	
Decommissioning Operations Contractor (DOC)			
Site Management & Support	38.9		42
Home Office Support	1.6		2
Physical Decommissioning Activities	28.6		31
Fee	5.4		6
Total DOC Costs		74.5	81
Other	0.2		<1
		0.2	
Total, Decommissioning Costs		91.3	100

(a) Costs shown in the table are derived from information contained in Reference 7.

Shippingport was not licensed by the NRC; therefore, DOE did not have to obtain NRC's approval for the decommissioning activities conducted at the plant. However, DOE established a formal site release criteria that limited the radiation exposure from the decommissioned site to less than 100 mrem/yr and as low as reasonably achievable for the maximum-exposed individual. The decommissioned site fully met the criteria, with a calculated maximum exposure of 2 mrem/yr for the worst-case plausible scenario. A site release certification was prepared for each of the 75 subdivisions of the Shippingport site. It contained the data that confirmed the conformance to the release criteria. The decommissioning operations contractor issued a Post Remedial Action Report that was used by DOE as a summary document, distilling key information of site history, decontamination reports, limiting conditions for release criteria and radiological status.

The following conclusions pertaining to the Shippingport decommissioning project are drawn directly from Reference 5:

- Utility executives that the GAO investigators contacted said the lessons learned from DOE's planning efforts at Shippingport could facilitate their planning for future decommissioning projects.
- Shippingport provided only limited information to reduce worker exposures on future projects where the pressure vessel would be cut-up (in the decommissioning plan, DOE's contractor proposed a

worker exposure limit of about 1,010 person rem for the project; the actual exposure was 155 person rem).

- With the exception of Northern States Power, which has removed the pressure vessel from Pathfinder in one piece, there is little evidence that Shippingport influenced other decommissioning projects. DOE developed extensive information on Shippingport, but the usefulness of the data will diminish as the utilities defer decommissioning of their plants.

- DOE did not develop any new technology, such as remotely operated equipment or robotics, to decommission Shippingport because one of the project's objectives was to demonstrate that a nuclear plant could be safely and economically decommissioned using existing technology.

- Lastly, DOE had predetermined sites to dispose of the spent (used) fuel from Shippingport as well as the low-level and mixed waste generated from decommissioning activities. DOE sent the spent fuel to its Idaho National Engineering Laboratory and the low-level waste to a government disposal facility at Hanford. Currently, no disposal site exists for the spent fuel from commercial plants; DOE expects that the earliest a permanent disposal site would be available is 2010.

J.1.1.2 Pathfinder Reactor, Sioux Falls, South Dakota

Pathfinder, a 66-MWe boiling water reactor (BWR), was placed in passive safe storage by its owner, Northern States Power Company (NSPC). The reactor was shut down in 1967, and the plant was converted to fossil-fueled operation. NSPC started to decontaminate the plant in 1968 after removing the spent fuel and shipping it off-site. The modification of the turbine cycle equipment, at a cost of about $3.6 million, was the major activity. This equipment still has 0.041 curies of residual radioactivity, and thus requires an NRC Part 30 license.[8]

Pathfinder's piping and turbine components were decontaminated during the plant conversion process. Decontaminating fluids were placed in barrels, solidified, and shipped for burial. Over 300 0.2-m^3 barrels of solidified waste were removed from the site. The utility removed all contaminated pipe outside the reactor and fuel handling buildings, drained and filled the reactor pressure vessel with gravel and grouted it in place. The utility did not decontaminate the piping system inside the reactor building and left it in place. After partially decontaminating the reactor and fuel handling buildings, NSPC sealed the areas in 1971 to prevent unauthorized access. The cost of this Phase 1 decommissioning work was $1.87 million.[9]

In 1990, NSPC began to decontaminate the previously sealed areas. The onsite decommissioning staff averaged only 30-35 full-time employees, occasionally supplemented with outside contract personnel, such as for the reactor pressure vessel (RPV) lift. The utility disposed of most of the low-level radioactive waste at a commercial site operated by U.S. Ecology in Richland, Washington. Because of the weight (290 tons) and size (12 feet x 32 feet) of the RPV (in one piece) and the shipping package, the utility rented a special railcar and train to transport it.[9] The RPV was buried at the U.S. Ecology-Richland site in August 1991.

Pathfinder's decommissioning cost, through July 1992, was $12.31 million. Cost projections were reevaluated in August 1992 based on accomplishments to date and forecasts for future expenditures. The revised projections reflect a total project cost estimate of about $13.0 million, down from a June 1991 cost estimate of $13.38 million, and an original cost estimate of $16.0 million (to green field condition). The reduction in the August 1992 cost estimate resulted from costs for RPV shipment and burial being less than anticipated.[10]

J.1.1.3 Fort St. Vrain Reactor, Platteville, Colorado

Fort St. Vrain, a 330-MWe high-temperature gas-cooled reactor (HTGR), is owned by the Public Service Company (PSC) of Colorado. The plant began commercial operation in 1979. In August 1989, the utility shut the plant down after years of operating problems. During its lifetime, Fort St. Vrain operated for about 21,360 hours, generating about 4.3-billion kilowatt-hours of electricity. At the time the plant was shut down, company officials estimate that the reactor contained about 900,000 curies of radioactive contamination.

Fort St. Vrain is physically quite different from Shippingport and the other 112 domestic nuclear power plants. For example, the plant used graphite as the moderator and helium as the coolant, whereas Shippingport and the other commercial power reactor plants generally use water for both functions. Also, the fuel used in Fort St. Vrain differed from that used in Shippingport and other plants. In November 1989, the utility began removing the spent fuel and planned to send it to DOE's Idaho National Engineering Laboratory, but shipment was halted by state of Idaho court action. As an interim measure, the company is now storing the spent fuel in an independent spent fuel storage installation (ISFSI) at the site.

PSC selected DECON as its decommissioning option for Fort St. Vrain, and is now proceeding with that option following approval of the plan by the NRC in November 1992. PSC estimates the costs for dismantlement at $157 million.

J.1.1.4 Rancho Seco Nuclear Generating Station, Clay Station, California

Rancho Seco Nuclear Generating Station (RSNGS), a 913-MWe PWR, is owned and operated by the Sacramento Municipal Utility District (SMUD). On June 7, 1989, SMUD shut down the plant in response to a voter referendum to close the plant. During its lifetime, RSNGS operated for about 51,595 hours and generated about 44-billion kilowatt-hours of electricity. Company officials estimate that the amount of radioactivity in the plant at shutdown exceeded 9 million curies.[5]

In May 1991, SMUD submitted a decommissioning plan to NRC. The decommissioning plan outlines SMUD's intent to store spent fuel in the spent fuel pool during the initial phase of decommissioning (Custodial-SAFSTOR). The Hardened-SAFSTOR phase of decommissioning will follow Custodial-SAFSTOR, after the fuel has been placed in dry storage at an onsite ISFSI. Deferred-DECON (decontamination and dismantlement) will commence thereafter. An estimated $280.8 million will be required to decommission the plant, including site restoration.[11]

J.1.1.5 Three Mile Island 2, Londonderry Township, Pennsylvania

Three Mile Island Unit 2 (TMI-2), a 792-MWe PWR operated by GPU Nuclear Corporation, was closed in March 1979 due to a nuclear accident. The information base is extensive concerning the TMI-2-related cleanup, research, and development activities following the accident. Many contributions of potential benefit to future nuclear power plants decommissioning programs have resulted from the overall accident cleanup program at TMI-2. The brief summaries of a few such contributions of the TMI-2 research and development (R&D) program that follow were extracted from Reference 12. Other potential decommissioning-related contributions from TMI-2 are further described in References 13-17.

One important contribution of the TMI-2 R&D program has been the high-level radioactive waste technology developed at the national laboratories. From the standpoint of volume reduction, the use of the EPICOR II system[b] reduced the radioactive waste volume by a factor of 10, and the submerged demineralizer system (SDS) reduced the volume by a factor of 500 over conventional waste processing systems.

Another accomplishment has been the development of the high-integrity containers (HICs). The concrete HIC is durable, tested, licensed, and equipped with a one-way vent system for exhausting the gases produced inside. The HIC's design and scale could be adapted according to industry needs.

In addition, the knowledge gained from the handling of large radioactive components at TMI-2, and their subsequent disposal, should assist operating nuclear power plants in formulating and carrying out plans for decommissioning their own nuclear power plants.

J.1.1.6 La Crosse Reactor, Genoa, Wisconsin

La Crosse, a 50-MWe BWR, was placed in safe storage (SAFSTOR) by its owner, Dairyland Power Cooperative (DPC), in May 1987. All fuel was removed from the reactor vessel, and DPC plans to monitor the reactor and the stored fuel until such time as the fuel can be sent away to a federal high-level waste or spent fuel facility. Decommissioning of the reactor facility would take place only after the fuel has left.[18] The possession-only license for La Crosse has been approved to March 2031.

(b) The contaminated water at TMI-2, approximately 2,120,000 liters, was decontaminated using this three-stage demineralization system, which contained organic and inorganic ion exchange media.

J.1.1.7 Peach Bottom 1, York County, Pennsylvania

Peach Bottom Unit 1, a 40-MWe prototype high-temperature gas-cooled reactor (HTGR), is owned by the Philadelphia Electric Company. The plant operated from June 1967 until October 1974. During this 7-year period, the plant operated for about 32,375 hours, generating about 1.4-billion kilowatt-hours of electricity. At the time the plant was shut down, the radioactivity in the pressure vessel was more than 3 million curies.

Philadelphia Electric decided to place the facility in SAFSTOR and started to decontaminate the site in January 1976. The company completed these activities in February 1978, using about 179 man-months of labor, at a cost of about $3.5 million. The utility removed all radioactive liquids, drained refrigerants and cooling water, and sent the spent fuel to DOE's Idaho National Engineering Laboratory. The company left the reactor vessel, piping systems, and steam generators in the plant, and officials estimate that they will not start to remove these components or otherwise decommission the plant for about 20 more years.[5]

J.1.1.8 Saxton Nuclear Experimental Reactor, Saxton, Pennsylvania

The Saxton Nuclear Experimental Reactor, a 3-MWe prototype PWR, is owned by the Saxton Nuclear Experimental Corporation (SNEC). The reactor was placed in SAFSTOR following its shutdown in 1972. Work on decommissioning the reactor and site started in 1986. To date, decontamination activities have been completed in the control room and radwaste building. The reactor containment building is not scheduled for dismantling until the mid-1990s.[19]

J.2 FOREIGN EXPERIENCE IN DECOMMISSIONING NUCLEAR REACTORS SINCE 1978

According to an October 1991 Nucleonics Week article,[20] "the OECD Nuclear Energy Agency (NEA) has solved the puzzle of why estimates of nuclear facility decommissioning costs have varied so widely: it's not the size of the facility that counts, nor even the scope of the planned decommissioning, but rather the amount of waste the job is projected to generate that makes the difference. The finding is significant not only because it will help nuclear facility owners better project their own decommissioning costs, but also because the wide variation in decommissioning cost estimates worldwide has undermined the credibility of all those estimates, essentially with the cheaper ones being disbelieved by the public."

An assessment of foreign decommissioning technology with potential application to U.S. decommissioning needs is presented in Appendix K. Discussions of some of the significant foreign reactor decommissionings follow, based on information extracted from References 21 and 22. When cited in the references, the decommissioning costs and reactor power levels are given.

J.2.1 Decommissioning Projects in Canada

Gentilly-1 is a 296-MWe CANDU (Canadian Deuterium Uranium Reactor), moderated with heavy water and cooled with boiling light water. It has been mothballed since 1979. Canadian strategy calls for keeping the facility in a "static state,"[(c)] monitor it for 50-80 years, then dismantle the facility. Extensive use was made of an electrically driven water blaster (hydrolaser) for decontamination of fuel bundles, equipment, and spent fuel pool surfaces. The decommissioning to the "static state" was completed in 1986 at a cost of $13 million (Canadian); surveillance cost is about $1 million (Canadian) per year.

Douglas Point is a 216-MWe CANDU pressurized heavy-water reactor that operated from 1968 to 1984 and was permanently shut down in 1984. All 23,000 spent fuel assemblies (300 MTU) were moved into 47 above-ground concrete canisters (completed in 1987) for storage until a permanent repository is available. The reactor facility was sealed and kept intact in "static state," pending a decision on possible future use.

J.2.2 Decommissioning Projects in France

France is relying on the nuclear industry to make decisions based upon economics and applicable regulations; numerous decommissioning projects have been completed or are under way following this policy. Like most countries,

(c) A "static state" was achieved by sealing the reactor building and consolidating the contaminated wastes (including spent fuel) in the turbine building. This work was completed in the spring of 1986.

France adheres to the IAEA's three-stage decommissioning pattern in planning its decommissioning projects:[23]

- Stage 1 decommissioning relates to the period immediately following final shutdown of the nuclear power plant, usually assumed to be a planned operation rather than the result of an accident or major breakdown. In this stage the reactor is defueled and made safe, the work essentially being an extension of normal operations.

- Stage 2 decommissioning has the objective of dismantling all plant external to the biological shield. This stage is characterized by the ability to dismantle the plant using built-in facilities or readily available brought-in engineering equipment.

- Stage 3 is the removal of the reactor itself together with its biological shield, or pre-stressed concrete vessel, and final clearance of the site rendering it safe for further use.

Past and current reactor decommissioning projects in France include the following:

- Cesar GCR (gas-cooled reactor) at Cadarache has been decommissioned to Stage 3, i.e., complete dismantlement and removal of radioactive facilities and equipment.

- Chinon A1 (70 MWe), A2 (180 MWe), and A3 (360 MWe) GCRs have been shut down since 1973, 1985, and 1990, respectively. A1 has been decommissioned through Stage 1. Decommissioning of Chinon A2 to Stage 2 is expected to take 5 years and cost 100 million FF ($17 million U.S.).

- EL2, EL3, Zoe HWRs at Fontenay-aux-Roses have been shut down. EL2 was decommissioned to Stage 2 in 1968 and EL3 was decommissioned through Stage 3 in 1984. Zoe has been decommissioned through Stage 2.

- The EL4 (70 MWe) GCHWR at Monts d'Arree has been shut down since 1985 and decommissioning is underway.

- G1 (3 MWe), G2 (40 MWe), and G3 (40 MWe) GCRs at Marcoule have been shut down. G1 has been decommissioned through Stage 2; G2 decommissioning is underway; and G3 decommissioning is planned to be complete by 1993. Decommissioning of the G2 and G3 reactors to Stage 2 is estimated to cost 20 million FF ($3.3 million U.S.).

- Minerve, Nereide, and Triton experimental LWRs at Fontenay-aux-Roses are being decommissioned. Minerve and Triton have been decommissioned through Stage 3. The Nereide reactor decommissioning is underway.

- The Pegase and Peggy experimental LWRs, along with the 40-MWt Rapsodie experimental LMFR (Liquid Metal Fast Reactor) at Cadarache, have been shut down. Pegase and Peggy have been decommissioned to Stage 3 and decommissioning of Rapsodie is just starting.

J.2.3 Decommissioning Projects in Federal Republic of Germany

The Federal Republic of Germany (FRG), having a large nuclear program, has undertaken numerous decommissioning projects. Major projects include the following:

- FR-2 research reactor at Karlsruhe: This 44-MWt, tank-type HWR operated between 1961 and 1981. The fuel has been removed and non-radioactive structures are being removed (Stage 2). The core structure and bioshield will be dismantled in 30 years.

- MZFR research reactor at Karlsruhe: This 58-MW PWR operated between 1965 and 1984. The facility, except for the fuel storage building, is out of operation and in safe enclosure.

- Niedereichbach nuclear power plant: This heavy-water-moderated, gas-cooled, 100-MWe reactor operated from 1972-1974. Decommissioning started in 1987. The site is to be restored to "green field" condition. The estimated cost for the program is 100 million DM. Contaminated steel (about 1700 tons) from the project is to be melted after size reduction in an induction-melting furnace installed in the decontaminated and decommissioned building of the FR-2 reactor (facility name "EIRAM").

- KRB-A power plant at Gundremmingen: This 250-MWe BWR operated between 1966 and 1977. Fuel has been removed and all systems but the biological shield and reactor vessel are expected to be dismantled by 1992.

- KWL Lingen power plant: This 268-MWe BWR operated between 1968 and 1977. The facility has been placed in safe enclosure (Stage 1). Dismantlement will start after 25 years.

- AVR and THTR-300 reactors: The first stage of decommissioning and dismantling of the 296-MWe THTR-300 high temperature, gas-cooled reactor will be completed in 1992. The FRG's other HTR, the 15-MWe AVR pilot HTR at Julich, was shut down in 1988 and is awaiting decommissioning licenses from the state regulators. Spent fuel from the two units will be disposed at Gorleben.

- Nuclear Ship "Otto Hahn": This nuclear-powered ship, built in 1963, was shut down in 1979. All activated and contaminated components were removed and the rooms were decontaminated. The ship is used for non-nuclear purposes. The decommissioning and dismantling cost 21.7 million DM ($11 million U.S.).

J.2.4 Decommissioning Projects in Italy

Major decommissioning projects in Italy include the following:

- Garigliano nuclear power plant: This 160-MWe BWR operated from 1964-1973. The nuclear steam supply system is to be placed in protective storage for 30 years.
- Decommissioning of the Latina GCR (153 MWe) has begun. The fuel unloading is expected to take three years (fuel shipments are suspended during summer). The possible reuse of the plant's turbines for non-nuclear combined-cycle power generation is under investigation. Approximately 270 MT of the reactor's fuel will be shipped to the United Kingdom for reprocessing.

J.2.5 Decommissioning Projects in Japan

The Japanese policy on decommissioning of closed nuclear power plants is to mothball them for 5-10 years, and then dismantle them completely so that the land can be reused. Current estimates are 30 billion yen ($220 million) for complete dismantling of a 1000-MWe reactor unit. JAERI (Japan Atomic Energy Research Institute) is at an advanced stage of decommissioning the Japan Power Demonstration Reactor (JPDR). This was a 12.5-MWe BWR at Tokai. Dismantling was started in 1986, with project completion scheduled in late 1993.

J.2.6 Decommissioning Projects in Spain

It has been assumed for calculation and planning purposes that once the useful life of Spain's nuclear power plants (estimated at 30 years) comes to an end and after a "cooling" period of about 5 years, total dismantling would begin, lasting approximately another 5 years, leaving the site ready for other unrestricted uses. Spain's main efforts and expenditures on decommissioning nuclear facilities are predicted to be in 2000-2025. Furthermore, Spain does not deem it advisable to undertake specific research and development projects on decommissioning; rather, it plans to follow the R&D programs in other countries, especially those in the European Community. However, it may undertake direct collaboration/participation in some foreign projects.

The 20-year old Jen-1, a 3-kW experimental reactor, is being dismantled. The shutdown Vandellos 1, a 480-MWe GCR whose turbo-generator was severely damaged in a fire in 1989, is also to be decommissioned. The Spanish government has estimated the cost of dismantling the Vandellos 1 reactor at 15 billion pesetas (about $146 million U.S.).

J.2.7 Decommissioning Projects in the United Kingdom

The United Kingdom's (UK's) plans for R&D of nuclear power reactors covers three phases: 1) removing spent fuel and bulk wastes; 2) dismantling and removing the non-radioactive equipment/facilities around the reactor; and 3) removing the radioactive portions of the reactor after a 100-year delay to allow decay of the radioactivity. Past and planned decommissioning projects include:

- Four nuclear power stations, the 13-MWe Dounreay Fast Reactor (DFR), the Berkeley Magnox units 1 (138 MWe) and 2 (138 MWe), and the prototype 28-MWe Windscale Advanced Gas-Cooled Reactor (WAGR), have been shut down. Decommissioning of the Berkeley units is just starting with Stage 2 decommissioning expected to be complete in about 10 years. Phase 1 decommissioning of the DFR has been completed with no plans for further work, while Phase 3 decommissioning of the WAGR is expected to be completed in the mid/late-1990s. The cost of decommissioning the U.K.'s outdated Magnox power stations and reprocessing their wastes was estimated at $2.4 billion U.S. as reported in a 1988/89 annual report of the Central Electricity Generating Board (CEGB). The total for CEGB was estimated at $18.5 billion U.S. (13 Magnox reactors) and at $2.9 billion U.S. for the South of Scotland Electricity Board (3 Magnox reactors). Recent studies indicate substantial savings can be realized by "mounding over" obsolete Magnox reactors instead of completely decommissioning them.

- Decommissioning of the Windscale Piles, shut down after a serious fire in 1957, is just beginning.

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APPENDIX K

REVIEW OF DECOMMISSIONING TECHNICAL DEVELOPMENTS SINCE 1978

APPENDIX K

REVIEW OF DECOMMISSIONING TECHNICAL DEVELOPMENTS SINCE 1978

Because of finite resources and the wide-range of topics researched during the course of this re-evaluation study, it was not possible to obtain information on decommissioning-related equipment/processes from all vendors or suppliers. However, the selected equipment/processes and suppliers described in this chapter are believed to be representative of state-of-the-art in those areas. It should be recognized, however, that the identification of specific vendors, processes, and/or equipment does not constitute an endorsement of those entities.

K.1 DOMESTIC AND FOREIGN TECHNICAL DEVELOPMENTS SINCE 1978

Both domestic and foreign technical developments were reviewed for potential direct applications to decommissioning pressurized water reactors (PWRs). The results of that review are briefly described in the following sections.

K.1.1 Domestic Technical Developments

Perhaps the most significant ongoing industrial activities with potential direct applications to decommissioning PWRs that have occurred since 1978 concern steam generator replacement projects. These programs have yielded significant information on decommissioning (e.g., steam generator removal technology and associated exposure reduction techniques). In turn, this information on removal activities has been incorporated into this reexamination of the decommissioning of the reference PWR.

Current information on chemical decontamination of light-water reactors was obtained from a comprehensive review of the literature and from discussions with senior staff of Pacific Nuclear Services (PNS), located in Richland, Washington. The PNS staff emphasized that it should be recognized that: 1) full-system chemical decontaminations of light water reactors are very plant-specific; 2) the amount of radwastes depends on the solvent used for the job; and 3) since no commercial PWR has yet undergone a full-system chemical decontamination in the United States, a first-of-a-kind (FOAK) full system chemical decontamination of a PWR could cost in the range of $20-25 million. However, when such decontaminations of PWRs become "routine" (defined for purposes of this reevaluation study as after at least 3 such campaigns have been successfully completed), a cost in the range of $10-$15 million could be anticipated for a full-system chemical decontamination. This latter cost includes mobilization/demobilization costs, all contractor staff costs, the costs of chemicals, mobile equipment, hoses, etc., onsite radwaste processing, high-integrity containers (HICs) for the resultant waste, and transportation costs, but not final burial costs of the HICs.

In addition, Pacific Nuclear staff related that their experiences to date with chemical decontamination of drain systems indicates that it is probably not cost-effective, nor practical, to chemically decontaminate reactor drain systems prior to disassembly. Therefore, the piping in the drain systems at the reference PWR analyzed in this report are not postulated to be chemically decontaminated before disassembly.

In summary, primary system chemical decontamination programs for both PWRs and BWRs have become major contributors to ALARA programs at operating sites.[1-3] Practical and proven reactor coolant system chemical decontamination technology is a major dose reduction procedure being used by U.S. nuclear utilities today. Primary system decontamination as a precursor to decommissioning (especially the base scenario analyzed in Appendix D of this report, where maximum benefits could be achieved) will undoubtedly be seriously considered in future decommissionings.

According to an Electric Power Research Institute (EPRI) survey,[4] nuclear power plants have increased the use of industrial video cameras as support tools for a variety of plant operations and outage tasks. It was found that many plants are using video cameras as surveillance and monitoring tools to significantly reduce personnel radiation exposure during both routine and specialized tasks. Typical uses include remote health physics support, observation of workers to ensure that they position themselves to minimize exposure, job planning prior to entry into a radiation zone, and videotaping jobs for training purposes. Video cameras are also used as communication tools so that supervisors and task engineers can provide technical direction from outside the work zone. Area surveillance, such as fire watch during welding, leak detection, and general observation during plant operations, is another common application.

Robots are yet another application of closed-circuit television (CCTV) at nuclear power plants. Though still considered developmental at many utilities, they have performed a broad range of productive tasks (e.g., surface decontamination, sludge removal, waste handling and packaging, area radiation surveys, transporting shielding, sample acquisition, concrete scabbling, concrete coring, fire watch, and component inspections). This is particularly true at TMI-2, where extensive contamination made robots the only option for some plant recovery tasks.[5] In recent years, many plants have used underwater surveillance vehicles for inspection, cleaning, object retrieval, and monitoring divers. These submersibles are equipped with cameras and lights, thus they are another nuclear plant application of CCTV.[4]

Though special radiation-hardened cameras have for many years been used for tasks such as in-vessel inspections and fuel-assembly examinations, a new generation of industrial video cameras is finding many new plant applications. These cameras are versatile, relatively inexpensive, and easy to install and operate. In summary, the EPRI survey concluded that video cameras are important tools for reducing radiation exposure and improving productivity through more efficient use of personnel.

Many plants are using advanced image retrieval and processing systems to store, search, display, and print visual information. Using microcomputer hardware and proprietary software, these systems can access images stored on videotape, microfilm, laser disc, or in computer memory. The most common application is for surrogate walk-throughs. That is, thousands of photographs of the nuclear power plant are stored on laser disc, and a joy-stick control is used to "walk" through areas visually for orientation, job planning, etc.[4]

K.1.2 Foreign Technical Developments

In 1987, the Pacific Northwest Laboratory (PNL) conducted a study[6] for the U.S. Department of Energy to identify and technically assess foreign decommissioning technology developments that may represent significant improvements over decommissioning technology currently available or under development in the United States. Technology need areas for nuclear power reactor decommissioning operations were identified and prioritized using the results of past light water reactor (LWR) decommissioning studies to quantitatively evaluate the potential for reducing cost and decommissioning worker radiation dose for each major decommissioning activity.

Based on these identified needs, current foreign decommissioning technologies of potential interest to the U.S. were identified through personal contacts and the collection and review of an extensive body of decommissioning literature. These technologies were then assessed qualitatively to evaluate their uniqueness, potential for a significant reduction in decommissioning costs and/or worker radiation dose, development status, and other factors affecting their value and applicability to U.S. needs.

The results of that study show that the major cost elements in LWR decommissioning, and thus the activities with the greatest potential for cost savings through improved technology, are: 1) management of radioactive decommissioning wastes, 2) the demolition of heavily reinforced nonradioactive structures, and 3) the detachment, removal and segmentation of fluid systems and components. Similarly, decommissioning worker radiation dose data show clearly that improved technology for the last category represents the major opportunity for worker dose reduction.

The technology assessment in that study indicates that no specific decommissioning technology needs were identified that are not addressed to some degree either by the foreign technology development work or by existing U.S. technology development programs. In addition, there are no presently identified, fully developed foreign technologies directly applicable to major U.S. decommissioning needs that are not currently available in the U.S. There are, however, several promising technologies in the conceptual or

R&D/demonstration stage that should be monitored and periodically reassessed as further development and demonstration studies are conducted. Based on the outcome of the ongoing R&D work, the technology need areas that potentially could benefit most from additional R&D emphasis would include improved monitoring methods for metallic waste to assure compliance with release criteria, better survey/sampling methods for contaminated concrete surfaces to guide operations on the extent of concrete removal, and cost-effective treatment processes for secondary decontamination wastes.

K.2 FACILITATION TECHNIQUES FOR DECOMMISSIONING LIGHT WATER POWER REACTORS

NUREG/CR-3587[7] contains a comprehensive review of the available experience in the identification and evaluation of practical techniques to facilitate the decommissioning of nuclear power generating facilities. The objectives of the "facilitation techniques" evaluated in that report were to reduce public/occupational exposure and/or reduce volumes of radioactive waste generated during the decommissioning process.[a]

The report presents the possible facilitation techniques identified during the study (circa 1986) and discusses the corresponding facilitation of the decommissioning process. Techniques are categorized by their applicability of being implemented during three stages of reactor life: design/construction, operation, or decommissioning. Detailed cost-benefit analyses were performed for each technique to determine the anticipated exposure and/or radioactive waste reduction; the estimated cost for implementing each technique was then calculated. Finally, these techniques were ranked by their effectiveness to facilitate the decommissioning process.

K.3 CONCLUSIONS

Concerning technology development for nuclear power reactor decommissioning, most experience and development have been in such areas as training, developing specialized tools, physical decontamination, lifting and removing

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(a) This study is part of the NRC's evaluation of decommissioning policy and modification of regulations pertaining to the decommissioning process. The findings can be used by utilities in the planning and establishment of the activities to ensure that all objectives of decommissioning will be achieved.

heavy objects in high radiation fields, remote visual inspection techniques, and demolition of nonradioactive components. These areas are fairly well developed and radical new developments which will affect decommissioning costs significantly are not expected. Areas where technology development is likely to occur and may have significant cost effects include chemical decontamination, remote disassembly, waste reduction and recycling, and waste disposal.[8]

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11. ABSTRACT (200 words or less)

With the issuance of the Decommissioning Rule (June 27, 1988), nuclear power plant licensees are required to submit to the U.S. Nuclear Regulatory Commission (NRC) for review, decommissioning plans and cost estimates. This reevaluation study provides some of the needed bases documentation to the NRC staff that will assist them in assessing the adequacy of the licensee submittals. This report presents the results of a review and reevaluation of the PNL 1978 decommissioning study of the Trojan nuclear power plant for the DECON, SAFSTOR, and ENTOMB decommissioning alternatives. These alternatives now include an initial 5-7 year period during which the spent fuel is stored in the spent fuel pool, prior to beginning major disassembly or extended safe storage of the plant. This report also includes consideration of the NRC requirement that decommissioning activities leading to termination of the nuclear license be completed within 60 years of final reactor shutdown, consideration of packaging and disposal requirements for Greater-Than-Class C low-level waste, and reflects all costs in 1993 dollars. Sensitivity of the total license termination cost to the disposal costs at different low-level radioactive waste disposal sites, and to different depths of contaminated concrete surface removal within the facilities are also examined.

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