NUREG/CR-1756
Addendum

Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors

Sensitivity of Decommissioning Radiation Exposure and Costs to Selected Parameters

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Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory
Commission

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FOREWORD
BY
NUCLEAR REGULATORY COMMISSION STAFF

The NRC staff is reappraising its regulatory position relative to the decommissioning of nuclear facilities.[1] As a part of this activity, the NRC has initiated two series of studies through technical assistance contracts. These contracts are being undertaken to develop information to support the preparation of new standards covering decommissioning.

The basic series of studies covers the technology, safety, and costs of decommissioning reference nuclear facilities. Light water reactors and fuel-cycle and non-fuel-cycle facilities are included. Facilities of current design on typical sites are selected for the studies. Separate reports are prepared as the studies of the various facilities are completed.

The first report in this series covers a fuel reprocessing plant;[2] the second addresses a pressurized water reactor;[3] and the third deals with a small mixed oxide fuel fabrication plant.[4] The fourth report, an addendum to the pressurized water reactor report,[5] examines the relationship between reactor size and decommissioning cost, the cost of entombment, and the sensitivity of cost to radiation levels, contractual arrangements, and disposal site charges. The fifth report in this series deals with a low-level waste burial ground;[6] the sixth covers a large boiling water reactor power station;[7] and the seventh examines a uranium fuel fabrication plant.[8] The eighth report covers non-fuel-cycle nuclear facilities.[9] The ninth report, an addendum to the low-level waste burial ground report,[10] supplements the description of environmental radiological surveillance programs used in the parent document. The tenth report deals with a uranium hexafluoride conversion plant.[11] The eleventh report addresses the decommissioning of nuclear reactors at multiple-reactor power stations.[12] The twelfth report covers nuclear research and test reactors.[13] The thirteenth report examines the decommissioning of reference light water reactors following postulated accidents.[14] The fourteenth and fifteenth reports are addendums to the pressurized water reactor report and the boiling water reactor report, respectively, and examine the impacts on decommissioning of both of these plant types of a temporary inability to dispose of waste offsite at the time of decommissioning.[15,16] This addendum contains an analysis of the sensitivity of decommissioning radiation exposure and costs to selected parameters at nuclear research and test reactor facilities.

Additional decommissioning topics will be reported on the tentative schedule as follows:

FY 1983 • Independent Spent Fuel Storage Installations
• Post-Accident Decommissioning at Fuel Cycle Facilities

The second series of studies covers supporting information on the decommissioning of nuclear facilities. Five reports have been issued in the second series. The first consists of an annotated bibliography on the decommissioning of nuclear facilities.(17) The second is a review and analysis of current decommissioning regulations.(18) The third covers the facilitation of the decommissioning of light water reactors.(19) The fourth covers the establishment of an information base concerning monitoring for compliance with decommissioning survey criteria.(20) The fifth addresses the technology and cost of termination surveys associated with decommissioning of nuclear facilities.(21)

The information provided in this addendum on the decommissioning of research and test reactors, including any comments, will be included in the record for consideration by the Commission in establishing criteria and new standards for decommissioning. Comments on this report should be mailed to:

Chief
Chemical Engineering Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

REFERENCES

1. Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities. NUREG-0436, Rev. 1, Office of Standards Development, U.S. Nuclear Regulatory Commission, December 1978.

2. Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant. NUREG-0278, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1977.

3. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1978.

4. Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant. NUREG/CR-0129, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

5. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130 Addendum, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

6. Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground. NUREG/CR-0570, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1980.

7. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1980.

8. Technology, Safety and Costs of Decommissioning a Reference Uranium Fuel Fabrication Plant. NUREG/CR-1266, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1980.

9. Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities. NUREG/CR-1754, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1981.

10. Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground. NUREG/CR-0570 Addendum, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, May 1981.

11. Technology, Safety and Costs of Decommissioning a Reference Uranium Hexafluoride Conversion Plant. NUREG/CR-1757, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1981.

12. Technology, Safety and Costs of Decommissioning Nuclear Reactors at Multiple-Reactor Stations. NUREG/CR-1755, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, January 1982.

13. Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors. NUREG/CR-1756, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, March 1982.

14. Technology, Safety and Costs of Cleanup and Decommissioning of Reference Light Water Reactors Involved in Accidents, NUREG/CR-2601, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1982.

15. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG-CR/0130 Addendum 2, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1983.

16. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672 Addendum, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1983.

17. Decommissioning of Nuclear Facilities - An Annotated Bibliography. NUREG/CR-0130, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

18. Decommissioning of Nuclear Facilities - A Review and Analysis of Current Regulations. NUREG/CR-0671, Pacific Northwest Laboratory and Battelle Human Affairs Research Centers for U.S. Nuclear Regulatory Commission, August 1979.

19. Facilitation of Decommissioning of Light Water Reactors. NUREG/CR-0569, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, December 1979.

20. Monitoring for Compliance with Decommissioning Termination Survey Criteria. NUREG/CR-2082, Oak Ridge National Laboratory for U.S. Nuclear Regulatory Commission, June 1981.

21. Technology and Cost of Termination Surveys Associated with Decommissioning of Nuclear Facilities. NUREG/CR-2241, Oak Ridge National Laboratory for U.S. Nuclear Regulatory Commission, February 1982.

ABSTRACT

Additional analyses of decommissioning at the reference research and test (R&T) reactors and analyses of five recent reactor decommissionings are made that examine some parameters not covered in the initial study report (NUREG/CR-1756). The parameters examined for decommissioning are: 1) the effect on costs and radiation exposure of plant size and/or type; 2) the effects on costs of increasing disposal charges and of unavailability of waste disposal capacity at licensed waste disposal facilities; and 3) the costs of and the available alternatives for the disposal of nuclear R&T reactor fuel assemblies.

The volumes of radwaste and the total decommissioning costs from the five recent research reactor decommissioning projects are seen to exhibit some correlation with overall reactor power rating for that class of facility. However, until more data are available from decommissioning of specific reactor types, it will be difficult to establish the effect of reactor type on costs or to correlate radiation dose with reactor facility size and/or type with any degree of confidence.

The effect on decommissioning costs of increasing disposal charges at waste disposal facilities is examined. In the case of the reference test reactor conceptually decommissioned in NUREG/CR-1756, it is concluded that a doubling of the burial ground charges would result in an increase of about 13% in the overall cost of DECON. In addition, the effect on decommissioning of interim inability to dispose of radwastes offsite for the reference R&T reactors is examined. In each case, if offsite waste disposal were not available, the technology, safety, and costs of decommissioning would be altered, most likely resulting in selection of a different preferred alternative for completing the decommissioning.

The impact on decommissioning costs of disposing of R&T reactor fuel hinges on whether the fuel is privately owned or is owned by the U.S. Department of Energy (DOE). Licensees who own their own fuel must bear all costs associated with fuel disposal, including cask rental and shipment of fuel. At those universities where DOE retains ownership of the fuel, the universities can frequently borrow DOE-owned casks free of charge to transport this fuel after irradiation; however, they still must pay for the shipment of the fuel.

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FIGURES

TABLES

1.0 INTRODUCTION

In the course of the analyses of decommissioning the reference nuclear research and test (R&T) reactors, as reported in NUREG/CR-1756,[1] certain parameters were identified as warranting additional study. The most important of these parameters are presented in this addendum. They are:

- the effect on decommissioning costs and radiation exposure of plant size and/or type
- the effects on decommissioning costs of increasing disposal charges and of unavailability of waste disposal capacity at licensed waste disposal facilities
- the costs of and the available alternatives for the disposal of nuclear R&T reactor fuel assemblies.

The purpose of this addendum is to present the results of the research into the abovementioned areas because these results make a valuable addition to the information presented in NUREG/CR-1756 and increase its general applicability.

The study approach taken in this addendum is presented in Section 3. The analyses are based on the reference nuclear R&T reactors reported in NUREG/CR-1756 and on five recent reactor decommissioning case histories described in Appendix A. The analyses are presented in Sections 4 through 6 and are summarized in Section 2. In addition, decommissioning cost factors that are identified as being difficult to quantify generically are included in Section 7 for completeness. A discussion of observations based on these analyses is presented in Section 8.

Persons who supplied information for this addendum are listed in Appendix B. Appendix C is a glossary of abbreviations, terms, and definitions directly related to the decommissioning of R&T reactor facilities.

REFERENCES

1. G. J. Konzek, J. D. Ludwick, W. E. Kennedy, Jr. and R. I. Smith, Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, March 1982.

2.0 SUMMARY

The detailed decommissioning analyses for the reference research and test (R&T) reactors reported in NUREG/CR-1756 as well as information resulting from five recent reactor decommissionings provide the bases for the sensitivity analyses presented in this addendum report. Brief descriptions of and the conclusions resulting from each analysis are presented in the following subsections.

2.1 ESTIMATED COSTS AND RADIATION DOSES AS A FUNCTION OF PLANT SIZE

It was originally planned that the sensitivity analysis presented in this report was to be developed by obtaining decommissioning information from enough reactors (e.g., AGNs, TRIGAs, and other common research reactor types), so that a reasonable number of data points could be provided for correlation with other reactors of the same genre. For example, although TRIGA reactors are identified in NUREG/CR-1756 as the most common type of research reactor in the United States, fewer than five have been decommissioned to date, and limited data are available on the decommissioning of only one. Therefore, until more data are available from decommissioning specific reactor types, it will be difficult to establish the effect of plant type on costs of decommissioning with any reasonable degree of confidence.

In addition, quantitative data sufficient to correlate radiation dose to reactor facility size and/or type in a meaningful way do not currently exist. On the positive side, the volumes of radwastes and decommissioning costs from five recent decommissioning projects are seen to exhibit some correlation with overall plant size. The five decommissioning case histories are listed in Table 2.1-1, together with the cost of DECON for each reactor, with the estimated total costs adjusted to 1981 dollars for comparison purposes. The data presented in the table suggest an apparent relationship between the cost of decommissioning and reactor power rating and between the volume of radwaste and reactor power rating, regardless of reactor type for the class of facilities studied, namely research and test reactors. It should be recognized that extrapolation of this relationship to power reactor decommissionings would be inappropriate and incorrect.

The total cost of decommissioning the selected nuclear nonpower facilities depends on several factors, including:

- the size of the facility, including all contaminated ancillary facilities
- facility design and construction

TABLE 2.1-1. Selected Reactor Case Histories Utilized for Evaluation Purposes in this Study Addendum

Docket No./ Facility (Acronym)	Reactor Type	Current Status	Base Year of Costs Used for This Study	Cost of DECON, $	Adjusted Costs (1981 Dollars)[a]
Diamond Ordnance Radiation Facility (DORF)[b]	Pool-Type	Dismantled	1979	336,000	398,436
Ames Laboratory Research Reactor (ALRR)[b]	Tank-Type - D_2O	Dismantled	1980	4,292,000	4,629,823
50-99/Lynchburg Pool Reactor (LPR)	Pool-Type	Dismantled	1982	86,000	77,637[c]
50-111/North Carolina State University Reactor-3 (NCSUR-3)	Pool-Type	Dismantling Order Issued 6-1-81	1981	33,000	33,000
50-106/Oregon State University (AGN-201, Serial 114)	Closed Vessel, Solid homogeneous Fuel	Dismantled	1980	10,000	10,914

(a) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(b) Non-licensed facility.
(c) Note that the LPR costs are de-escalated from 1982 to 1981 dollars for comparison purposes.

- the type of labor utilized, including extent of use of subcontractors

- operating practices during the lifetime of the facility.

It should be recognized that the sensitivity results presented in this addendum are subject to a large number of variables, each with wide ranges of values that can possibly impact, either singly or in combination, on costs and radiation exposure estimates for other nuclear R&T facilities. However, because the five actual decommissionings evaluated in this addendum represent recent historical data, the data are considered to be both realistic and current. The estimated cost and dose conclusions reported in NUREG/CR-1756 for the reference nuclear R&T reactor facilities fall within the ranges of costs and doses (where data were available) for these actual decommissionings and thus are reasonably well supported by the five case histories.

2.2 EFFECTS ON DECOMMISSIONING OF INTERIM INABILITY TO DISPOSE OF RADWASTES OFFSITE

Of the three alternative approaches to decommissioning (i.e., DECON, SAFSTOR, and ENTOMB), only SAFSTOR appears to be practical at the reference R&T reactors examined in NUREG/CR-1756 if onsite storage of low-level waste (LLW) is required. Both DECON and ENTOMB have characteristics that appear to make them generally unsuitable for the decommissioning of the reference R&T reactors with onsite waste storage.

The estimated cost impacts of onsite storage of decommissioning wastes (excluding irradiated fuel) during SAFSTOR at the reference R&T reactors are summarized in Tables 2.2-1 and 2.2-2, respectively.

As shown in Table 2.2-1, onsite storage of all LLW generated during preparations for safe storage of the reference research reactor in the adjusted case has virtually no effect on the total costs of all phases of SAFSTOR. Waste management costs remain virtually unchanged as a result of shredding, solidifying, and storing the combustible radioactive wastes that were shipped offsite in the base case (i.e., the combustible radioactive wastes as reported in NUREG/CR-1756). Therefore, it is concluded that there are no significant differences in total costs of all phases for SAFSTOR of the reference research reactor between the base case and the adjusted case presented in this analysis.

As shown in Table 2.2-2, onsite storage of all LLW generated during preparations for safe storage of the reference test reactor in the adjusted case is estimated to increase the total costs of all phases of SAFSTOR less than 3%. However, some of the waste management costs that would normally occur during preparations for safe storage are delayed until deferred decontamination.

TABLE 2.2-1. Estimated Costs of SAFSTOR at the Reference Research Reactor Facility as a Function of Onsite Radwaste Storage

Cost Category	Estimated Costs (Millions of 1981 Dollars)(a) Base Case from Reference 1	Adjusted Case for Onsite Radwaste Storage
Preparations for Safe Storage		
Staff Labor	0.419	0.419
Waste Management(b)	0.097	0.097
Other Costs	0.053	0.053
Totals, Preparations for Safe Storage	0.569	0.569
Safe Storage		
Annual Continuing Care Costs	0.033	0.033
Totals, 100 Years of Safe Storage	3.300	3.300
Deferred Decontamination		
Totals, Deferred Decontamination	0.716	0.726
TOTAL SAFSTOR COSTS (100-YEAR STORAGE)	4.585	4.595

(a) All costs presented include 25% contingency; the number of significant figures shown is for computational completeness.
(b) Includes $76,200 for irradiated fuel shipment to a U.S. government-owned storage facility and/or reprocessing plant.

TABLE 2.2-2. Estimated Costs of SAFSTOR at the Reference Test Reactor Facility as a Function of Onsite Radwaste Storage

Cost Category	Estimated Costs (Millions of 1981 Dollars)(a) Base Case from Reference 1	Adjusted Case for Onsite Radwaste Storage
Preparations for Safe Storage		
Staff Labor	3.870	3.870
Waste Management(b)	1.985	0.636
Other Costs	1.084	1.084
Totals, Preparations for Safe Storage	6.939	5.590
Safe Storage		
Annual Continuing Care Costs	0.120	0.122
Totals, 100 Years of Safe Storage	12.000	12.200
Deferred Decontamination		
Totals, Deferred Decontamination	8.5	10.404
TOTAL SAFSTOR COSTS (100-YEAR STORAGE)	27.439	28.194

(a) All costs presented include 25% contingency; the number of significant figures shown is for computational completeness.
(b) Includes $0.255 million for irradiated fuel shipment to U.S. government-owned reprocessing plant.

Summaries of the estimated safety impacts of SAFSTOR at the reference R&T reactors under normal (base case) circumstances and under the total onsite radioactive waste storage case (adjusted case) considered in this addendum are presented in Tables 2.2-3 and 2.2-4, respectively.

As shown in Table 2.2-3, occupational radiation doses at the reference research reactor under the adjusted case scenario are estimated to increase only slightly (about 1%), due primarily to the shredding and solidifying task postulated in the adjusted case.

As shown in Table 2.2-4, occupational radiation doses at the reference test reactor are estimated to be unaffected by onsite LLW storage. However, radiation doses to transport workers and the public from subsequent offsite waste shipments during deferred decontamination are anticipated to be reduced by about 97% by onsite LLW storage, due to radioactive decay during safe storage.

TABLE 2.2-3. Estimated Safety Impacts of SAFSTOR at the Reference Research Reactor as a Function of Onsite Waste Storage

Group - Activity	Estimated Radiation Dose (man-rem)[a] Base Case[b]	Adjusted Case[c]
Decommissioning Workers - Onsite Decommissioning Activities	13.91	14.11
Transportation Workers - Offsite Waste Shipments and Irradiated Fuel Shipments	0.16	0.09
Public - Offsite Waste Shipments and Irradiated Fuel Shipments	0.03	0.02

(a) In both cases, the estimated radiation doses include the sum of the doses for the preparations for safe storage, 100 years of continuing care, and the doses resulting from deferred decontamination.
(b) The base case is based on the analysis given in Appendix J.1 and Section 12 of Reference 1 where the irradiated fuel is shipped to a government repository, combustible radioactive wastes are shipped to a shallow-land burial site, and all other radioactive wastes remain onsite during the continuing care period.
(c) Only the fuel is shipped offsite to a government-owned facility in the adjusted case. The combustible radwastes are shredded and solidified and stored onsite, together with all other radioactive wastes.

TABLE 2.2-4. Estimated Safety Impacts of SAFSTOR at the Reference Test Reactor as a Function of Onsite Waste Storage

Group - Activity	Estimated Radiation Dose (man-rem)[a]	
	Base Case[b]	Adjusted Case[c]
Decommissioning Workers - Onsite Decommissioning Activities	113	113
Transportation Workers - Offsite Waste Shipments and Irradiated Fuel Shipments	12.27	0.27
Public - Offsite Waste Shipments and Irradiated Fuel Shipments	0.15	0.043

(a) In both cases, the estimated radiation doses include the sum of the doses for the preparations for safe storage, 100 years of continuing care, and the doses resulting from deferred decontamination.
(b) The base case is based on the analysis given in Appendix J.2 and Section 12 of Reference 1 where the irradiated fuel is shipped to a government reprocessing plant, combustible radioactive wastes are shipped to a shallow-land burial site, and all other radioactive wastes remain onsite during the continuing care period.
(c) Only the fuel is shipped offsite to a government-owned facility in the adjusted case. The combustible radwastes are incinerated and solidified and stored onsite, together with all other radioactive wastes.

2.3 SENSITIVITY OF DECOMMISSIONING COSTS TO RADIOACTIVE WASTE DISPOSAL CHARGES

The impact of increases in disposal charges at a shallow-land burial ground on the total cost of decommissioning the reference test reactor conceptually decommissioned in NUREG/CR-1756 is examined. It is concluded that a doubling of the burial ground charges would result in an increase of about 13.2% in the overall cost of DECON.

During the past 7 years the charge per unit volume for burial in a licensed burial ground has increased by 369%. It is likely that these disposal rates will continue to increase as operating costs increase and as projected decommissioning costs for burial grounds become better defined. Although the historical cost trend is sharply upwards, there is no clear-cut way to project what these costs will be in future years. In any case, it would seem prudent for R&T reactor owners/operators to track these cost increases carefully since disposal charges control what this fraction of the total cost of decommissioning will be.

2.4 DISPOSITION OF R&T REACTOR FUEL

The impact on decommissioning cost of the disposition of R&T reactor fuel is examined together with the relationship of nuclear fuel ownership (government or private) to the overall cost of decommissioning. It is concluded that since the majority (79%) of reactors are directly associated with an institution of higher learning--university, college, or institute--their reactor facilities do not generate income as do commercial power plants. Therefore, the majority of research reactor licensees must obtain funds to pay all of the costs associated with terminating the NRC license at the end of their facility's operating lifetime, including fuel disposal costs.

Regardless of who owns the fuel, subsequent offsite storage and/or reprocessing is handled by the U.S. Department of Energy (DOE). In general, the final destination of fuel from R&T reactors is determined by the cognizant DOE field office. The licensee, under certain conditions, may have the option to ship the fuel to a DOE site or to another licensee.

In general, the cost of fuel disposal hinges on fuel ownership. Thirty-five of 51 licensed university research or training reactors in the U.S. use enriched uranium fuel owned by DOE that is loaned to the universities with no charge for use, burnup, or reprocessing. While the universities can frequently borrow DOE-owned casks free of charge to transport this fuel after irradiation, they still must pay for the shipment of the fuel in almost all cases. On the other hand, licensees who own their fuel also can ship it to DOE fuel reprocessing sites but must bear all costs associated with fuel disposal, including cask rental and shipment of fuel.

In NUREG/CR-1756, the costs of fuel shipment are estimated to be about $61,000 and $204,000 for the reference research reactor and the reference test reactor, respectively. Were these costs to be included as decommissioning costs, they would represent about 8.3% and 1.6%, respectively, of the total costs (excluding contingency) of decommissioning the reference R&T reactors.

Other factors that could affect the costs of fuel disposal include cask availability, shipping distance, and the number of shipments. It is concluded that: 1) scheduling of casks for irradiated fuel shipment is currently necessary as much as 1 to 2 years in advance of actual use; and, 2) a research or test reactor licensee contemplating decommissioning would be well advised to contact DOE early in the planning and preparation phase to ascertain DOE's current disposal requirements for his type of fuel.

REFERENCES

1. G. J. Konzek, J. D. Ludwick, W. E. Kennedy, Jr., and R. I. Smith, Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, March 1982.

3.0 STUDY APPROACH

This addendum examines parameters identified as warranting additional study as a result of the analyses of decommissioning the reference nuclear research and test (R&T) reactors reported in NUREG/CR-1756.[1] The sensitivity to costs of these parameters--plant size and/or type, increased radwaste disposal charges and unavailability of waste disposal capacity, and fuel disposition--are explored. The detailed decommissioning analyses for the reference R&T reactors reported in NUREG/CR-1756, as well as analyses associated with the costs of other reactor decommissionings, provide the bases for these sensitivity analyses.

Brief descriptions of the aforementioned parameters and a discussion of the study approach used for these sensitivity analyses are contained in the following subsections.

3.1 TYPES OF REACTORS

The effect of plant size and/or type on costs and radiation exposure for decommissioning is examined. The parent document, NUREG/CR-1756, shows that there are differences in costs and occupational exposure for two reactor types--a research reactor and a test reactor--that are significantly different in size. In this addendum, data from selected recent reactor decommissionings are examined to quantify decommissioning costs for various plant sizes and types.

Simplified summary data sheets are used to incorporate the information obtained on the selected reactor decommissionings related to the following topics:

- Facility, reactor type and design, and operating history
- Decommissioning technology, including data on:
  - costs
  - occupational exposure
  - waste disposition, including packaging, transportation, and disposal site
  - fuel disposition
  - other (ALARA efforts, radionuclide inventories, scheduling, etc.).

Where reactor-specific information is likely to impact decommissioning planning for other reactors of a similar type, it is also reported.

3.2 DISPOSAL OF NUCLEAR WASTE

Disposal of nuclear waste from the decommissioning of nuclear R&T reactor facilities can be a significant cost item. The effects on decommissioning of interim inability to dispose of radwastes offsite for the reference R&T reactor facilities reported in NUREG/CR-1756 is examined as well as the impact on decommissioning costs of increases in disposal charges at commercial shallow-land burial grounds currently accepting radioactive wastes.

3.3 DISPOSITION OF R&T REACTOR FUEL

The impact on decommissioning cost of the disposition of R&T reactor fuel is examined. The relationship of nuclear fuel ownership (government and private) to the overall cost of decommissioning is examined.

3.4 TECHNICAL APPROACH

A methodology is developed to guide the assessment of the industry, government, and university data that are obtained for the selected areas of interest.

The study methodology, which is designed to provide direction for data gathering, proper use of the literature, and careful evaluation of information, is shown in Figure 3.4-1. The first step of the process is to acquire background material by consulting the literature. Coinciding with that task are contacts with various nuclear R&T reactor licensees (both current and former) as well as burial ground operators, state and Federal government officials, and other persons familiar with the subject areas of interest. A complete listing of these contacts is contained in Appendix B and is not repeated here.

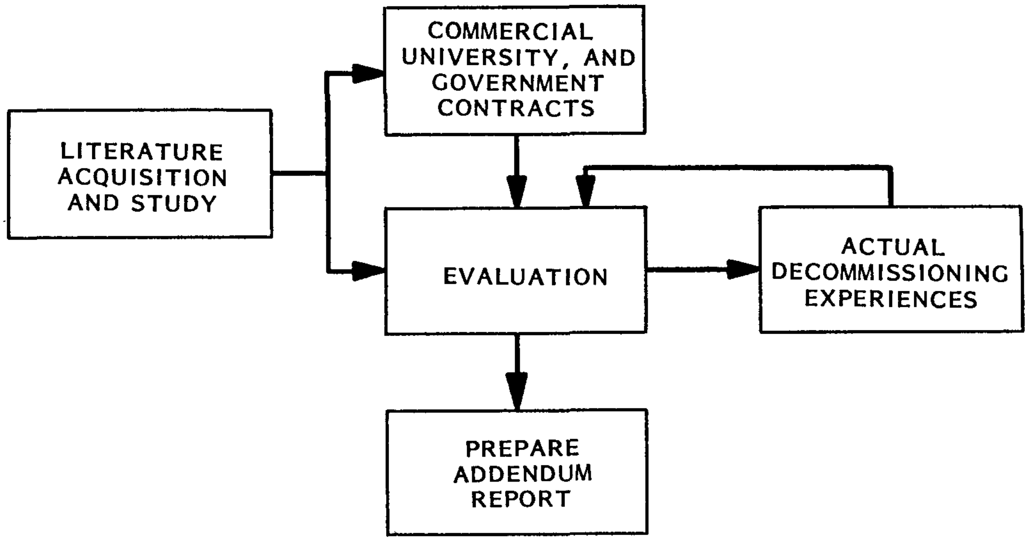

FIGURE 3.4-1. Addendum Study Methodology

REFERENCES

1. G. J. Konzek, J. D. Ludwick, W. E. Kennedy, Jr., and R. I. Smith, Technology, Safety, and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, March 1982.

4.0 SENSITIVITY OF DECOMMISSIONING COSTS AND OCCUPATIONAL RADIATION DOSE TO PHYSICAL PLANT SIZE AND REACTOR TYPE

The purpose of this investigation is to determine the effect on costs and occupational radiation exposure of plant size and/or type (i.e., a sensitivity analysis). It was originally planned that this sensitivity analysis be developed by obtaining sufficient decommissioning information on enough reactors (e.g., AGNs, TRIGAs, and other common research reactor types), so that a reasonable number of data points could be provided for correlation with other reactors of the same genre.

While a number of factors or parameters can be identified generically, many of the factors and work titles that are given in the literature are not standardized. Thus, attempts at grouping the data into separate and useable parameters for comparison are generally inconclusive. Many of the decommissioning reports do not provide cost and/or specific decommissioning activity information in the detail necessary for a sensitivity analysis.

Until more data are available from decommissioning specific reactor types, it will be difficult to establish the effect of plant type on costs of decommissioning with any reasonable degree of confidence. For example, although TRIGA reactors are identified in NUREG/CR-1756[1] as the most common type of research reactor in the U.S., fewer than five have been decommissioned to date, and limited data are available on the decommissioning of only one. In addition, quantitative data sufficient to correlate radiation dose to reactor facility size and/or type in a meaningful way is not currently available.

On the positive side, the volume of radwastes and decommissioning costs from decommissioning projects is seen to exhibit some correlation with overall plant size. Therefore, in this section an attempt is made to utilize these apparent relationships to perform a sensitivity analysis of obviously limited scope. For example, this analysis demonstrates the variations among different types and sizes of these facilities and the range of data for these facilities, but more importantly demonstrates that extrapolation and even interpolation of the data is not practical and can be misleading. As explained subsequently in Section 7, case-specific details must be carefully considered.

A discussion of background information, the technical approach used for the analysis, and the results of the analysis are presented in the following subsections.

4.1 BACKGROUND INFORMATION

All of the decommissioning case histories described in Appendix A relate to reactors either already dismantled or currently being dismantled. Therefore, any detailed discussion of the factors that led the owners to the original selection of which decommissioning alternative to use would be moot. However, for the owner/operator who must still make that decision, these numerous "up front" factors that could impact ultimately on total decommissioning cost constitute very useful pieces of information. Therefore, the factors influencing the selection of the decommissioning alternative are presented in Table 4.1-1. A discussion of these factors and a logical method for arriving at the optimum decommissioning decision can be found in Reference 2.

It should be recognized that many of the factors listed in the table are interrelated. In fact, changes in one or more of the factors could significantly impact the occupational radiation dose and costs of decommissioning R&T reactors. After careful examination of the decommissioning data provided by the case histories reviewed in Appendix A, the most significant factors affecting doses and costs of decommissioning were determined. These factors are tabulated in Table 4.1-2, together with additional considerations related to the parameters themselves.

Each reactor described in Appendix A was unique in its structure and experimental functions and so too was the approach used to decommission each reactor. Even for reactors of somewhat similar design (but different power level), the number of other parameters--operating lifetime, ancillary facilities, total integrated power, etc.,--make any direct comparisons difficult.

In the open literature associated with R&T reactor decommissionings, light water reactors (LWRs) are predominant as a class. The Ames reactor, utilizing D_2O, is illustrative of additional problems that must be considered when a facility-specific parameter is introduced (see Appendix A, Section A.2.2. for details).

For the case histories investigated, information was obtained on the total radwaste volumes but information was not available on itemized material quantities or lists of specific equipment; thus, a comparative analysis for unit components was not possible. In addition, it should be recognized that radwaste volumes are dependent on the decay period preceding dismantling, the types and sizes of radioactively contaminated ancillary facilities, and the decommissioning methods employed, including the decontamination requirements. The decontamination requirements and associated costs, in turn, depend on the radiation levels in the reactor facilities, the extent of decontamination, and the

TABLE 4.1-1. Factors Influencing Selection of Decommissioning Alternative[a]

Public Health and Safety

Radiation Exposure:
- Decommissioning Program
- Transportation
- Accident Consequences

Occupational Safety

- Radiation Exposure
- Personnel Safety
- Accident Analysis/Consequence

Environmental Impact

Site Dedication
Protected Storage Facility Form:
- Aesthetic Impact

Program Accomplishment Impact on:
- Financing
- Labor Force
- Housing/Schools
- Traffic
- Local Economy
- Use of Materials and Natural Resources

End-Product/Site Use:
- Interaction with Environment

End-Product/Facility Use:
- Interaction with Environment

Waste Type:
- Radioactive
- Non-radioactive

Waste Volumes
Repository Availability

Cost

Program Cost:
- Labor
- Materials
- Equipment
- Rentals
- Services
- Waste Containers
- Waste Transportation

Cost cont'd

Program Costs: (cont'd)
- Waste Burial/Disposal
- Taxes/Insurance
- Management

Protection Storage Costs:
- Duration of Period
- Facility Operation
- Security/Surveillance
- Environmental Monitoring
- Facility Maintenance
- Taxes/Insurance
- Management

Value of Site for Future Use:
- Unrestricted/Restricted

Value of Facility for Future Use:
- Unrestricted/Restricted

Availability of Funds:
- Financing Methods
- Regulatory Interaction

Other Influences

Regulations:
- Federal/State/Local

Ease/Complexity of Decommissioning Process

Compatability (of selected decommissioning alternative) with Intended Future Use of Site

Required Duration of Protected Storage Period

Availability of Management and Plant-Knowledgeable Personnel after Protected Storage Period.

Condition of Required Systems after Protected Storage Period

Distance to Waste Disposal Site(s)

(a) This data taken from Table 3.1 of Reference 2.

TABLE 4.1-2. Significant Factors Impacting Occupational Radiation Dose and Costs of Decommissioning Reactors

Significant Factor	Associated Considerations
Plant Design	• Plant-specific • Number and kind of ancillary structures/areas
Labor, Staff	• Length of decommissioning • Degree of staff involvement • Man-hour estimates • Salary Rates
Labor, Craft	• Local site labor rates • Man-hour estimates • Number of shifts
Decontamination Requirements	• Radiation levels • Extent of decontamination required • Extent and effectiveness of onsite radwaste treatment facilities • Need of temporary, radwaste treatment systems
Radwaste Volume	• Decommissioning alternative[a] • R&T reactor facility size, design, radiation levels, and number and kind of ancillary structures/areas • Dormancy period • Extent of decontamination • Cost for shipment and burial (depends on volume and distance from burial site)
Occupational Radiation Exposure	• Decommissioning alternative[a] • Radiation levels (depends on dormancy period prior to start and associated decay characteristics of significant radionuclides) • Requirements of tooling for remote operations Equipment and material (including shielding) requirements
Public Radiation Exposure	• Extent of environmental radiological monitoring program during decommissioning and/or during the safe storage period.

(a) See Table 4.1-1 for factors that influence the selection of the decommissioning alternative.

availability and the effectiveness of onsite facilities for the safe treatment and disposal of contaminants.

4.2 TECHNICAL APPROACH

Data from selected case histories of research reactor decommissionings are compared in Table 4.2-1. As can be seen in the table, the volume of radwastes from each of the decommissionings suggests a relationship to plant size exists for making comparisons between the various research facilities, irrespective of reactor type. Costs are adjusted to 1981 dollars in three major cost categories and summed in each case. The categories are: labor, radwaste volumes, and other (i.e., a grouping of the various cost segments remaining in each case).

Since fuel disposal costs are not accurately known for all the decommissionings, they are excluded for purposes of this analysis. However, since these costs can be significant, they should be considered carefully when estimating the total costs of decommissioning specific R&T reactor facilities (also see Section 6 for fuel disposal alternatives). For example, depending on the accounting procedure used, fuel ownership (as in the case of the LPR; see Appendix A, Section A.2.3.1 for details) can have a significant impact on the cost of decommissioning.

4.2.1 Labor Costs

The factors used in escalating/adjusting labor costs to 1981 dollars are derived from the average of building trades labor rates for six U.S. regions.[3] These data are listed in Table 4.2-2.

4.2.2 Radwaste Burial Costs

Burial site costs used in previous decommissioning studies in this series are based on actual charges at U.S. Ecology low-level waste burial grounds at Beatty, Nevada, and Richland, Washington. These costs correspond fairly well with charges at Chem-Nuclear's Barnwell, South Carolina, site. Recent cost increases, in dollars per cubic meter, for burial of low-level wastes (0-200 mr/hr) are given in Table 4.2-3. Adjustments associated with the packaging and transportation of the wastes are treated subsequently in this section as parts of the third major cost category--other--and are adjusted separately for each case history reviewed in Appendix A.

4.2.3 Other

The U.S. Department of Labor's Consumer Price Index (CPI)[4], presented in Table 4.2-4, is used to adjust the remaining cost segments in each case.

TABLE 4.2-1. Comparison of Data from Selected Case Histories of Research Reactor Decommissionings[(a)]

Reactor	Current Status	Thermal Power	Decommissioning Period	Decommissioned by	Radwaste Vol, m^3/Wt,Mg/Activity,Ci	Occupational Radiation Dose, man-rem	Costs of Decommissioning[(b)] (year(s) of Costs)
DORF	Dismantled	250 kW intermittent	Sept, '79 - Feb '80	U.S. Army & Subcontractors	~33/27.4/1.17 x 10^{-4}	<2	336,000 (1979 - 80)
ALRR	Dismantled	5 MW	Jan '78 - Sept '81	DOE & Sub-contractors	~1157/1224/6,881	69.4	4,292,000 (1979 - 81)
LPR	Dismantled	200 kW nat. Convection 1 MW forced convection	Apr '81 - Mar '82[(c)]	B&W (owner)	~20/~14/<1	<0.1	86,000 (1981 - 82)
NCSUR-3	Undergoing Dismantling[(d)]	10 kW	1973 - Present[(e)]	Faculty, student labor & subcontractor	~10/~1.5/Unknown	<1 (estimated to date)	~33,000 (to date)
OSU/AGN-201	Dismantled	0.1w	June 10 to 20, 1980	OSU Staff & Plant Services	<0.3/Negligible/Unknown	Negligible	~10,000[(f)] (1980)

(a) The data presented in this table are derived from the specific case histories presented in Appendix A of this addendum.
(b) Does not include costs of fuel disposal.
(c) The effort to dismantle the LPR facility took approximately 12-months. The paperwork to allow the dismantling to proceed took 9-months and the actual dismantling took 5-months (shipment of fuel early November to dismantling completion end of March).
(d) Dismantling Order Issued 6-1-81.
(e) The extended decommissioning period is the result of the licensee's plan to minimize costs while assuring public safety. The decommissioning tasks to date have been safely accomplished in discrete stages by the university staff, together with paid student labor. One of the end product tasks, a fixed price bid for concrete demolition, is expected to be awarded to a contractor in mid-1982.
(f) The fuel remains onsite in secured storage.

TABLE 4.2-2. Escalation Factors for Labor Costs

Year[a]	Index Value[b]	Index Ratio	Escalation Factor
1975	677	1044/677	1.54
1976	737	1044/737	1.42
1977	784	1044/784	1.33
1978	839	1044/839	1.25
1979	889	1044/889	1.17
1980	943	1044/943	1.11
1981	1044	1044/1044	1.0
1982	1164	1044/1164	0.9[c]

(a) As of January 1 of each year.
(b) Composite average building trades labor index for six U.S. regions; based on Reference 3.
(c) Only applicable to the de-escalation of the LPR costs from 1982 to 1981 dollars.

TABLE 4.2-3. Escalation Factors for Commercial Shallow-Land Burial of Radwastes

Year	Index Value ($/m^3)	Index Ratio	Escalation Factor
1975	88	307/88	3.49
Sept. 1, 1977	94	307/94	3.27
June 1, 1978	168	307/168	1.83
Oct. 1, 1979	203	307/203	1.51
Mar. 1, 1980	274	307/274	1.12
Nov. 17, 1980	307	307/307	1.0
Jan. 15, 1982	413	307/413	0.74[a]

(a) Only applicable to the de-escalation of the LPR costs from 1982 to 1981 dollars.

TABLE 4.2-4. Escalation Factors for the Third Major Cost Category--Other

Year[(a)]	Index Value[(b)]	Index Ratio	Escalation Factor
1975	161.2	261/161.2	1.62
1976	170.5	261/170.5	1.53
1977	181.5	261/181.5	1.44
1978	195.3	261/195.3	1.37
1979	217.7	261/217.7	1.20
1980	247.0	261/247.0	1.06
1981	261	261/261	1.0
1982	282	261/282	0.93[(c)]

(a) As of January 1 of each year; U.S. Dept. of Labor Consumer Price Index (CPI); based on Reference 4.
(b) CPI - 1967 = 100; CPI given is for all items.
(c) Only applicable to the de-escalation of the LPR costs from 1982 to 1981 dollars.

4.3 SENSITIVITY ANALYSIS

The percentages for the cost categories of labor, radwaste volume, and other (i.e., a grouping of the various cost segments remaining from each of the case history decommissionings) are presented in Table 4.3-1. In all cases the data are derived from either the information reviewed in Appendix A or the referenced documents associated with the decommissionings. As can be seen in the table, decommissioning is a labor intensive activity.

From the escalation factors presented in Tables 4.2-2, -3, and -4 for labor, radwaste volumes, and other, respectively, the range of total costs (in 1981 dollars) of decommissioning the research reactor case histories reviewed in Appendix A, is presented in Table 4.3-2. The costs in each case are

TABLE 4.3-1. Percentages Breakdown of the Three Major Cost Categories for the Five Case History Decommissionings Reviewed in this Addendum

Reactor	Base Year of Costs Used for This Study	Percentage of Total Costs			Percent Total	Cost of Decom, $
		Labor	Radwastes	Other		
DORF	1979	43	1.6	55.4	100.0	336,000
ALRR	1980	42.1	3.9	54	100.0	4,292,000
LPR	1982	46.5	7	46.5	100.0	86,000
NCSUR-3	1981	28[b]	9.4	62.6	100.0	33,000
OSU/AGN-201	1980	64	1	35	100.0	10,000

(a) For purposes of establishing the above percentages, costs are based on the costs of decommissioning given in Table 4.2-1.
(b) This lower-than-normal percentage of total costs reflects the use of student labor (see Appendix A.2.4 for details).

TABLE 4.3-2. Summary of Estimated Total Costs of the Five Case History Decommissionings, Adjusted to 1981 Dollars

Reactor	Base Year Used for Costs Incurred	Adjusted Costs (1981 Dollars)			Estimated Total Costs (1981 Dollars)
		Labor	Radwastes	Other	
DORF	1979	169,042	6,021	223,373	398,436
ALRR	1980	2,005,695	167,388	2,456,741	4,629,823
LPR	1982	35,991	4,455	37,191	77,637
NCSUR-3	1981	9,240	3,102	20,658	33,000
OSU/AGN-201	1980	7,104	100	3,710	10,914

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

adjusted to 1981 dollars using the following equation:

$$(X) \left\{[(L)\ (L_a)] + [(R)\ (R_a)] + [(O)\ (O_a)]\right\} = \text{Adjusted Total Cost (1981 Dollars)}$$

where:

L = the labor costs as a percent of the total decommissioning costs

R = the radwastes burial costs as a percent of the total decommissioning cost

O = all other costs as a percent of the total decommissioning cost

X = total decommissioning cost (in dollars of the year that the costs were incurred)

L_a = a factor utilized to adjust labor costs from the year incurred to 1981 dollars

R_a = a factor utilized to adjust radwastes burial costs from the year incurred to 1981 dollars

O_a = a factor utilized to adjust all other costs from the year incurred to 1981 dollars.

The data presented in Table 4.3-2 suggest an apparent relationship between the cost of decommissioning and reactor power rating and between the resultant volume of radwastes and reactor power rating, regardless of reactor type for the research reactors studied.

The total costs of decommissioning the selected nuclear nonpower facilities depend on several factors, including:

- the size of the facility, including all contaminated ancillary facilities
- facility design and construction
- the type of labor utilized, including extent of use of subcontractors
- operating practices during the lifetime of the facility.

It is interesting to note that by utilizing the methodology developed in Section 13 of NUREG/CR-1756, the average unit component cost of decommissioning a hot cell in the reference test reactor (i.e., the PBRF) was estimated to be about $114,300. This estimated cost compares quite well with the $118,500 actual cost of decommissioning the single hot cell at the ALRR (see Appendix A, Table A.2-13).

It should be recognized that the sensitivity results presented in this section are subject to a large number of variables, each with wide ranges of values, that can possibly impact, either singly or in combination, on costs and radiation exposure estimates for other, nuclear R&T facilities. Due to the many variables indicated, the relationship discussed above is not necessarily considered to be a fixed relationship; however, it does illustrate the approximate magnitude of the variations among these types of facilities. It should be recognized: 1) that care should be taken in employing this relationship that case-specific details are considered and 2) that extrapolation of the relationship to power reactors would be inappropriate and incorrect. Because the five decommissionings evaluated in this section represent recent historical data, the data are considered to be both realistic and current. The estimated cost and dose conclusions reported in NUREG/CR-1756 for the reference nuclear R&T reactor facilities are reasonably well supported by results from the five case histories.

REFERENCES

1. G. J. Konzek, J. D. Ludwick, W. E. Kennedy, Jr., and R. I. Smith, Technology, Safety, and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, March 1982.

2. W. J. Manion and T. S. LaGuardia, Decommissioning Handbook, DOE/EV/10128-1, Prepared by Nuclear Energy Services for U.S. Department of Energy, November 1980.

3. Handy-Whitman Index of Public Utility Construction Costs, to January 1, 1982, Bulletin No. 115, Whitman, Requart and Associates, Baltimore, Maryland, 21218.

4. Bureau of Labor Statistics, U.S. Department of Labor, 1982.

5.0 EFFECTS ON DECOMMISSIONING OF INTERIM INABILITY TO DISPOSE OF RADWASTES OFFSITE AND SENSITIVITY OF DECOMMISSIONING COSTS TO RADIOACTIVE WASTE DISPOSAL CHARGES

In the previous analyses of decommissioning the reference NRC-licensed nuclear research and test (R&T) reactor facilities, as reported in the parent document (NUREG/CR-1756),[1] it was assumed that the radioactive waste materials (including irradiated reactor fuel) resulting from decommissioning could be permanently disposed of offsite at the time of decommissioning. Consideration should also be given to the possibility that offsite disposal of the radwastes may not be possible at the time of decommissioning. Such consideration does not have to be extended to the irradiated fuel from the reference nuclear R&T reactors since, in both cases, the fuel is owned by the Federal government. Therefore, either offsite irradiated fuel storage and/or fuel reprocessing capabilities are anticipated to continue to be available for fuels from R&T reactors into the foreseeable future. The disposal of the radwastes is a separate and distinct matter, however, and it was determined that the analyses of decommissioning the reference R&T reactors need be extended to include the impacts of an inability to dispose of decommissioning radwastes offsite at the time the reference R&T reactor decommissionings take place.

Interstate compacts entered into by states pursuant to the Low-Level Radioactive Waste Policy Act (Public Law 96-573) of 1980 would tend to alleviate problems of lack of burial site availability, especially for facilities decommissioned past 1986. In that Act, Congress declared as the policy of the Federal government that each state be responsible for providing for storage capacity for disposing of low-level radioactive waste generated within its borders. This capacity may exist either within or outside the state. Nevertheless, the analysis presented in this addendum was prepared to consider what impacts there could be on decommissioning the reference nuclear R&T reactor facilities if radwastes must be stored onsite due either to inability to dispose of them offsite or to onsite storage during SAFSTOR. For example purposes only, the period of onsite storage chosen for these analyses is 100 years. This period was chosen to estimate the bounds on impacts; it is not suggested as a recommended storage time. Although 30 years appears optimum for the reference nuclear R&T reactor facilities reported in Reference 1, for some other R&T reactors, shorter time periods may be used, perhaps as short as 5 years.

Costs are derived in 1981 dollars, based on the original data,[1] to provide a basis for comparison with later reports in this decommissioning series.

The study approach for examining the inability to dispose of radwastes offsite for the reference R&T reactors reported in NUREG/CR-1756 is presented in Section 5.1. The study analyses of these effects on decommissioning is presented in Section 5.2. The impact of increased disposal costs on the total cost of decommissioning for the radwastes removed from the reference test reactor during DECON, as developed in NUREG/CR-1756, is examined in Section 5.3. Since another purpose of this addendum is to increase the general applicability of NUREG/CR-1756 to owners/operators of various other types of nuclear R&T reactors, supplemental information that could impact on the cost of disposal is presented in Section 5.4.

5.1 STUDY APPROACH FOR EXAMINING THE EFFECTS ON DECOMMISSIONING OF INTERIM INABILITY TO DISPOSE OF RADWASTES OFFSITE

It is possible that, in the future, offsite disposal of radioactive wastes (radwastes) from NRC-licensed R&T reactors may not be continually available. These constraints would apply not only to radwastes generated during operation of the reference R&T reactors, but also to wastes resulting from decommissioning following the operational lifetimes of these facilities.

A basic assumption in the previous analyses of decommissioning the reference R&T reactor facilities[(1)] was all radioactive waste materials resulting from the decommissioning processes could be disposed of offsite at the time of decommissioning. In each case, if offsite waste disposal were not available, the technology, safety, and costs of decommissioning would be altered, most likely resulting in selection of a different preferred alternative for completing the decommissioning.

In this addendum, the impacts on the decommissioning of the reference R&T reactor facilities are examined for the single case predicated on the inability to dispose of the decommissioning radwastes offsite. For both reference reactors, a maximum onsite waste storage period of 100 years is assumed.

5.1.1 Decommissioning Alternatives

The three alternative approaches to decommissioning, discussed at some length in the parent document,[(1)] are summarized as follows:

- DECON - The immediate removal from the facility of all material with residual radioactivity levels greater than those permitted for unrestricted use of the property.
- SAFSTOR - Activities designed to place (preparations for safe storage) and maintain (safe storage) a radioactive facility in such a condition that the risk to public safety is within acceptable bounds. At the conclusion of the safe storage period, the facility

must be decontaminated to levels that permit its release for unrestricted use (deferred decontamination).

- ENTOMB - Cleanup and decontamination to a lesser extent than for DECON is coupled with the confinement of the remaining contaminated components in a strong and structurally long-lived material to assure retention until the radioactivity decays to levels that permit unrestricted release of the property.

The applicability of each of the alternative approaches to decommissioning the reference R&T reactors is affected by constraints on the offsite disposal of decommissioning wastes. In this addendum, analyses are performed only for the decommissioning alternatives that appear to be practical under the previously specified onsite waste storage case, as shown in Table 5.1-1 and discussed in the following subsections.

TABLE 5.1-1. Practical Decommissioning Alternatives with Onsite Radwaste Storage

Decommissioning Alternative	Reference Reactor Facility	
	Research	Test
DECON	Partial DECON may be practical[a]	Partial DECON may be practical[a]
SAFSTOR	Practical	Practical
ENTOMB	Not Practical	Not Practical

(a) Not analyzed in this addendum; see text (Section 5.1.1.1).

5.1.1.1 DECON

DECON implies the prompt removal of all decommissioning radwastes from the site to allow unrestricted release of the property. Onsite storage of the decommissioning radwastes would prevent release of the site until the radwastes are subsequently removed to an offsite disposal facility. Therefore, DECON appears to be generally inconsistent with onsite storage of decommissioning radwastes.

A form of partial DECON may be practical if only low-level waste (LLW) must be stored onsite. In this case, R&T facilities structures would be decontaminated to release levels, and the resulting wastes would be packaged and stored inside one of the buildings. This may be desirable if the availability of offsite LLW disposal is likely to be restored in a short time (i.e., less than about 5 years) because the waste could then be shipped offsite and the site released for unrestricted use in the shortest possible time. However, if early release of the site is not of paramount importance, SAFSTOR (as discussed in the following subsection) is the more logical choice because of reduced occupational radiation doses resulting from radioactive decay and because of reduced initial costs. Partial DECON with short-term onsite storage of LLW would result in very nearly the same costs and safety impacts as DECON with prompt offsite waste disposal, as presented in the reference study,[1] and, therefore, this alternative is not analyzed further in this addendum for either of the reference R&T reactor facilities.

5.1.1.2 SAFSTOR

SAFSTOR appears to be the practical decommissioning alternative for the specified onsite waste storage case for both of the reference R&T reactors. Initial decommissioning activities are minimized, resulting in relatively little waste being generated during preparations for safe storage. Furthermore, the radioactive contamination present in both of the reference R&T reactor facilities is reduced by radioactive decay during safe storage, thus reducing the amount of waste to eventually be removed. As stipulated previously, the irradiated fuel is anticipated to either be stored or reprocessed at a government-owned facility. Therefore, the decommissioning tasks at each of the reference R&T reactors associated with their respective spent fuel storage pool and its associated systems and services remain unchanged from the descriptions given in the parent document.[1]

It is assumed in these analyses that both of the reference R&T reactor facilities are kept in safe storage at least until offsite disposal capacity becomes available. For purposes of these analyses, an onsite storage period of 100 years is assumed for both of the reference R&T reactor facilities.

5.1.1.3 ENTOMB

ENTOMB is one of the alternatives considered in the parent document[1] for the decommissioning of the reference R&T reactors. ENTOMB, as defined by the Nuclear Regulatory Commission (NRC), implies that the radioactivity contained within the entombment structure will decay sufficiently during a 100-year entombment period to permit unrestricted release of the property at the end of that time. This requirement necessitates the removal and disposal elsewhere of materials containing long-lived radionuclides. Thus, it was postulated that the highly activated core internals of the reference R&T reactors were removed, but slightly activated materials were enclosed within the entombment structure. However, for the purposes of this addendum, it was postulated that no LLW disposal site is available at the time of the reference R&T reactor decommissionings. Predicated on this presumed inability to dispose of the reactor internals, the selection of ENTOMB as a decommissioning alternative for either of the reference R&T reactors is no longer viable.

For the cases under consideration, the entombment structures must be dismantled after 100 years when the reference R&T reactor internals are left in place, thus negating the principal benefits of ENTOMB. A comparison of the occupational radiation doses from the three decommissioning alternatives analyzed for the reference R&T reactors is given in Table 5.1-2. As shown in the table, there are reductions in radiation doses associated with choosing alternatives other than ENTOMB in all cases except DECON at the reference research reactor (for which case the difference is only about 10%).

TABLE 5.1-2. A Comparison of Occupational Radiation Doses (in man-rem) from the Alternatives for Decommissioning the Reference R&T Reactors Relative to ENTOMB[a,b]

Decommissioning Alternative	Reference Reactor Facility	
	Research	Test
DECON	18.62	344
SAFSTOR	13.91	125
ENTOMB	16.71	444

(a) Man-rem data presented in this table are based on Tables 2.14-1 and 2.14-2 of Reference 1 for the reference research and test reactors, respectively.
(b) Doses include those to decommissioning and transportation workers.

5.1.2 Technical Approach

To determine the effects of the onsite waste storage case on the decommissioning of the reference nuclear R&T reactor facilities, the following analyses are performed in this addendum:

1. Major changes in SAFSTOR activities and requirements from the base study[1] are identified and discussed, to provide a basis for quantification of the impacts.

2. The postulated treatment and storage conditions for the wastes to be retained onsite are outlined.

3. The cost and safety impacts are estimated for the case of the onsite storage of LLW.

The analyses presented in this addendum are based primarily on information developed in the reference study.[1]

5.2 STUDY ANALYSES OF THE EFFECTS ON DECOMMISSIONING OF INTERIM INABILITY TO DISPOSE OF RADWASTES OFFSITE

The analyses of the effects of the unavailability of offsite disposal for decommissioning radwastes at the time of decommissioning of the reference R&T reactors are presented in this section. As discussed previously, the only decommissioning alternative discussed in these analyses for the reference R&T reactors is SAFSTOR. Only the case of LLW stored onsite, with offsite disposal of irradiated fuel disposal available, is considered for each reactor. For these analyses, it is assumed that stored wastes remain onsite for a period of 100 years, after which they are shipped offsite for permanent disposal. Offsite disposal capacity is assumed to be reestablished prior to the time of deferred decontamination.

The first half of this section is concerned with the reference research reactor, while the last half is concerned with the reference test reactor. The format followed for both reactors is the same. The changes from normal SAFSTOR at the reference reactors that result from onsite waste storage are discussed first, together with the treatment and storage of the wastes that are to remain onsite. The resulting cost impacts on the decommissioning are presented second, and the safety impacts are described last.

5.2.1 Decommissioning Analysis for the Reference Research Reactor Facility

The potential need for onsite storage of decommissioning wastes is anticipated to result in changes in the requirements for carrying out SAFSTOR at the reference research reactor. The changes, the resulting cost impacts on the decommissioning, and the safety impacts are discussed in the following subsections.

5.2.1.1 Changes from Normal SAFSTOR at the Reference Research Reactor Facility

In the SAFSTOR alternative, a minimum of decommissioning effort is expended following reactor shutdown to ensure that risk to public safety is within acceptable bounds during the safe storage period. Normally, the reactor is defueled and the irradiated fuel shipped offsite for storage or reprocessing, dispersible contamination in the facility is removed, the remaining contamination is fixed and sealed in place, facility systems and services are deactivated, and the facility is secured to ensure the containment of residual radioactive contamination and the security of the facility during the safe storage period. The bulk of the radioactive material in the facility remains in place until deferred decontamination following the safe storage period. Relatively little LLW is shipped offsite during the initial phase (preparations for safe storage) of SAFSTOR and, therefore, only relatively minor changes are needed to accommodate onsite storage of the LLW resulting from preparations for safe storage.

In the parent document,[1] only combustible radioactive wastes (about 10.4 m^3) were postulated to be disposed of at a shallow-land burial ground during normal SAFSTOR (hereinafter called the "base case") at the reference research reactor. These dry solid wastes include discarded contaminated materials such as plastic sheeting, rags, and anticontamination clothing, and are assumed in the base case to be compacted to reduce their volume prior to offsite shipment. It is assumed for this analysis (hereinafter called the "adjusted case") that the dry solid wastes must be shredded and solidified in concrete prior to onsite storage. Because offsite LLW disposal capacity is as likely to be unavailable during reactor operations prior to decommissioning as during decommissioning, it is assumed that the necessary mechanical equipment to process the radwastes is available onsite prior to decommissioning to process combustible wastes generated during operation of the facility. For purposes of this analysis, it is judged that the original compacted waste volume is increased by a factor of two as a result of the shredding/solidifying process described previously. Thus, about 21 m^3 of concreted radwastes are anticipated to require onsite storage at the reference research reactor facility during safe storage for the adjusted case.

Manpower requirements for treating the waste and placing it in storage onsite are judged to be about the same for both cases. Adequate space suitable for waste storage within the reference facility is anticipated to be readily available (e.g., within the pool irradiation facility cavity and/or at a designated area of the Reactor Building).

No significant additional changes to the requirements for normal preparations for safe storage at the reference research reactor are anticipated to be needed to accommodate onsite storage of LLW for the adjusted case. The onsite storage of LLW has no significant effect on activities during the safe storage period. The only changes during the deferred decontamination of the reference research reactor following safe storage are that the packaged LLW has to be removed and shipped offsite for disposal at that time and the shredder/

solidifying equipment has to be decommissioned. However, these activities are anticipated to have only minor impact on the deferred decontamination of the facility.

Surveillance, maintenance, and monitoring activities during the safe storage period are anticipated to remain essentially unchanged from those analyzed in the base case (see Section J.1 of Reference 1 for details).

During the deferred decontamination of the reference research reactor facility, the deferred decontamination activities are the same as those described in Section J.1 of Reference 1. The LLW from preparations for safe storage is shipped offsite, the shredder/concreting equipment is disassembled and packaged for subsequent shipment, the associated systems and services are decommissioned, and the deferred decontamination then proceeds in the same manner as if the radwastes had been shipped offsite during preparations for safe storage. Therefore, the requirements for deferred decontamination are not anticipated to be significantly different than those described in Reference 1 for the reference research reactor facility.

5.2.1.2 Cost Impacts of Onsite Radwaste Storage During SAFSTOR at the Reference Research Reactor Facility

A summary of the costs of SAFSTOR at the reference research reactor facility under normal circumstances (base case) compared to the costs of SAFSTOR under the onsite radwaste storage (adjusted case) considered in this addendum is presented in Table 5.2-1. All costs are reported in constant 1981 dollars. The costs of SAFSTOR at the reference research reactor facility are based on data presented in Section 11 and Appendix J of Reference 1. The derivation of the costs for the onsite radwaste storage case (the adjusted case) is described in the following paragraphs.

In the base case SAFSTOR analysis[1] for the reference research reactor, it was postulated that only the combustible radwastes were shipped to a shallow-land burial ground. All other contaminated materials were stored onsite, within the pool irradiation facility cavity or at a designated area of the Reactor Building. The packing and storage of these materials are included in the cost of an additional task, Task 20, in Figure J.1-1 of Reference 1.

Waste management costs remain virtually unchanged during the preparations for safe storage for the adjusted case. The reason for this is that the packaging (boxes), transportation, and burial costs in the base case are offset almost exactly by the costs of drums and solidifying agents for the adjusted

TABLE 5.2-1. Estimated Costs of SAFSTOR at the Reference Research Reactor Facility as a Function of Onsite Radwaste Storage

Cost Category	Estimated Costs (Millions of 1981 Dollars)[a] Base Case From Reference 1	Adjusted Case for Onsite Radwaste Storage
Preparations for Safe Storage		
Staff Labor	0.419	0.419
Waste Management[b]	0.097	0.097
Other Costs	0.053	0.053
Totals, Preparations for Safe Storage	0.569	0.569
Safe Storage		
Annual Continuing Care Costs	0.033	0.033
Totals, 100 Years of Safe Storage	3.300	3.300
Deferred Decontamination		
Totals, Deferred Decontamination	0.716[c]	0.726[d]
Total SAFSTOR Costs (100-Year Storage)	4.585	4.595

(a) All costs presented include 25% contingency, while the number of significant figures shown is for computational completeness.
(b) Includes $76,200 for irradiated fuel shipment to a government-owned storage facility and/or reprocessing plant.
(c) From Table J.1-15 of Reference 1.
(d) From Table 5.2-4.

case, as shown in Table 5.2-2. Operation and maintenance of the shredder/solidifying equipment during preparations for safe storage are assumed to be carried out by decommissioning staff on an as-needed basis, and no significant additional staffing requirement is anticipated.

Onsite storage of the solidified LLW during the safe storage period does not result in any significant changes in the required continuing care activities. Therefore, the costs for the safe storage period are judged to be the same as the costs for the same period given in Table 11.1-5 of Reference 1.

TABLE 5.2-2. Comparison of Waste Management Costs Between the Base Case Preparations for Safe Storage and the Adjusted Case Preparations for Safe Storage at the Reference Research Reactor

Waste Management Cost Category	Estimated Costs (1981 Dollars)[a] Base Case	Adjusted Case
Fuel Disposal	76,200	76,200
Combustible Radwastes	6,913[b]	6,500[c]
Storage of Radioactive Materials and Contaminated Wastes	14,000	14,000
Total	$97,113	$96,700

(a) All costs presented include 25% contingency, while the number of significant figures shown is for computational completeness.
(b) Data from Table J.1-7 of Reference 1.
(c) Cost breakdown includes: 100 drums @ $30/drum plus about $2,200 for solidifying agents plus the 25% contingency, for a total of $6,500.

During deferred decontamination with all of the LLW stored onsite, it is assumed that staff labor requirements are very similar for each remaining deferred decontamination task as it is for DECON (see Table I.1-3 of Reference 1), except for reductions in decommissioning workers as a result of lower radiation doses for each task. Some reduction in radioactive waste volumes and in the absolute radionuclide quantities are also expected with time due to radioactive decay.

No credit is taken for decay of the solidified radwastes (100 drums) estimated in the adjusted case. Conservatively, the entire 100 drums are transported to a shallow-land burial site during deferred decontamination for the adjusted case. The estimated cost of offsite disposal for those materials is given in Table 5.2-3. As shown in the table, these costs amount to about $9,210 in 1981 dollars, or about $11,510 including the 25% contingency.

A summary of estimated costs for decontamination and dismantlement of the reference research reactor from its safe storage posture for the base case and for the adjusted case after 100 years is given in Table 5.2-4. As a comparison, the costs of DECON, taken from Table I.1-6 of Reference 1, are included.

TABLE 5.2-3. Estimated Costs of Disposal for Solidified Radwastes During Deferred Decontamination of the Reference Research Reactor for the Adjusted Case[a]

Component	Number of Disposable Containers[b]	Number of Shipments	Transportation Costs ($)[c]	Burial Volume (m^3)	Burial Costs ($)[d]	Total Disposal Costs ($)[e]
Solidified Radwastes	100	2	2530	21	6680	9210

(a) All costs are in 1981 dollars.
(b) Based on standard 0.21-m^3 steel drums used for solidifying combustible radwastes during the preparations for safe storage of the reference research reactor.
(c) Based on Table M.4-4 of Reference 1 for two overweight shipments.
(d) Based on Table M.5-1 of Reference 1; surface dose rates assumed to be <0.2 R/hr for all containers; rounded to the next highest $10.
(e) The number of figures shown is for computational accuracy only and does not imply precision to that many significant figures.

TABLE 5.2-4. Comparison of Estimated Deferred Decontamination Costs Between the Base Case and the Adjusted Case for the Reference Research Reactor

Cost Category	Estimated Costs ($ thousands)		
		Decontamination Deferred 100 Years	
	DECON[a]	Base Case[b]	Adjusted Case
Disposal of Radioactive Materials			
Neutron-Activated Materials	16.61	8.79	8.79
Contaminated Materials	60.06	10.64	10.64
Radioactive Wastes	9.62	1.20	9.21[c]
Staff Labor	530.57	516.73	516.73
Energy	13.79	13.50	13.50
Special Tools and Equipment	21.15	4.28	4.28
Miscellaneous Supplies	6.21	5.15	5.15
Nuclear Insurance	4.62	0.64	0.64
License Fees	13.95	12.00	12.00
Subtotal	676.58	572.93	580.94
Contingency (25%)	169.15	143.23	145.24
Totals	845.73	716.16	726.18

(a) From Table I.1-6 of Reference 1.
(b) From Table J.1-15 of Reference 1.
(c) From Table 5.2-3.

Small cost reductions with time are apparent due to:

- radionuclide quantity reductions discussed in this section
- decommissioning worker reductions discussed in this section
- energy reductions due to increased work efficiencies at lower dose rates
- reduced remote control tool requirements.
- reduced supply requirements as tool requirements are eliminated
- reduced insurance as the potential radioactive hazard diminishes.

Additional cost during deferred decontamination other than for waste management is judged to be negligible. The total additional cost during deferred decontamination of the reference research reactor with onsite storage of the solidified radwastes is estimaed to be about $10,000, bringing the total cost for the deferred decontamination in the adjusted case to about $726,000. Thus, the total estimated cost for all phases of SAFSTOR at the reference research reactor in the adjusted case is about the same as for the base case--about $4.6 million (see Table 5.2-1). Therefore, financing considerations for decommissioning are not affected.

5.2.1.3 Safety Impacts of Additional Onsite Waste Storage During SAFSTOR at the Reference Research Reactor

The safety impacts considered in the analyses of decommissioning the reference research reactor presented in Reference 1 include occupational and public safety impacts from both onsite (decommissioning) and offsite (combustible waste and irradiated fuel transportation) activities. Because impacts to the public from onsite activities are estimated in Reference 1 to be extremely small, and because these impacts are not considered to be significantly influenced by the addition of the solidified radwastes being stored onsite, public safety impacts from onsite activities are not considered further in this analysis. Furthermore, nonradiological safety impacts from decommissioning activities are also not considered in this analysis. Therefore, the safety impacts considered are as follows:

- occupational radiation doses to workers performing onsite decommissioning activities
- occupational radiation doses to transportation workers during the offsite shipment of wastes and irradiated fuel
- radiation doses to members of the public resulting from the offsite shipment of wastes and irradiated fuel.

Irradiated fuel from the reference research reactor is assumed to be shipped by truck (2 shipments) to a government-owned facility located 800 km away (see Section 1.1.3.7 of Reference 1). The cumulative radiation doses for transportation workers and the general public for these shipments were not included in the parent document[1] because they are exceedingly small. However, they are included in this addendum for completeness. The method used to estimate routine radiation doses to transportation workers and to members of the general public from these shipments is based on the methods given in References 2 and 3, with the results summarized in Table 5.2-5. Radiation doses received by workers unloading the radioactive materials at the government facility are not considered in this addendum.

A summary of the estimated safety impacts of SAFSTOR at the reference research reactor under normal (base case) circumstances and under the total

TABLE 5.2-5. Estimated Radiation Doses from Truck Transport of Irradiated Fuel at the Reference Research Reactor[a,b]

Group	Exposure Time per 800 km of Transportation (hr)	Exposure Rate per Shipment (millirem/hr)	Number of People Involved per Shipment	Dose Per Shipment per 800 km (man-rem)
Drivers				
Operation	10	2	2	0.04
Cargo Inspection	0.5	50	2	0.05
Garagemen	0.075	2	2	0.0003
Onlookers	0.025	50	10	0.013
Population			330,000	0.009
				0.11
Subtotal				x 2 shipments
Total (man-rem)				0.22

(a) Not transshipped.
(b) Calculations are based on information given in References 2 and 3.

onsite radioactive waste storage case (adjusted case) considered in this study is presented in Table 5.2-6. As shown in the table, the external occupational radiation doses to onsite decommissioning workers during SAFSTOR at the reference research reactor (base case) is estimated to be about 13.91 man-rem. This includes about 13.08 man-rem during the preparations for safe storage, about 0.82 man-rem during 100 years of continuing care, and approximately 0.01 man-rem during deferred decontamination, as shown in Table 12.2-10 of Reference 1. The decay of the residual radioactivity in the facility during the safe storage period accounts for the relatively low occupational doses during continuing care and deferred decontamination.

Onsite storage of the shredded and solidified combustible wastes is estimated to add about 0.2 man-rem to the decommissioning workers in the adjusted case, bringing the total to about 14.11 man-rem during all phases of SAFSTOR at the reference research reactor.

As shown in Table 5.2-6, the occupational radiation doses to transportation workers during SAFSTOR at the reference reactor total about 0.16 man-rem,

TABLE 5.2-6. Estimated Safety Impacts of SAFSTOR at the Reference Research Reactor as a Function of Onsite Waste Storage

Group - Activity	Estimated Radiation Dose (man-rem)[a] Base Case[b]	Adjusted Case[c]
Decommissioning Workers - Onsite Decommissioning Activities	13.91	14.11
Transportation Workers - Offsite Waste Shipments and Irradiated Fuel Shipments	0.16	0.09
Public - Offsite Waste Shipments and Irradiated Fuel Shipments	0.03	0.02

(a) In both cases, the estimated radiation dose includes the sum of the doses for the preparations for safe storage, 100 years of continuing care, and the doses resulting from deferred decontamination.
(b) The base case is based on the analysis given in Appendix J.1 and Section 12 of Reference 1 where the irradiated fuel is shipped to a government repository, combustible radioactive wastes are shipped to a shallow-land burial site, and all other radioactive wastes remain onsite during the continuing care period.
(c) Only the fuel is shipped offsite to a government-owned facility in the adjusted case. The combustible radwastes are shredded and solidified and stored onsite, together with all other radioactive wastes.

based on information presented in Table 12.4-1 of Reference 1 and in Table 5.2-5 of this addendum. These doses are due almost entirely to activities during preparations for safe storage because, by the time the other waste materials are removed from the facility during deferred decontamination, the doses associated with these materials have been reduced by more than two orders of magnitude by radioactive decay.

In the adjusted case, the occupational radiation doses to transportation workers total about 0.09 man-rem, resulting from the two offsite shipments of irradiated fuel to a government-owned facility.

The release of radionuclides during safe storage is expected to be negligible compared to the release during preparations for safe storage. This is because of the rugged construction of the reference research reactor facilities, the erection of rigid barriers preventing migration of radionuclides, and the limited human contact during surveillance and maintenance operations. Thus, no public radiation doses are calculated for safe storage. The calculated public radiation doses for DECON are small,[1] and since the radioactivity levels are significantly reduced by radioactive decay during safe storage, public radiation doses for deferred decontamination are expected to be insignificant.

Onsite storage of all LLW significantly reduces radiation doses to transportation workers and to the public during the preparations for safe storage in the adjusted case. As previously mentioned, the shipment of the LLW after 100 years of safe storage is anticipated to result in negligible exposures to the transportation workers and to the public due to radioactive decay.

5.2.1.4 Conclusions of this Analysis for the Reference Research Reactor

Of the three alternative approaches to decommissioning (i.e., DECON, SAFSTOR, and ENTOMB), only SAFSTOR appears to be practical at the reference research reactor if onsite storage of LLW is required. Both DECON and ENTOMB have characteristics that appear to make them generally unsuitable for the decommissioning of the reference research reactor with onsite waste storage. If all the LLW were to be stored onsite and the duration of onsite storage were relatively short, a form of partial DECON may be practical, in which the plant structures would be decontaminated to release levels and the resulting wastes would be packaged and stored in one of the buildings. This approach would result in very nearly the same costs and safety impacts as DECON with prompt offsite waste disposal, as presented in the reference study.[1] Therefore, this approach is not analyzed in this addendum.

The estimated cost impacts of onsite storage of decommissioning wastes (excluding irradiated fuel) during SAFSTOR at the reference research reactor are summarized in Table 5.2-1 presented previously. As shown in the table, onsite storage of all LLW generated during preparations for safe storage in the adjusted case has virtually no effect on the total costs of all phases of SAFSTOR. Waste management costs remain virtually unchanged as a result of shredding, solidifying, and storing the wastes that were shipped offsite in the base case (i.e., the combustible radioactive wastes--see Table 5.2-2 for details). Therefore, there are no significant differences in total costs of all phases for SAFSTOR of the reference research reactor between the base case and the adjusted case presented in this analysis.

The estimated radiological safety impacts of storage of all radioactive wastes during SAFSTOR at the reference research reactor facility are summarized in Table 5.2-6 presented previously. As shown in the table, occupational radiation doses are estimated to increase only slightly (about 1%), due primarily to the shredding and solidifying task postulated in the adjusted case. In either case, it should be noted that the estimated safety impacts of SAFSTOR at the reference research reactor facility are judged to be low.

5.2.2 Decommissioning Analysis for the Reference Test Reactor Facility

The potential need for onsite storage of decommissioning wastes is anticipated to result in changes in the requirements for carrying out SAFSTOR at the reference test reactor. The changes, the resulting cost impacts on the decommissioning, and the safety impacts are discussed in the following subsections.

5.2.2.1 Changes from Normal SAFSTOR at the Reference Test Reactor Facility

In the SAFSTOR alternative, a minimum of decommissisning effort is expended following the reactor shutdown to ensure that the risk to public safety is within acceptable bounds during the safe storage period. Normally, the reactor is defueled and the irradiated fuel shipped offsite for reprocessing, dispersible contamination in the facility is removed, the remaining contamination is fixed and sealed in place, facility systems and services are deactivated, and the facility is secured to ensure the containment of residual radioactive contamination and the security of the facility during the safe storage period.

A significant amount of LLW (2821 m^3)--wet solid wastes, dry solid wastes, and contaminated concrete pipe and soil--in the reference test reactor facility requires disposal during preparations for safe storage in the base case.[1] Table 5.2-7 contains a summary of these wastes for the base case, together with disposal costs and estimated volumes. As shown in the table, the total cost of disposal for all of these materials is about $1.4 million (not including contingency) and is approximately 26% of the total cost of preparations for safe storage in the base case. The disposal cost includes the container, transportation, and burial costs, but does not include the direct labor costs for removing and packaging these materials.

In this analysis (hereinafter called the adjusted case), several changes are considered necessary to accommodate the onsite storge of the LLW at the reference test reactor site. The labor required to remove and package these wastes will not change. Instead of loading the containers onto trucks, they are placed in onsite storage.

Wet solid wastes result from the processing of chemical decontamination solutions and contaminated water volumes. These wastes include slurry from the cleanout of the HRA tanks, water filters, and spent demineralizer resins. Wet solid wastes are assumed to be mixed with a cement solidifying agent and encapsulated in 0.21-m^3 steel drums for subsequent storage onsite. The volume of these wet solid wastes remains the same as in the base case, with the same type and number of storage containers.

TABLE 5.2-7. Summary of Costs of Offsite Disposal for Radioactive Materials While Placing the Reference Test Reactor in Safe Storage for the Base Case Analysis[a]

Material Category	Number of Shipments	Burial Volume (m^3)	Disposal Costs ($ millions)
Contaminated			
Concrete Pipe and Soil	163	2779	1.352
Radioactive Wastes			
Dry Solid Wastes	3	25	0.021
Wet Solid Wastes	2	17	0.011
Totals	168	2821	1.384

(a) Based on data presented in Table J.2-13 of Reference 1.

The dry solid wastes include discarded contaminated materials such as plastic sheeting, rags, anticontamination clothing and exhaust filters, and are assumed in the parent document to be compacted to reduce their volume prior to offsite shipment. It is assumed for this analysis that the dry solid wastes must be incinerated and the resulting ash solidified prior to onsite waste storage. For purposes of this analysis, it is judged that the original compacted waste volume results in a decrease by a factor of 10 as a result of the incineration/solidification process.[4] Because offsite LLW disposal capacity is as likely to be unavailable during reactor operations prior to decommissioning as during decommissioning, it is assumed that a waste incineration facility has been constructed onsite prior to decommissioning to process combustible wastes generated during operation of the reference test reactor.

The manpower requirements for treating the waste and placing it in storage onsite are judged to be about the same as for packaging and loading the waste on trucks for shipment to an offsite disposal facility. Adequate space for waste storage within the reference test reactor facility buildings is not anticipated to be available, necessitating construction of an additional storage building.

No significant additional changes to the requirements for normal preparations for safe storage at the reference test reactor are anticipated to be needed to accommodate onsite storage of LLW. The onsite storage of LLW has no significant effect on activities during the safe storage period. The only changes during the deferred decontamination of the reference test reactor following safe storage are that the packaged LLW has to be removed and shipped offsite for disposal at that time and the incinerator facility has to be decommissioned. However, these activities are anticipated to have only minor impact on the deferred decontamination of the facility.

Surveillance and maintenance activities during the safe storage period remain virtually unchanged from those analyzed in the parent document (see Section J.2 of Reference 1 for details).

During the deferred decontamination of the reference test reactor facility, the deferred decontamination activities are the same as those described in Section J.2 of Reference 1. The LLW from preparations for safe storage is shipped offsite, the incinerator is disassembled and packaged for subsequent shipment, the associated systems and services are decommissioned, and the deferred decontamination then proceeds in the same manner as if the radwastes had been shipped offsite during preparations for safe storage. Therefore, the requirements for deferred decontamination are not anticipated to be significantly different than those described in Reference 1 for the reference test reactor facility.

5.2.2.2 Cost Impacts of Onsite Radwaste Storage During SAFSTOR at the Reference Test Reactor Facility

A summary of the costs of SAFSTOR at the reference test reactor facility under normal circumstances (base case) compared to the costs of SAFSTOR under the onsite radwaste storage case (adjusted case) considered in this addendum, is presented in Table 5.2-8. All costs are reported in constant 1981 dollars. Therefore, no updating of the base case costs from Reference 1 is necessary. The costs of SAFSTOR at the reference test reactor facility are based on data presented in Section 11 and Appendix J of Reference 1. The derivation of the costs for the onsite radwaste storage case (the adjusted case) is described in the remainder of this subsection.

The large volume of contaminated soil and buried concrete pipe (see Table 5.2-7) that is removed during the preparations for safe storage in the base case is also judged to be removed in the adjusted case since the reference radionuclide inventory for soil and concrete pipe on the reference test reactor site is such that the radioactivity in the soil and concrete piping will continue to be present in quantities beyond unrestricted release levels for more than 100 years. The soil is packaged as before, in plastic-lined, specially fabricated fiberglassed boxes and stored onsite. For both cases, the wet solid wastes are solidified and stored onsite. As described previously, the dry solid wastes are incinerated, solidified, and stored onsite. Adequate space for waste storage within the reference test reactor facility buildings is not anticipated to be available, necessitating construction of an additional storage building.

TABLE 5.2-8. Estimated Costs of SAFSTOR at the Reference Test Reactor Facility as a Function of Onsite Radwaste Storage

	Estimated Costs (Millions of 1981 Dollars)[a]	
Cost Category	Base Case	Adjusted Case for Onsite Radwaste Storage
Preparations for Safe Storage		
Staff Labor	3.870	3.870
Waste Management[b]	1.985	0.636[c]
Other Costs	1.084	1.084
Totals, Preparations for Safe Storage	6.939	5.590
Safe Storage		
Annual Continuing Care Costs	0.120	0.122
Totals, 100 Years of Safe Storage	12.000	12.200
Deferred Decontamination		
Totals, Deferred Decontamination	8.5[d]	10.404[e]
Total SAFSTOR Costs (100-Year Storage)	27.439	28.194

(a) All costs presented include 25% contingency, while the number of significant figures shown is for computational completeness.
(b) Includes $0.255 million for irradiated fuel shipment to a government-owned reprocessing plant.
(c) See Table 5.2-9 for cost breakdown.
(d) See Table J.2-22 of Reference 1.
(e) See Table 5.2-13 for cost breakdown.

Waste management costs associated with the preparations for safe storage are reduced almost 215% in the adjusted case relative to the base case, as shown in Table 5.2-9, by storing the LLW onsite. This is due primarily to: 1) the cost reductions for waste transportation and burial (including handling costs); and 2) the volume reduction and subsequent use of fewer containers because of the incineration and solidification of the dry solid wastes. Operation and maintenance of the incinerator and solidifying equipment during the preparations for safe storage are assumed to be carried out by decommissioning staff on an as-needed basis, and no significant additional staffing requirement is anticipated.

TABLE 5.2-9. Comparison of Waste Management Costs Between The Base Case Preparations for Safe Storage and the Adjusted Case Preparations for Safe Storage at the Reference Test Reactor Facility

Waste Management Cost Category	Estimated Costs (1981 Dollars)[a] Base Case	Adjusted Case
Fuel Disposal	255,000	255,000
Storage of Radioactive Materials and Contaminated Wastes:		
Wet Solid Wastes	14,000[b]	4,200[c]
Dry Solid Wastes	26,600[b]	825[d]
Contaminated Concrete Pipe and Soil	1,690,000[b]	313,000[c]
Construction of New All-Steel Building to House Waste Containers	Not Applicable	62,500[e]
Totals	1,985,600	635,525

(a) All costs presented include 25% contingency, while the number of significant figures shown is for computational completeness.
(b) Data from Table J.2-13 of Reference 1.
(c) Represents the costs of the containers for storing the radwastes onsite.
(d) Cost breakdown includes: 12 drums @ $30/drum plus about $300 for solidifying agents plus the 25% contingency, for a total of $825. These incinerated and solidified wastes in the adjusted case were assumed to be compacted in the base case.
(e) See text, Section 5.2.2.2 for rationale.

The onsite storage of the LLW previously presented in Table 5.2-7 presents complications for safe storage in the adjusted case because of the volume of the wastes. A summary of the number and type of waste containers, their estimated volumes, and the source for each type is given in Table 5.2-10. Table 5.2-11 presents various onsite waste storage alternatives available for long-term storage of these wastes and includes some advantages and disadvantages for each alternative. If the large volume of wastes mentioned previously are stored within the reference test reactor facility buildings, considerable time would be spent in removing the containers from the buildings before deferred

TABLE 5.2-10. Summary of Radwaste Containers Requiring Onsite Storage at the Reference Test Reactor for the Adjusted Case

Estimated Reference Inventory	Component[a]	Location	Number of Disposable Containers[b]	Estimated Storage Volume (m^3)
Reference 1, Appendix C	Concrete Piping Plus Soil	Ditches	350[c]	500
	Concrete Piping	Ditches	45	164
	Soil	Ditches and ERB	447	1627
	Soil	CRA	134	488
Reference 1, Table I.2-12	Wet Solid Wastes	As Applicable	80	~17
Reference 1, Table J.2-12	Dry Solid Wastes	All	12[d]	~3
Totals (from all locations)			626 boxes, 92 drums, +350[c]	2,799

(a) CRA is Cold Retention Area; ERB is Emergency Retention Basin.
(b) Assumed to be 1.2-m by 1.2-m by 2.4-m plywood boxes, unless otherwise noted.
(c) Different size concrete pipes are nested with the remaining internal volume filled with contaminated dirt and the ends concreted to form individual burial packages.
(d) In the base case, 120 disposable containers are required (see Table J.2-12 of Reference 1). For this analysis, the wastes are incinerated and solidified (see text), resulting in a 10-fold reduction in the number of containers.

decontamination could begin. Therefore, Alternative Number 3, given in Table 5.2-11, is judged to be the most viable onsite storage alternative for the adjusted case. Subsequently, shipping of the stored wastes and the deferred decontamination of the reference test reactor facility are judged to proceed concurrently without interferring with each other.

The cost of an all-steel storage building of adequate storage capacity for the wastes is conservatively estimated at $62,500 (including 25% contingency). An additional allowance of $2,000/year is added to the annual safe storage costs estimated for the base case (see Table J.2-19 of Reference 1) for

TABLE 5.2-11. Summary of Various Onsite Waste Storage Alternatives at the Reference Test Reactor Considered for the Adjusted Case

Alternative Number	Waste Storage Alternative	Considerations: Advantages	Considerations: Disadvantages
1	Store Waste Containers in Existing Test Reactor Facility Bldgs.	• no new structure required • stored inside, out of the weather	• limited space available; too crowded • complicates timely start of deferred decontamination • potential (but remote) fire hazard • space within more than one building is required
2	Bury Waste Containers in the Emergency Retention Basin Area (after removal of contaminated soil from the ERB)	• quick, simple, relatively inexpensive • containers are subject to elements of nature (not analyzed in this addendum)	• unorthodox, never been done before at a licensed reactor site; new LLW burial ground license may be required (as well as an EIS) • surveillance & security of containers can not be assured
3	Store Waste Containers in Specially-Built All-Steel Building	• relatively inexpensive • nominal surveillance requirements • out of the weather • minimum fire hazard potential • waste containers can easily be removed for subsequent loading onto trucks during deferred decontamination	• may require technical specifications change

maintenance and repair of this new building and for radiation surveys, bringing the estimated annual total cost to approximately $122,000/year for the adjusted case.

The costs of accomplishing deferred decontamination for the adjusted case are estimated by examining the general cost categories for DECON shown in Table I.2-7 of Reference 1 and determining the impact of the differences in accomplishing decontamination after a 100-year period of safe storage. It is assumed that the management and support staff is the same for deferred decontamination as it is for DECON. A number of DECON tasks are accomplished during the preparations for safe storage (i.e., discharging and shipping the fuel to a government reprocessing plant; draining of contaminated liquid systems; removal and packaging of contaminated soil from the ERB, the CRA, and buried concrete piping from the site ditches). During deferred decontamination, the time not expended on these tasks is offset by the time spent on familiarization of the work force with the facility, and restoration of essential services that were unneeded during the safe storage period. Therefore, it is assumed that the basic work force and time required for deferred decontamination are the same as for DECON. However, fewer decommissioning workers are required for deferred decontamination since the aforementioned tasks were performed previously and the radiation dose rates are lower.

For both the base case and the adjusted case, estimates are given in Table 5.2-12 of the volumes of the various types of radioactive materials that are packaged and shipped for burial when decontamination occurs either immediately or 100 years after reactor shutdown. In addition, the burial volume of radioactive waste from preparations for safe storage is given in comparison. The volume of contaminated material is assumed to remain constant through 30 years, but to decrease to 18 m^3 by 50 years and thereafter in the base case (see Section J.2.5.3 of Reference 1). The volume of contaminated material in the adjusted case is the sum of the amount assumed for the preparations for safe storage in the base case, plus the volume estimated for the deferred decontamination, and includes an estimated burial volume of approximately 3.5 m^3 for the incinerator, for a total of about 2800 m^3 for the adjusted case.

For both cases, the volume of activated material is assumed to remain constant over the 100-year span.

The volume of radioactive waste (wet and dry solid wastes) estimated for deferred decontamination in the adjusted case after 100 years is assumed to be the difference between the volumes for DECON and for preparations for safe storage. However, since all wastes are assumed to be stored onsite, this volume includes the wet and dry solid wastes (~20 m^3; see Table 5.2-10) plus the 38 m^3 at 100 years assumed for the base case, for a total of 58 m^3.

TABLE 5.2-12. Burial Volumes of Radioactive Materials from Decommissioning the Reference Test Reactor for the Base Case and for the Adjusted Case

		Burial Volume (m^3)				
Decommissioning Alternative	Start of Decommissioning (years after shutdown)	Activated Material	Contaminated Material	Radioactive Waste	Alternative Total	Decommissioning Total
• DECON[(a)]	0	62	4762	110	4934	4934
• Preparations for Safe Storage, Base Case[(b)]	0	--	2779	42	2821	--
• Preparations for Safe Storage, Adjusted Case[(c)]	0	--	--	--	--	--
• Deferred Decontamination, Base Case[(d)]	100	62	18	38	118	2939
• Deferred Decontamination, Adjusted Case[(c)]	100	62	~2800[(e)]	58	2920	2920

(a) Based on Table I.2-8 of Reference 1.
(b) Based on Table J.2-13 of Reference 1.
(c) Based on this analysis for the adjusted case (see text for details).
(d) Based on Table J.2-20 of Reference 1.
(e) Includes an estimated burial volume of ~3.5 m^3 for the incinerator.

A summary of estimated costs for deferred decontamination of the reference test reactor following safe storage for the base case and for the adjusted case after 100 years is given in Table 5.2-13. As a comparison, the costs of DECON, taken from Table I.2-7 of Reference 1, are included.

TABLE 5.2-13. Comparison of Estimated Deferred Decontamination Costs Between the Base Case and the Adjusted Case for the Reference Test Reactor

Cost Category	Estimated Costs ($ millions)		
		Decontamination Deferred 100 Years	
	DECON[a]	Base Case[b]	Adjusted Case
Disposal of Radioactive Materials			
Neutron-Activated Materials	0.135	0.135	0.135
Contaminated Materials	2.338	0.009	1.369
Radioactive Wastes	0.099	0.036	0.116
Staff Labor	8.63	6.076	6.091
Energy	0.076	0.055	0.055
Special Tools and Equipment	0.361	0.260	0.260
Miscellaneous Supplies	0.203	0.140	0.140
Specialty Contractors	0.616	0.107	0.107
Nuclear Insurance[c]	--	--	--
License Fees[d]	0	0	0
Construction of All-Steel Bldg.[e]	--	--	0.050
Subtotal	12.458	6.818	8.323
Contingency (25%)	3.115	1.705	2.081
Totals	15.573	8.523	10.404

(a) From Table I.2-7 in Appendix I of Reference 1.
(b) From Table J.2-21 in Appendix J of Reference 1.
(c) Indemnity fees are currently $100/yr for each license (i.e., the test reactor license and the MUR license) at the reference test facility and are not included in this study since they represent only a small fraction of 1% of the total decommissioning cost.
(d) Because the reference test reactor is assumed to be federally owned, these fees are not applicable; however, where applicable for other nuclear R&T reactor facilities, the schedule of fees for license amendments and other approvals required by the license or NRC regulations is given in 10 CFR 170.
(e) From Table 5.2-9.

During deferred decontamination with the LLW stored onsite, additional decommissioning staff is needed to ship the extra LLW offsite and to decommission the incinerator. The cost of this additional staff is estimated as shown in Table 5.2-14. It is assumed that the additional crew is needed for

TABLE 5.2-14. Additional Staff Labor Requirements and Costs During Adjusted Case Deferred Decontamination at the Reference Test Reactor Facility

Labor Category	Number Required[a]	Labor Requirement[b] (man-years)	Unit Cost/ Man-Year[c] ($ thousands)	Total Cost ($ thousands)
Crew Leader	1	--[d]	--	--
Utility Operator	1	0.038	32.1	1.2
Laborer	2	0.269	30.9	8.3
Health Physics Technician	1	0.058	30.0	1.7
Craftsman[e]	1	0.115	32.1	3.7
Subtotal				14.9
+25% Contingency				3.7
Total				18.6

(a) Based on crew makeups for similar tasks shown in Reference 1.
(b) Based on one shift per day, five days/week: 1.5 months for waste shipping and 3 weeks for incinerator decommissioning.
(c) From Table M.1-1 of Reference 1.
(d) Regular salaried employee; full-time attendance for these tasks is not required.
(e) For incinerator decommissioning only.

approximately 1.5 months (one shift per day, 5 days per week) to ship the stored waste and for about 3 weeks (also one shift per day, 5 days per week) to decommission the incinerator. Only craftsman are assumed to be needed for the latter task. The total additional staff labor cost during deferred decontamination of the reference test reactor facility with onsite storage of LLW is $18,600 in 1981 dollars, including the 25% contingency. There are also additional waste management costs associated with the offsite disposal of: 1) the LLW generated during preparations for safe storage and stored onsite, and 2) the wastes generated during the decommissioning of the incinerator. The estimated additional waste management costs during deferred decontamination are summarized in Table 5.2-15. As shown in the table, these costs are estimated to add a total of about $1.4 million to the cost of deferred decontamination, including the 25% contingency. Additional costs during deferred decontamination other than for staff labor and waste management are judged to be

TABLE 5.2-15. Additional Waste Management Costs During the Adjusted Case Deferred Decontamination of the Reference Test Reactor Facility

Waste Category	Container Costs, $	Transportation Costs, $	Burial Costs, $	Total Costs, $
Incinerated & Solidified Dry Wastes	--[a]	1,076	800	1,876
Incinerator Wastes[b]	1600	1,650	4,080	7,330
Contaminated Concrete Pipe and Soil[c]	--	218,818	883,170	1,101,988
Wet Solid Wastes[d]	--	2,480	5,340	7,820
Subtotals	1,600	224,024	893,390	1,119,014
+25% Contingency				279,754
Total				1,398,768

(a) Dashes indicate costs incurred during preparations for safe storage.
(b) Assumed four 3.46-m^3 fiberglassed plywood boxes; see Table M.2-1 of Reference 1.
(c) Based on Table I.2-11 in Reference 1.
(d) Based on Table I.2-12 in Reference 1.

negligible. Thus, the total additional cost during deferred decontamination of the reference test facility with onsite storage of the LLW is estimated to be about $1.42 million, bringing the total cost for the adjusted case deferred decontamination to about $10.4 million (see Table 5.2-13).

The total estimated cost (1981 dollars) for all phases of SAFSTOR at the reference test reactor facility for the adjusted case is about $28.2 million (see Table 5.2-8 for details), as compared to a total of about $27.4 million for the base case presented in Appendix J.2 of Reference 1--approximately a 3% increase in total costs.

5.2.2.3 Safety Impacts of Additional Onsite Waste Storage During SAFSTOR at the Reference Test Reactor

The safety impacts considered in the analyses of decommissioning the reference test reactor presented in Reference 1 include occupational and public safety impacts from both onsite (decommissioning) and offsite (combustible waste and irradiated fuel transportation) activities. Because impacts to the public from onsite activities are estimated in Reference 1 to be extremely small, and because these imapcts are not considered to be significantly influenced by the addition of the incinerated/solidified radwastes being stored onsite, public safety impacts from onsite activities are not considered further in this analysis. Furthermore, nonradiological safety impacts from decommissioning activities are also not considered in this analysis. Therefore, the safety impacts considered are as follows:

- occupational radiation doses to workers performing onsite decommissioning activities
- occupational radiation doses to transportation workers during the offsite shipment of wastes and irradiated fuel
- radiation doses to members of the public resulting from the offsite shipment of wastes and irradiated fuel.

Irradiated fuel from the reference test reactor is assumed to be shipped by truck (15 shipments) to a government reprocessing plant located 2400 km[a] by road from the reference test reactor (see Section I.2.3.9 of Reference 1). The cumulative radiation doses for transportation workers and the general public for these shipments were not included in the parent document[1] because they are relatively small considering the large number of people involved. However, they are included in this addendum for completeness. The method used to estimate routine radiation dose to transportation workers and to members of the general public from these shipments is based on the methods given in References 2 and 3, with the results summarized in Table 5.2-16. Radiation doses

TABLE 5.2-16. Estimated Radiation Doses from Truck Transport of Irradiated Fuel at the Reference Test Reactor[a,b]

Group	Exposure Time per 2400 km of Transportation (hr)	Exposure Rate per Shipment (millirem/hr)	Number of People Involved per Shipment	Dose Per Shipment per 2400 km (man-rem)
Drivers				
Operation	30	2	2	0.12
Cargo Inspection	1.5	50	2	0.15
Garagemen	0.23	2	2	0.00092
Onlookers	0.08	50	10	0.04
Population			330,000	0.00027
				0.31
Subtotal				x 15 shipments
Total (man-rem)				4.7

(a) Not transshipped.
(b) Calculations are based on information given in References 2 and 3.

(a) For comparative purposes, this assumed shipping distance is consistent with that used in previous decommissioning studies in this series.

received by workers unloading the radioactive materials at the government facility are not considered.

A summary of the estimated safety impacts of SAFSTOR at the reference test reactor under normal (base case) circumstances and under the total onsite radioactive waste storage case (adjusted case) considered in this study is presented in Table 5.2-17. As shown in the table, the external occupational radiation doses to onsite decommissioning workers during SAFSTOR at the reference test reactor (base case) is estimated to be about 113 man-rem. This includes about 112 man-rem during the preparations for safe storage, essentially no occupational exposure during 100 years of continuing care (see below for rationale) and approximately 1 man-rem during deferred decontamination, as shown in Table 12.2-11 of Reference 1. Many of the ALARA considerations (e.g., fences, locks, withdrawing of ladders from Q&Cs, and other methods for barring access to radiation zones) exercised in this study of the SAFSTOR alternative for the reference test reactor are the same as those used at PBRF in 1973. Therefore, it is assumed that similar conditions prevail and that external radiation exposures for surveillance and maintenance personnel at the reference test reactor during safe storage are at the threshold levels of detection for personnel monitoring devices. Security techniques, administrative procedures, and the physical layout of the reference test reactor, plus the aforementioned ALARA considerations, provide the means for controlled entrance, observation, surveillance, and egress from all buildings and areas without deliberately exposing the safe storage personnel to external radiation of reactor origin. This conclusion is based on the negligible external radiation exposures reported for the surveillance, maintenance, and security forces during the past 8 years of safe storage of the PBRF.[a] In addition, the decay of the residual radioactivity in the facility during the safe storage period accounts for the relatively low occupational doses during deferred decontamination.

Since the same amount of dry solid waste is initially handled in both cases, the onsite storage of the incinerated and solidified combustible wastes in the adjusted case is judged not to add any significant occupational exposure to decommissioning workers. In fact, onsite storage of the LLW generated during preparations for safe storage is anticipated to have only very minor effects on the activities required for SAFSTOR; thus, the occupational radiation doses to workers during the adjusted case SAFSTOR are assumed to be the same as during the base case SAFSTOR.

(a) Based on information supplied by Mr. John E. Ross of Teledyne Isotopes, General Manager of Plum Brook Operations, Sandusky, Ohio.

TABLE 5.2-17. Estimated Safety Impacts of SAFSTOR at the Reference Test Reactor as a Function of Onsite Waste Storage

Group - Activity	Estimated Radiation Dose (man-rem)[a] Base Case[b]	Adjusted Case[c]
Decommissioning Workers - Onsite Decommissioning Activities	113	113
Transportation Workers - Offsite Waste Shipments and Irradiated Fuel Shipments	12.27	0.27
Public - Offsite Waste Shipments and Irradiated Fuel Shipments	0.15	0.043

(a) In both cases, the estimated radiation doses include the sum of the doses for the preparations for safe storage, 100 years of continuing care, and the doses resulting from deferred decontamination.
(b) The base case is based on the analysis given in Appendix J.2 and Section 12 of Reference 1 where the irradiated fuel is shipped to a government-owned reprocessing plant, combustible radioactive wastes are shipped to a shallow-land burial site, and all other radioactive wastes remain onsite during the continuing care period.
(c) Only the fuel is shipped offsite to a government-owned facility in the adjusted case. The combustible radwastes are incinerated and solidified and stored onsite, together with all other radioactive wastes.

As shown in Table 5.2-17, the occupational radiation doses to transportation workers during SAFSTOR at the reference test reactor total about 12.27 man-rem, based on information presented in Table 12.4-2 of Reference 1 and on Table 5.2-16 of this addendum. These doses are due almost entirely to activities during preparations for safe storage because, by the time the other waste materials are removed from the facility during deferred decontamination, the doses associated with these materials have been reduced by more than two orders of magnitude by radioactive decay.

In the adjusted case, the occupational radiation doses to transportation workers total about 0.27 man-rem, resulting from the 15 offsite shipments of irradiated fuel to a government-owned facility.

The release of radionuclides during safe storage is expected to be negligible compared to the release during preparations for safe storage. This is because of the rugged construction of the reference test reactor facilities, the erection of rigid barriers preventing migration of radionuclides, and the limited human contact during surveillance and maintenance operations. Thus, no public radiation doses are calculated for safe storage. The calculated public radiation doses for DECON are small,[1] and since the radioactivity levels are significantly reduced by radioactive decay during safe storage, public radiation doses for deferred decontamination are expected to be insignificant.

Onsite storage of all LLW significantly reduces radiation doses of transportation workers and of the public during the preparations for safe storage in the adjusted case. As previously mentioned, the shipment of the LLW after 100 years of safe storage is anticipated to result in negligible exposures to the transportation workers and to the public due to radioactive decay.

5.2.2.4 Conclusions of this Analysis for the Reference Test Reactor

Of the three alternative approaches to decommissioning (i.e., DECON, SAFSTOR, and ENTOMB), only SAFSTOR appears to be practical at the reference test reactor if onsite storage of LLW is required. Both DECON and ENTOMB have characteristics that appear to make them generally unsuitable for the decommissioning of the reference test reactor with onsite waste storage. If all the LLW were to be stored onsite and the duration of onsite storage were relatively short, a form of partial DECON may be practical, in which the plant structures would be decontaminated to release levels and the resulting wastes would be packaged and stored in one or more of the buildings. This approach would result in very nearly the same costs and safety impacts as DECON with prompt offsite waste disposal, as presented in the reference study.[1] Therefore, this approach is not analyzed in this addendum.

The estimated cost impacts of onsite storage of decommissioning wastes (excluding irradiated fuel) during SAFSTOR at the reference test reactor are summarized in Table 5.2-8, presented previously. As shown in the table, onsite storage of all LLW generated during preparations for safe storage in the adjusted case is estimated to increase the total costs of all phases of SAFSTOR less than 3%. However, some of the waste management costs that would normally occur during preparations for safe storage are delayed until deferred decontamination.

The estimated radiological safety impacts of storage of all radioactive wastes during SAFSTOR at the reference test reactor facility are summarized in Table 5.2-17, presented previously. As shown in the table, occupational radiation doses are estimated to be unaffected by onsite LLW storage. Radiation doses to transport workers and to the public from offsite waste shipments are anticipated to be reduced by about 97% by onsite LLW storage. In either case, it should be noted that the estimated safety impacts of SAFSTOR at the reference test reactor facility are judged to be low.

5.3 SENSITIVITY OF DECOMMISSIONING COSTS TO RADIOACTIVE WASTE DISPOSAL CHARGES

The costs of disposal for the radioactive materials removed from the reference test reactor during DECON, as developed in NUREG/CR-1756,[1] were based on the assumption that all of these wastes were placed in a shallow-land burial facility. These costs were developed using the fee schedule for a commercially licensed radioactive waste burial ground, published in November 1980. The impact of increased disposal costs on the total cost of DECON is examined in Section 5.3.1. Supplemental information that could impact on the cost of disposal is presented in Section 5.3.2.

5.3.1 Impact of Increases in Shallow-Land Burial Costs

The component parts that make up the total disposal cost of DECON for the reference test reactor are shown in Table 5.3-1 (condensed from Table I.2-8 of NUREG/CR-1756). The cost of removing the irradiated fuel is deleted from the table, since it can be considered a final operating expense rather than a decommissioning cost. The costs shown in this section do not include a 25% contingency unless specifically stated.

TABLE 5.3-1. Estimated Costs of Disposal for Radioactive Material from the Reference Test Reactor[a]

Radioactive Material Category	Thousands of 1981 Dollars			
	Container[b]	Transportation[c]	Burial[d]	Total
Neutron-Activated Material				
Metal (Test Reactor)	13.35	38.78	79.21	131.34
Metal (MUR)	0.80	1.08	2.12	4.00
Contaminated Materials				
Metal 74.18	38.04	254.79	367.01	
Concrete and Soil	250.40	218.82	883.17	1,352.39
Concrete	131.40	107.75	379.46	618.61
Radioactive Wastes				
Wet Solid Wastes	3.36	2.48	5.34	11.18
Dry Solid Wastes	13.20	37.30	36.90	87.40
Totals 486.69	444.25	1,640.99	2,571.93	
% of Total	18.9	17.3	63.8	100

(a) All footnotes refer to NUREG CR-1756.
(b) Container costs as given in Table M.2-1, Appendix M.
(c) Includes cask rental for 5 days shipment, plus trucking costs, as given in Tables M.3-1 and M.3-2, Appendix M.
(d) Handling, burial, and surcharges as given in Table M.4-1, Appendix M.

The costs of all items that make up the total DECON cost are shown in Table 5.3-2 (modified from Table I.2-7 of NUREG/CR-1756).

In Table 5.3-2 it is seen that disposal of radioactive materials constitutes 20.7% of the total DECON cost. In Table 5.3-1 it is seen that the actual charges at the disposal facility constitute about 63.8% of the total disposal costs. Thus,

TABLE 5.3-2. Summary of Estimated Costs of DECON for the Reference Test Reactor

Cost Category		Estimated Costs ($ millions)[a,b]	Percent of Total
Disposal of Radioactive Materials			
Neutron-Activated Materials			
Reference Test Reactor	0.131		
Mock-Up Reactor (MUR)	0.004		
Contaminated Materials	2.338		
Radioactive Wastes	0.099		
Total Disposal Costs		2.572	20.7
Staff Labor		8.63	69.3
Energy		0.076	0.6
Special Tools and Equipment		0.361	2.9
Miscellaneous Supplies		0.203	1.6
Specialty Contractors[c]		0.616	4.9
Nuclear Insurance		--[d]	--
License Fees		--[e]	--
Subtotal		12.458	100.0
Contingency (25%)		3.115	
Total, DECON Costs		15.573	
Other Possible Costs			
Spent Fuel Shipment		0.204	
Facility Demolition Site Restoration		2.289	
Subtotal		2.493	
Contingency (25%)		0.623	
Total, Other Possible Costs		3.116	

(a) 1981 costs.
(b) The number of figures shown is for computational accuracy and does not imply precision to the nearest $1,000.
(c) Includes selected demolition, explosives, temporary radwaste, and environmental monitoring services.
(d) Indemnity fees are currently $100/yr for each license (i.e., the test reactor license and the MUR license) at the reference test facility and are not included in this study since they represent only a small fraction of 1% of the total decommissioning cost.
(e) Because the reference test reactor is assumed to be federally owned, these fees are not applicable; however, where applicable for other nuclear R&T reactor facilities, the schedule of fees for license amendments and other approvals required by the license or NRC regulations is given in 10 CFR 170.

about 13.2% of the total DECON costs are sensitive to the fee schedule at the disposal facility. As an example, if the burial ground charges are doubled, from $1.641 million to $3.282 million, the total DECON cost increases about 13.2%, from $12.458 million to $14.099 million.

The burial fee schedule used in NUREG/CR-1756 was increased on January 15, 1982, by the facility operator. The fees for burial (in dollars per cubic meter) were increased 30% for containers with low radiation levels, increased about 14.4% for containers with high radiation levels, and increased on a sliding scale in between. The basic curie surcharge per load was increased by 10%. The net impact of the increased fee schedule on the costs presented in NUREG/CR-1756 for the reference test reactor is to increase the burial costs from $1.641 million to $2.119 million, for a 3.8% increase in total DECON costs.

5.3.2 Additional Factors That Could Influence Disposal Costs

Several additional factors that could affect radioactive waste disposal charges have been identified. They are:

- regional compacts--fees for nonmember states may vary from that of member states
- burial criteria for disposal of highly activated and/or long-lived radioactive materials
- appropriate definitions of the amount of radioactivity that would be permitted on nonactivated, contaminated stainless steel and nonferrous metals for unrestricted use.

As mentioned previously, a basic assumption of this study is that all radioactive wastes from decommissioning operations can be disposed of by burial at a commercial shallow-land burial facility. Disposal requirements for highly radioactive and long-lived components from decommissioning operations are not yet defined. A requirement for deep geologic disposal of these materials would certainly increase the cost of disposal. Since a deep geologic disposal facility does not now exist, interim storage of wastes destined for geologic disposal might be necessary.

As discussed at the beginning of this section, the future status of commercial low-level waste burial sites is a major concern associated with future R&T reactor decommissionings, as is the possibility that offsite disposal of the radioactive waste materials resulting from decommissioning may not be possible or disposal may be delayed at the time of decommissioning. For example, the 27 August 1982 announcement regarding the closure of the low-level waste burial ground (LLWBG) at Beatty, Nevada,[5] forced those radwaste generators who had been using the Beatty site to decide on which of the two remaining LLWBGs they would utilize. In any event, future shipments may entail greater cost expenditures due to: 1) longer transportation routes to the remaining two commercial burial sites; 2) as mentioned previously, the possible variation in costs to non-compact members (when compacts become a reality); and 3) costs associated with delays in sites accepting radioactive waste material. The state of South Carolina, for example, has imposed a monthly allotment system on the volume of radwastes permitted for burial at the Barnwell site. Even temporary, short-term storage of packaged radwastes could be burdensome as well as costly to some research reactor facilities that do not have adequate space for storage. Therefore, if future cost savings are to be realized, the scheduling and planning for the disposition of radioactive materials is judged to be worthy of additional emphasis during decommissioning planning.

5.4 SUMMARY OF THE IMPACT OF INCREASED DISPOSAL COSTS ON THE TOTAL COST OF DECON FOR THE REFERENCE TEST REACTOR

The cost of shallow-land burial for the radioactive materials resulting from DECON of the reference test reactor conceptually decommissioned in NUREG/CR-1756 constitutes about 13.2% of the total decommissioning cost. Doubling the burial costs increases the total decommissioning cost by 13.2%, or about $1.6 million. An analysis of the impact of recent actual disposal-charge increases on the costs given in NUREG/CR-1756 results in a 3.8% increase, or about $0.5 million.

During the past 7 years the charge per unit volume for burial in a licensed burial ground has increased by 369% (see Section 4, Table 4.2-3 for details). It is likely that these charge rates will continue to increase as operating costs increase and as projected decommissioning costs for burial grounds become better defined. Although the historical cost trend is sharply upwards in direction, there is no clear-cut way to project what these costs will be in future years. In any case, it would seem prudent for R&T reactor owners/operators to continue to track these cost increases carefully since they control what this fraction of the total estimated costs of decommissioning will be.

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6.0 SENSITIVITY OF DECOMMISSIONING COSTS TO THE DISPOSITION OF R&T REACTOR FUEL

Irradiated fuel disposal is an important consideration during the planning and preparation phase that precedes decommissioning. Cask scheduling and subsequent shipment of the irradiated fuel assemblies are integral steps in the decommissioning schedules for R&T reactors.

This section contains information on disposal of R&T reactor fuel not contained in NUREG/CR-1756. It is anticipated that the information contained in this section will be especially useful to persons planning for decommissioning of R&T reactors. Background information is discussed in Section 6.1; the fuel disposition alternatives are discussed in Section 6.2; cask availability and licensing and certification considerations are discussed in Section 6.3; and cost impacts are discussed in Section 6.4.

6.1 BACKGROUND INFORMATION

The transport of commercial spent fuel in the United States has been the subject of numerous studies and reports and is well documented.[1,2] Similar information on shipments of irradiated fuel for R&T reactors was generally unobtainable, except for a few isolated cases. For example, the actual irradiated fuel shipments made after final shutdown of the reference test reactor, PBRF, are discussed in detail in Appendix I of NUREG/CR-1756.

A literature search conducted by the Transportation Technology Center at Sandia National Laboratories to obtain data associated specifically with the transportation of R&T reactor fuel found no transportation data for these fuels. However, through telephone contacts with licensees, former licensees, Battelle Memorial Institute, and several government officials (see Appendix B for a list of contactees), valuable information on experiences in the transportation of R&T reactor fuels and their probable destinations was obtained.

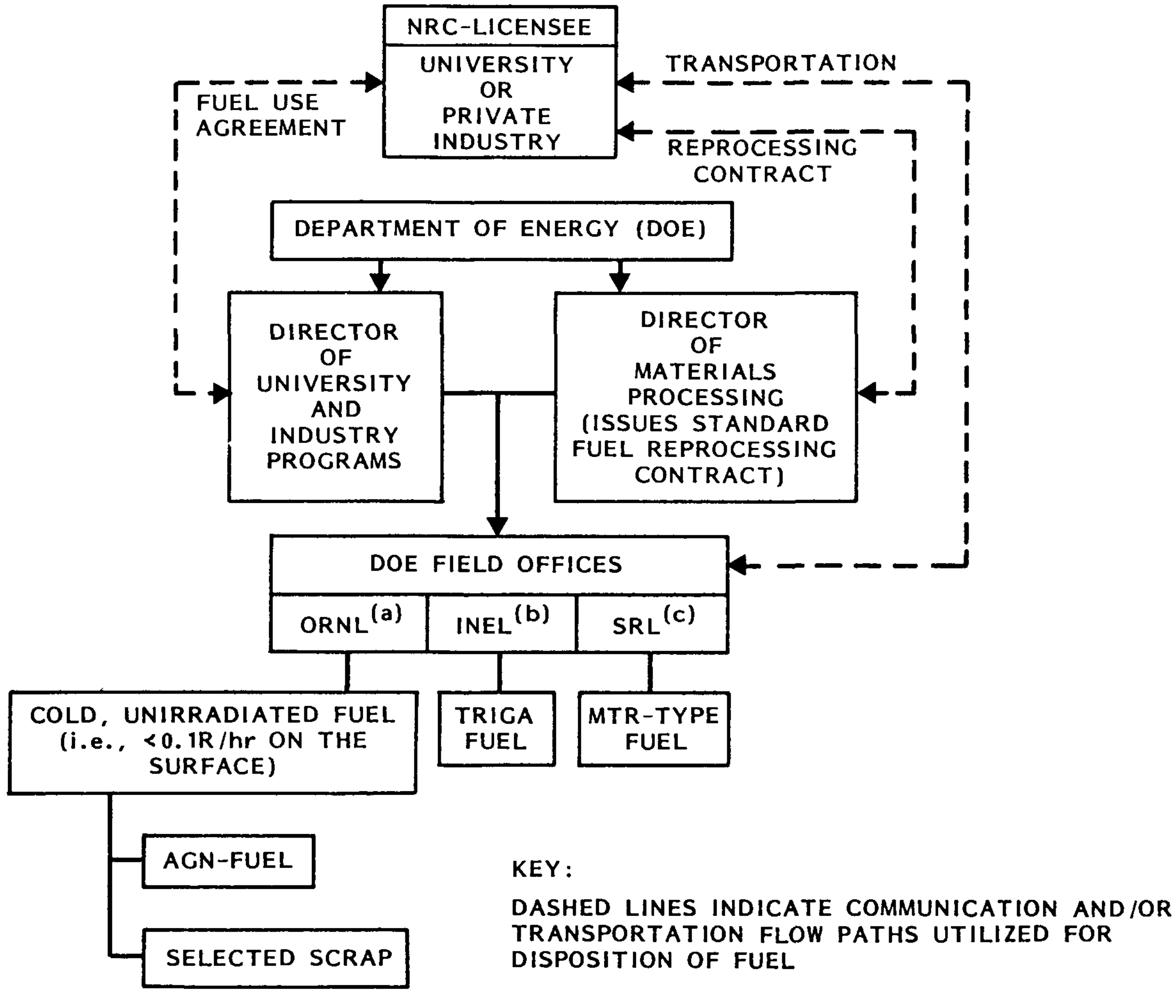
Thirty-five of 51 licensed university research or training reactors in the U.S. use enriched uranium fuel in the form of cylinders or pins, and in plates. This fuel is owned by the U.S. Department of Energy (DOE) and is loaned to universities with no charge for use, burnup, or reprocessing.[3] While universities can borrow DOE-owned casks free of charge to transport this fuel after irradiation, they still must pay for the shipment of the fuel in almost all cases. On the other hand, licensees who own their fuel also can ship it to DOE fuel processing sites but must bear all costs associated with fuel disposal, including cask rental and shipment of the fuel. In either case, the actual receipt, storage and/or reprocessing is initiated and documented via a standard Fuel Processing Contract between DOE and the licensee.

In NUREG/CR-1756, the fuel shipment costs (including cask rental, but excluding storage and/or reprocessing costs) are treated separately as "other possible costs." In conducting the series of studies on the decommissioning of commercial reactor power stations,[4,5] the costs of removal and subsequent shipment of spent fuel from commercial reactor power stations also are categorized as a cost item for inclusion as a final operating expense rather than a decommissioning cost. However, since the majority (79%) of the NRC-licensed research reactors are directly associated with an institution of higher learning--university, college, or institute--their reactor facilities do not generate funds as do commercial power plants. Therefore, the majority of research reactor licensees, specifically those which are Federally or state operated, must obtain funds to pay the costs associated with terminating the NRC license at the end of their facility's operating lifetime. As stated in NUREG/CR-1756 (Section 7.4): "Decommissioning costs of publicly owned R&T reactors will be paid from general tax revenues. It is important for Federal and state agencies and legislative bodies to be cognizant of the magnitude of funding requirements for decommissioning these reactors."

6.2 FUEL DISPOSITION ALTERNATIVES

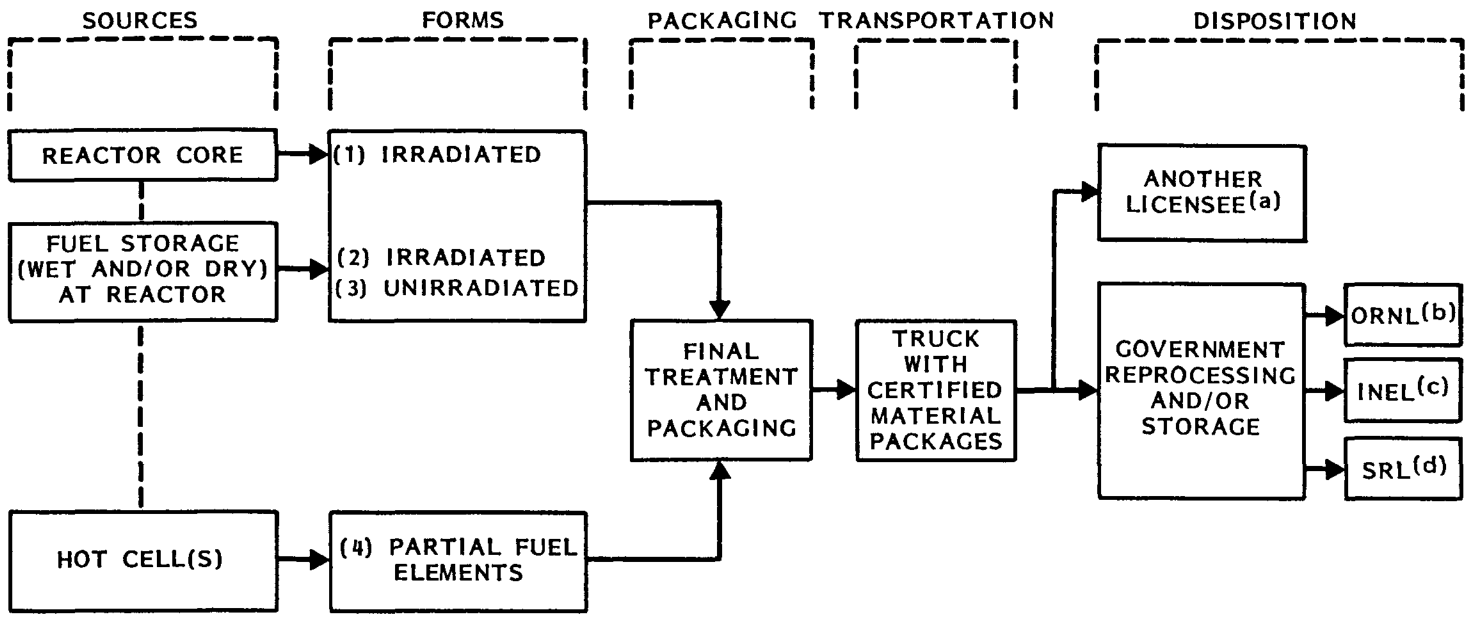
During the planning and preparation phase of decommissioning, the licensee must develop and set in motion a plan for the disposition of the facility's nuclear fuel. Regardless of who owns the fuel, subsequent offsite storage and/or reprocessing is handled by the DOE, as illustrated in Figure 6.2-1. The typical management path for the disposal of fuels from NRC-licensed R&T reactors is illustrated in Figure 6.2-2. In addition to the currently available storage and/or reprocessing alternatives at the three government facilities, the licensee may choose to transfer fuel to another licensee. If a receiver is located, additional cost savings could be realized if the receiver paid part or all of the transportation costs. However, the receiver's technical specifications may have to be changed to permit receipt of the fuel. Costs associated with any required license amendment fees would probably be borne by the receiver.

In general, the final destination of fuel from R&T reactors is determined by the responsible DOE field office (see Figure 6.2-1). Where the government facilities are approximately equidistant from the reactor location, the licensee may have a choice as to where to ship the fuel. As shown in Figure 6.2-1, the type of fuel is an important factor. Zirconium-clad unirradiated fuel (i.e., less than 0.1 R/hr at the surface) sent to the ORNL field office is stored, since no reprocessing is currently available for zirconium-clad fuel. On the other hand, aluminum-clad unirradiated fuel may be processed at ORNL's Y-12 plant, at the discretion of DOE.



(a) OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENNESSEE
(b) IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO FALLS, IDAHO
(c) SAVANNAH RIVER LABORATORY, AIKEN, SOUTH CAROLINA

FIGURE 6.2-1. Current Storage and/or Reprocessing Locations for the Various Types of R&T Reactor Fuels



(a) RECEIVER'S TECHNICAL SPECIFICATIONS MAY HAVE TO BE CHANGED TO PERMIT RECEIVING FUEL ELEMENTS.

(b) OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENNESSEE.

(c) IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO FALLS, IDAHO.

(d) SAVANNAH RIVER LABORATORY, AIKEN, SOUTH CAROLINA.

FIGURE 6.2-2. Typical Management Path for the Disposition of Fuel Elements from Licensed R&T Reactors

If recovery of ^{85}Kr from the fuel is necessary, then the licensee would be required to ship the fuel to INEL, since it is the only site having this capability. However, the Federal government may, at its discretion, pay the incremental transportation costs, if the distance to INEL is greater than the distance to another government site.

A research or test reactor licensee contemplating decommissioning would be well advised to contact DOE early in the planning and preparation phase to ascertain DOE's current disposal requirements for his type of fuel. Contractual obligations and requirements can be defined and any areas open to negotiation with potential subsequent cost impact could be determined at that time.

6.3 CASK AVAILABILITY AND CERTIFICATION CONSIDERATIONS

Because of the limited number of appropriate casks available, it is estimated that scheduling of actual cask use is necessary as much as 1 to 2 years in advance. In addition, depending on the type of fuel requiring transport, a cask basket or other specially constructed container could also require fabrication and certification. It should be recognized that certification requires both time and money. As a result, licensed cask availability may be impaired.

6.4 THE IMPACT OF FUEL DISPOSAL ON THE COST OF DECOMMISSIONING

Licensees will incur costs for irradiated fuel shipments when they decommission their facilities. In NUREG/CR-1756, the costs of fuel shipment were estimated to be about \$61,000 and \$204,000 for the reference research reactor and the reference test reactor, respectively. Were these costs to be included as decommissioning costs, they would represent about 8.3% and 1.6%, respectively, of the total costs (excluding contingency) of decommissioning the reference R&T reactors. Unfortunately, detailed costs of fuel disposal are available for only two of the five case history decommissionings examined in this addendum. Until more data on fuel disposal are made available, it is difficult to establish the factors affecting fuel disposal costs.

Information on the disposal of irradiated fuel from the reference R&T reactors analyzed in NUREG/CR-1756 and from the actual case history decommissionings examined in this addendum is presented in Table 6.4-1. In general, the limited data (and NUREG/CR-1756 estimates) seen in the table suggest that the smaller the reactor facility (e.g., the OSTR and the LPR), the greater the fraction of total costs of decommissioning and fuel disposal costs is attributable to disposal of the fuel.

TABLE 6.4-1. Summary of Information on the Disposal of Irradiated Fuel from R&T Reactor Facilities

Reactor	One-Way Shipping Distance (km)	Number of Shipments	Cost, $ (Year)	~% of Total Decon Cost	Destination
OSTR	800	2	~61,000 (1981)[a]	8.3	Hanford, WA
PBRF	2400	15	~204,000 (1981)[a]	1.6	Savannah River, SC
ALRR	--[c]	3	18,300 (1978)[b]	<1.0	Savannah River, SC
DORF	--[c]	--[c]	--[c]	--[c]	--[c]
LPR	--[c]	3	26,000 (1981)[d]	23	Savannah River, SC
NCSUR-3	--[e]	--[e]	--[e]	--[e]	Savannah River, SC
OSU/AGN-201	NA[f]	NA	NA	NA	--[g]

(a) Excluding 25% contingency.
(b) Data taken from Table 2 of Reference 6.
(c) These data were not obtained; destination of fuel is unknown.
(d) Includes shipment and cask rental costs.
(e) The fuel was shipped in the mid-1970s and shipping and cost data are unavailable.
(f) N.A. is not applicable.
(g) The fuel discs remain onsite in secured storage.

In the case of the LPR, the large fraction (about 23%) of total DECON costs shown resulted because the Babcock & Wilcox Company (B&W) owned the fuel and had to rent the shipping casks used. As discussed later in this addendum (Section A.2.3 of Appendix A), funds from the subsequent sale of the fuel almost paid the total cost of decommissioning the LPR, including the spent fuel shipping costs.

Other factors besides fuel ownership could impact the costs of fuel disposal, including cask availability (and its subsequent effect on the decommissioning schedule), shipping distance (including empty cask pickup and return as well as fuel destination), and the number of shipments. Factors that could potentially lead to cost savings include fuel ownership and costs that may be borne by other consignees of the fuel, such as another company or university.

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7.0 DECOMMISSIONING COST FACTORS THAT ARE DIFFICULT TO QUANTIFY GENERICALLY

The estimates of costs of decommissioning the reference nuclear R&T reactor facilities in the parent study (NUREG/CR-1756) were developed based on 1981 dollars, conditions, and regulatory climate. Several major areas that can impact on the total decommissioning cost--plant size/type, escalating waste disposal costs, and final fuel disposition--are discussed in detail in this addendum. However, several other factors more difficult to quantify generically should be recognized for their potential impact on nuclear R&T reactor decommissioning costs and for the need to consider them on a case-specific basis. These factors are discussed briefly in the following subsections.

7.1 OCCUPATIONAL AND NONOCCUPATIONAL RADIATION EXPOSURE

Permissible cumulative radiation doses to the occupational work force are being reviewed and could potentially be revised in the future. This revision could influence shielding and packing costs for disposal containers and could require additional shielding and increased task times for in-house task labor.

7.2 EQUIPMENT OBSOLESENCE

Various equipment at nuclear R&T reactors may have substantial salvage value. DECON (prompt dismantling) could generate some case-specific cost benefits as a result of diesel generators, compressors, motor controllers, transformers, cranes, etc., being used at other facilities or installations. It is unlikely that such equipment will be useable after a lengthy delay due to either obsolescence or general deterioration. In fact, substantial additional costs might be incurred to replace, repair or update this equipment before delayed dismantling and decontamination could be undertaken.

7.3 DEFERRED DECOMMISSIONING

Costs of deferred decommissioning will probably be greater than prompt decommissioning due to loss of knowledge and familiarity with the facility. These losses will affect not only decommissioning efficiency, but will increase risk factors in bidding by contractors, which subsequently could result in costly renegotiation of the contract and/or delays in the decommissioning schedule.

7.4 REGULATORY CLIMATE

In planning for and carrying out decommissioning the licensee must be aware of all regulations pertaining to decommissioning and how they will affect his activities and the associated costs of activities. A discussion of regulations applicable to decommissioning is contained in Section 5 of the parent document.(1)

Of direct interest to all NRC licensees, for example, is the NRC staff proposal to revise the NRC licensing fee schedule, which could almost triple the Commission's fee for construction permit and operating license reviews and other related services. As reported in the 5 November 1981 issue of Nucleonics Week, "The Commission, however, is not ready to accept the new fee schedule, and at a meeting this week, commissioners sent staff members back to their calculators with instructions to recalculate the professional rates. The staff had based calculations on the 1979 rates, making adjustments for inflation, pay increases and other factors. NRC commissioners suggested it might be more appropriate to just look at current data. Commissioners also questioned fee payments for inspection enforcement, directing staff to make sure IE would get paid for all the work it does."

7.5 FUTURE LAND USE

The reference test reactor used in this study, the PBRF, was originally located within the substantially larger Plum Brook station for a number of reasons, one of which was the buffer zone afforded by open, controlled-use land in close proximity to the reactor complex. This situation is also true of a number of other nuclear R&T reactor facilities. Therefore, the continued presence of these types of R&T reactors after final shutdown is likely to complicate future use of a much larger area than just the acreage presently allocated to a restricted access zone for sole-use by the reactor itself. As time goes on, the value of this land for alternate use will probably increase, giving added impetus for DECON as the optimum decommissioning alternative.

7.6 RADWASTE DISPOSAL COST CONSIDERATIONS

As discussed in Section 5.2, there are several factors that can influence disposal costs, including cost trends at commercial disposal sites, potential costs and criteria related to disposal of long-lived or highly activated materials, and disposal criteria for nonactivated contaminated steel and nonferrous metals. In developing case-specific costs, regulatory actions and disposal site status and costs in these areas would need to be closely considered.

7.7 MISCELLANEOUS FACTORS

Other factors can affect decommissioning costs such as climate (which affects the cost of utilities), contractor management, code requirements, and availability and deliverability of materials and supplies (including irradiated fuel shipping casks, as discussed in Section 6). These factors and those discussed previously in this section, while difficult to evaluate, are not solely dependent on the section of the country where the decommissioning takes place. In combination, these factors result in uncertainties that are unavoidable and, depending on the size of the decommissioning project, can be important. These case-specific factors have to be addressed through the application of judgement during the planning and preparation stage to assure that adequate contingency is provided.

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8.0 OBSERVATIONS, CONCLUSIONS, AND RECOMMENDATIONS

An evaluation of the five R&T reactor decommissionings examined in this addendum indicates an apparent relationship between decommissioning cost and reactor facility size or power level for this class of facilities, but not to reactor facility type.

The decommissioning of each of the nonpower reactors examined in this addendum was unique in the approach taken to achieve the end-product. Economics, personnel exposure, and containment of airborne contaminants were common factors considered in these decommissionings. The socioeconomic impact of these decommissionings appeared to be negligible, especially where relatively lengthy decommissioning took place. Decisions were required on the final permissible radioisotope concentrations that would be acceptable for future unrestricted use of the sites or facilities.

In general, guidelines for acceptable surface contamination limits and specific activity concentrations in concrete, structural materials, and/or soil followed NRC Regulatory Guide 1.86 limits. It should be recognized that the NRC staff is currently reappraising those limits as an integral part of its regulatory position relative to the decommissioning of nuclear facilities.(1)

It was found that decommissioning information on nuclear nonpower reactors (whether licensed or not) reported in the open literature and/or available from the public record is seldom detailed enough to permit direct comparisons with the results provided in the parent document (NUREG/CR-1756) or with the results presented in this addendum. In fact, future decommissioning planners will probably find historical records to be of limited use for comparative purposes unless those records are required by new regulation to include some form of standardized decommissioning closeout data sheet.

One major finding of this addendum is that sufficient quantitative data necessary to correlate the sensitivity of radiation dose to reactor facility size and/or type in a meaningful way for R&T reactors is not currently available.

Other major conclusions of this addendum are listed below. Each of these conclusions is discussed in subsequent subsections.

1. Decommissioning of nonpower reactor facilities can be accomplished using currently available technology.

2. Decommissioning of nonpower facilities can be accomplished with a minimum of radiation exposure to decommissioning workers and with no significant impact on the safety of the general public.

3. Decommissioning costs vary over a wide range from about a few thousand dollars to several million dollars, depending on several factors that include the size of facility (but not necessarily the type of facility), the nature and extent of the radioactive contamination, and the operating history of the facility.

4. Nonpower reactors design considerations and operating practices can have a significant effect on the time and cost of decommissioning these facilities.

8.1 DECOMMISSIONING TECHNOLOGY

A wide variety of necessary technology exists and has been successfully applied to a wide variety of nuclear R&T reactor facilities. Decommissioning of these facilities can be and is being accomplished using technology and equipment that are in common industrial use. The technology for the removal of radioactivity from contaminated surfaces is based on a cleaning technology that has been established for several decades. Almost all of the procedures and chemicals used to decontaminate nuclear equipment and facilities were first developed and used for cleaning equipment and facilities in non-nuclear industries.

Past R&T reactor decommissionings have resulted in few developments of tools or techniques specific to the task, although innovative approaches have invariably been used during each of the projects. The majority of these decommissionings have been accomplished by using relatively routine decontamination and demolition procedures adapted to the specific facility being decommissioned, or by adapting special techniques developed to repair existing facilities. A major reason for this is simply the size of the project; that is, the decommissioning budget for these facilities did not include funds for research and development, only for the ultimate decommissioning itself. This seems normal, since at the end of a nuclear facility's life the primary concern is to deal with it as with other redundant property and recover whatever valuable property and/or equipment remains; and perhaps make some of the resources previously applied to the facility available for other applications. Therefore, the scrap value of parts that could defray even a small portion of the cost of the work involved is usually worth considering.

Extensive experience has been gained in decommissioning radioactive nonpower reactor facilities (see Appendix A), and the aforementioned decontamination techniques are well documented.[2-6] Decommissioning involves many of the same procedures and techniques that are used to decontaminate a nuclear reactor facility during its operating lifetime. However, because of the uniqueness of each nonpower facility, no two facilities have identical problems or conditions. However, the basic approach to each decommissioning project remains virtually unchanged (i.e., the gathering of staff manpower and a period of planning and preparation followed by decontamination and mechanical removal operations). The fundamental course of events varies primarily with building design and with the inherent refinements potentially available or needed for a given facility. Areas that can use technology improvements are remote handling equipment, disassembly techniques, decontamination techniques, and waste volume reduction.

Efforts to develop facility-specific decommissioning technology (e.g., facility and equipment designs, and decontamination systems and techniques) that can minimize labor will significantly reduce overall decommissioning costs for nuclear R&T reactor facilities. It is interesting to note, however, that except for compaction, no other volume reduction methods were evident from the data obtained on the decommissionings discussed in Appendix A.

The decommissioning of nuclear nonpower reactor sites may involve site stabilization procedures or it may involve the removal of radioactive waste or contaminated soil. A variety of techniques exist for stabilizing a site against radionuclide transport mechanisms. These techniques are described in detail in another report in this series.[7] The removal of radioactive materials, such as contaminated drain lines, can be accomplished using standard earth-moving techniques and equipment.

8.2 PUBLIC AND OCCUPATIONAL SAFETY

Workers engaged in the decommissioning of radioactive nonpower reactor facilities generally experience similar levels of radiation exposure as workers engaged in normal facility operations. An exception exists for decommissioning operations that result in the production of significant quantities of airborne radioactivity. Operations in an environment with the potential for high inhalation exposure to radiation may require worker use of protective respiration equipment. The use of this equipment could result in a reduction of the inhalation dose by several orders of magnitude.

For the decommissioning case histories described in Appendix A, the safety impacts of the decommissioning operations on the public are small, with the principal impact on the public being the radiation dose resulting from the transport of radioactive materials to disposal sites.

An essential, but easily overlooked aspect of personnel safety, concerns the potential requirements for services of local hospitals during the decommissioning period. It would be useful to make arrangements (and estimate costs, if necessary) with a nearby hospital for aid in case of accidents involving radioactive contamination.

8.3 DECOMMISSIONING COSTS

The decontamination of nuclear nonpower contaminated facilities is a labor-intensive, hands-on effort. Thus, labor is a major fraction of the total decommissioning costs. In the case of university reactors, the planned use of student labor (which is usually intended to reduce the total cost of labor) must be balanced against the potentially undesirable effect of prolonging the overall time period of decommissioning, which could, in fact, increase the total cost of the project. The cost-effectiveness of the use of student labor over extended decommissioning periods is enhanced by accurate recordkeeping practices during the project.

Total costs of decommissioning nuclear nonpower facilities depend on several factors, including:

- the size of the facility, including all contaminated ancillary facilities
- facility design and construction
- the type and amount of radioactive contamination
- operating practices during the lifetime of the facility.

The cost of handling, packaging, transporting, and disposing of radioactive waste materials is a significant fraction of the total decommissioning cost. Development of facility designs and decontamination techniques that minimize the quantities of contaminated material that must be disposed of as radioactive waste could reduce overall decommissioning costs and the waste management burden.

It is interesting to note that by utilizing the methodology developed in Section 13 of the parent document, the average unit component cost of decommissioning a hot cell in the reference test reactor was estimated to be about $114,300. The estimated cost compares quite well with the $118,500 actual cost of decommissioning the single hot cell at the Ames Laboratory Research Reactor (see Appendix A, Table A.2-13).

The development of realistic nuclear R&T reactor facilities decommissioning cost estimates hinges on the performing of detailed analysis on the specific plant under consideration. Design differences among plants (also see Section 8.4) can have a significant impact on the types and amount of work involved in accomplishing decommissioning. Since R&T reactor facility designs are not standardized and are unlikely to become so, application of data from one facility can only be used as a first order approximation estimate for another facility. Therefore, specific analyses will likely continue to be necessary.

8.4 DESIGN CONSIDERATIONS AND OPERATIONS PRACTICES

Decommissioning of R&T reactors has not been a primary design consideration in the past. It is suggested that more attention should be given to the design of R&T reactors to simplify their eventual dismantling. Likewise, more attention should be given to facility layouts to optimize land reuse. A specific example of the latter is a thorough review of the need for and the use of underground tanks and piping systems at nuclear R&T reactor facilities. These design features can have an important effect on the ease with which a facility can be decommissioned.

There are other R&T reactor design considerations and operating practices that can have a significant impact on the time and cost of decommissioning. For example, design considerations should include the careful design of facility surfaces and equipment and the proper choice of construction materials for subsequent (and often times repeated) decontamination and dismantling, if required. Reactor facilities and facility components should be designed to minimize the surface area exposed to radioactivity and to eliminate sharp corners, crevices, and other difficult-to-decontaminate situations. Construction materials should be chosen that are corrosion-resistant and easy to decontaminate.

Operating procedures during the lifetime of a reactor facility also can have an important effect on the ease with which the facility can be decommissioned. Good operating practices maintain surface contamination at low levels and minimize the spread of contamination. The planning and performance of decommissioning are also facilitated if records that provide essential information about the facility operating history, radionuclide inventory data, and radiological survey data are maintained during the operating lifetime of the facility.

8.4.1 Facility As-Built Drawings

A potentially costly decommissioning problem area identified from the base data presented in Appendix A is directly associated with facility drawings that are not as-built (i.e., not up-to-date at the time of decommissioning). The effect here is twofold: 1) the accuracy of cost estimates for final disposal of radioactive materials is reduced; and, 2) work flow can be delayed. For example, once a project is begun and the task progresses, hidden or unknown difficulties can subsequently delay the start of other tasks. Should a subsequent task have to be delayed, costs may soon rise significantly if, for instance, contractors have to be delayed.

8.4.2 Radioactive Inventory

To identify the practical aspects of the decommissioning project during the planning and preparation phases, a knowledge of the total radioactive inventory and its decay, together with its distribution, is desirable. The inventory is composed of the neutron-induced radioactivity of the reactor structure, contamination within reactor systems arising from fuel failures and/or activated corrosion products, and stored operational activated/contaminated waste. An estimate of the radioactivity in the structure can be made on the basis of calculation but the accuracy is dependent upon a knowledge of the abundance of trace elements in the construction materials. The composition of these latter items is rarely known at R&T reactors to a high degree of precision. However, it is suggested that it would be useful to develop sufficient information on radiation levels and radioactivity content to more accurately estimate the costs of decommissioning. A major problem in providing such information is the potential exposure of personnel in obtaining it. Thus, the cost and time for the preparation of the necessary information would also be increased.[8]

It should also be noted that the inventory of activated concrete cannot be accurately predicted on a generic basis. The effect of activation on the actual cement-aggregate mixture used at a specific research or test reactor facility must be determined by actual spectographic measurement. It should be recognized that the variation in concrete radioactive inventory will not change the basic approach to concrete demolition and removal and, therefore, will not change the conclusions of the parent document, NUREG/CR-1756.

8.4.3 Decommissioning Paperwork and Subsequent Approvals

It is noteworthy that the paperwork preparations and subsequent approvals to allow decommissioning to proceed, both before and sometimes during the course of the decommissioning projects, can be lengthy. An example of the former is the B&W dismantling (see Section A.2.3 of Appendix A) and an example of the latter is the ALRR project (see Section A.2.2 of Appendix A). In both cases, appropriate administrative approvals were a necessary condition for assuring overall safety of the decommissionings.

Followup paperwork on repairs performed during the operational lifetime of a nonpower reactor facility has the potential for significant positive impacts on safety, ALARA aspects, and schedule when planning for the decommissioning of the facility. For example, the experiences and insights gained in working with contaminated reactor-related components in the B&W pool when it was drained for repair during its operating lifetime were recorded and saved. Subsequently, during decommissioning, that data proved invaluable to scheduling efforts and to selecting specific methods for decontaminating and dismantling components located within the pool area.

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6. P. T. Owen, et al., Decommissioning of Nuclear Facilities - A Selected Bibliography, Volume 2, ORNL/EIS-154/V2, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October, 1981.

7. E. S. Murphy and G. M. Holter, Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground, NUREG/CR-0570, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, June 1980.

8. Adolf F. Voigt, et al., FINAL REPORT - Decommissioning of the Ames Laboratory Research Reactor, IS-4789, Prepared for the U.S. Department of Energy under Contract W-7405-ENG-82, January 1982.

APPENDIX A

SELECTED CASE HISTORIES OF REACTOR DECOMMISSIONINGS

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The NRC-licensed nuclear research and test (R&T) reactor decommissionings in the United States are summarized in the parent document, NUREG/CR-1756. Subsequently, additional decommissioning information has been obtained on some of those reactors and on other selected reactors. That information is presented in this appendix in a standardized case history format, together with some decommissioning considerations based on these case histories.

For the reactor decommissionings selected for evaluation in this addendum, data are presented using simplified summary data sheets. It is felt that the cost information developed, together with suggested escalation factors (developed in Section 4) to put the estimates on approximately the same time-cost basis, provides the framework for an information data base upon which planning and preparation for other reactor decommissionings of similar size and type could be accomplished.

A.1 DECOMMISSIONING CONSIDERATIONS BASED ON PAST EXPERIENCES

It should be recognized that it is not always possible to extract from the public records (whether the reactors were licensed or unlicensed) many of the details of a particular reactor decommissioning project. Reasons for this are: 1) a requirement for a standard decommissioning closeout data sheet does not currently exist; 2) cost information is not always obtainable, since many of the smaller reactor decommissionings are done via the fixed-price, competitive bid system and the winning contractor's itemized cost breakdown could provide competitors with proprietory information of an advantageous nature on some future bid; and 3) at universities, where paid student labor is utilized over a lengthy decommissioning time frame, adequate cost records are not always available to reconstruct the total labor cost. Therefore, care should be taken in reaching conclusions based on these experiences, since they may reflect essentially first-time efforts and encompass variations in many important factors, such as extent of previous use, power levels, reactor types (including number and kind of support and/or ancillary facilities), site characteristics, the decommissioning contractor's experience, and the point in time when the contractor was brought on-line. Additional, more-difficult-to-quantify factors that can impact the cost of decommissioning R&T reactors are discussed in greater detail in Section 7.

Individual features of a selected reactor facility may vary considerably from supposedly similar reactor types because of design changes and/or modifications made to it over the facility's lifetime. In any case, a site-specific assessment is required for the safety analysis and for the environmental report submitted with the request for a license amendment prior to actively decommissioning a specific research or test reactor facility.[1]

A.2 SELECTED DECOMMISSIONING CASE HISTORIES

The nuclear reactor facilities considered for subsequent comparison and evaluation in this addendum are given in Table A.2-1. Information obtained on the decontamination and dismantlement experiences associated with these facilities is presented in subsequent subsections. For completeness, simplified illustrations of the major features of these selected reactors are included. In some cases, additional information (e.g., radiation dose rate data, locations of "hot spots," etc.) is included either in the illustrations or in accompanying tables.

The study methodology used to collect data related to these facilities is described in Section 3 and the numerous contacts made to obtain the information are discussed in Appendix B; therefore, neither of these areas are discussed further here.

Descriptions of selected reactor decommissionings follow, together with brief descriptions and general information about the facilities. If more detailed information is desired for a particular facility, the reader is directed to the general references listed at the end of this section.

A.2.1 Diamond Ordnance Radiation Facility TRIGA Mark F Reactor, Forest Glen, MD

The bulk of the information presented in this subsection on the decommissioning of the Diamond Ordnance Radiation Facility (DORF) TRIGA Mark F reactor--an unlicensed facility--is taken from Reference 2. The DORF was operated by the Department of the Army's Harry Diamond Laboratories. The regulatory agency governing operations was the U.S. Army. It should be recognized that very few TRIGA reactors (estimated at <5) have been decommissioned in the U.S. to date. In fact, the documentation on the DORF project was the only TRIGA decommissioning found in the open literature.

A.2.1.1 Description and History of the DORF

The DORF is located at the Forest Glen Section of Walter Reed Army Medical Center in Silver Spring, Maryland, about 8 miles north of the center of

TABLE A.2-1. Selected Reactor Case Histories Used for Evaluation Purposes in this Addendum

Docket No./ Facility (Acronym)	Reactor Type	Current Status	Owner and/or Managing Agency
[a]/Diamond Ordnance Radiation Facility (DORF)	Pool-Type	Dismantled	Department of the Army
[a]/Ames Laboratory Research Reactor (ALRR)	Tank-Type - D_2O	Dismantled	U.S. Department of Energy/Ames Laboratory, Iowa State University
50-99/Lynchburg Pool Reactor (LPR)	Pool-Type	Dismantled	Babcock and Wilcox, Inc.
50-111/North Carolina State University Reactor-3 (NCSUR-3)	Pool-Type	Dismantling Order Issued 6-1-81	North Carolina State University Raleigh, North Carolina 27650 North Carolina State University
50-106/Oregon State University (AGN-201, Serial 114)	Closed Vessel, Solid homogeneous Fuel	Dismantled	Oregon State University

(a) Non-licensed facility.

Washington, D.C. The building housing the TRIGA reactor is about 20 m by 15 m by 7.6 m high. It is located on a 1.7-hectacre site, encircled by an exclusion fence. The TRIGA Mark F reactor operated with two different cores from 1961 to 1977. The first core was aluminum clad. It was replaced with a stainless steel clad core in 1964. The reactor was designed for both steady-state (250-kW) and pulsed operation (2000 MW, maximum pulsing). A total of 242,451 kWh of operations were performed over the operating period of the reactor. General background information is presented in Table A.2-2.

Vertical and horizontal section views are shown in Figures A.2-1 and A.2-2, respectively. With the core suspended by a support structure from a motor-driven carriage mounted on rails, the carriage could traverse the tank. This allowed the reactor to be positioned behind lead doors so that entry could be made into the exposure room immediately after an irradiation test.

TABLE A.2-2. General Background Information on the Diamond Ordnance Reactor Facility

Item	Information
License Number	Not Applicable
NRC Docket Number	Not Applicable
Reactor Address	Harry Diamond Laboratories U.S. Department of Army Forest Glen, Maryland 20783
Reactor Owner/Operator	Harry Diamond Laboratories U.S. Department of Army
Operating Period	1961-1977
Decommissioning Period	September 1979 - February 1980
Current Status	Decommissioned
Reactor Type	Pool-type
Thermal Power	250 kW, intermittent 2000 MW, max. pulsing
Fuel Elements	TRIGA
Reactor and Building Cost Estimate	Not Available

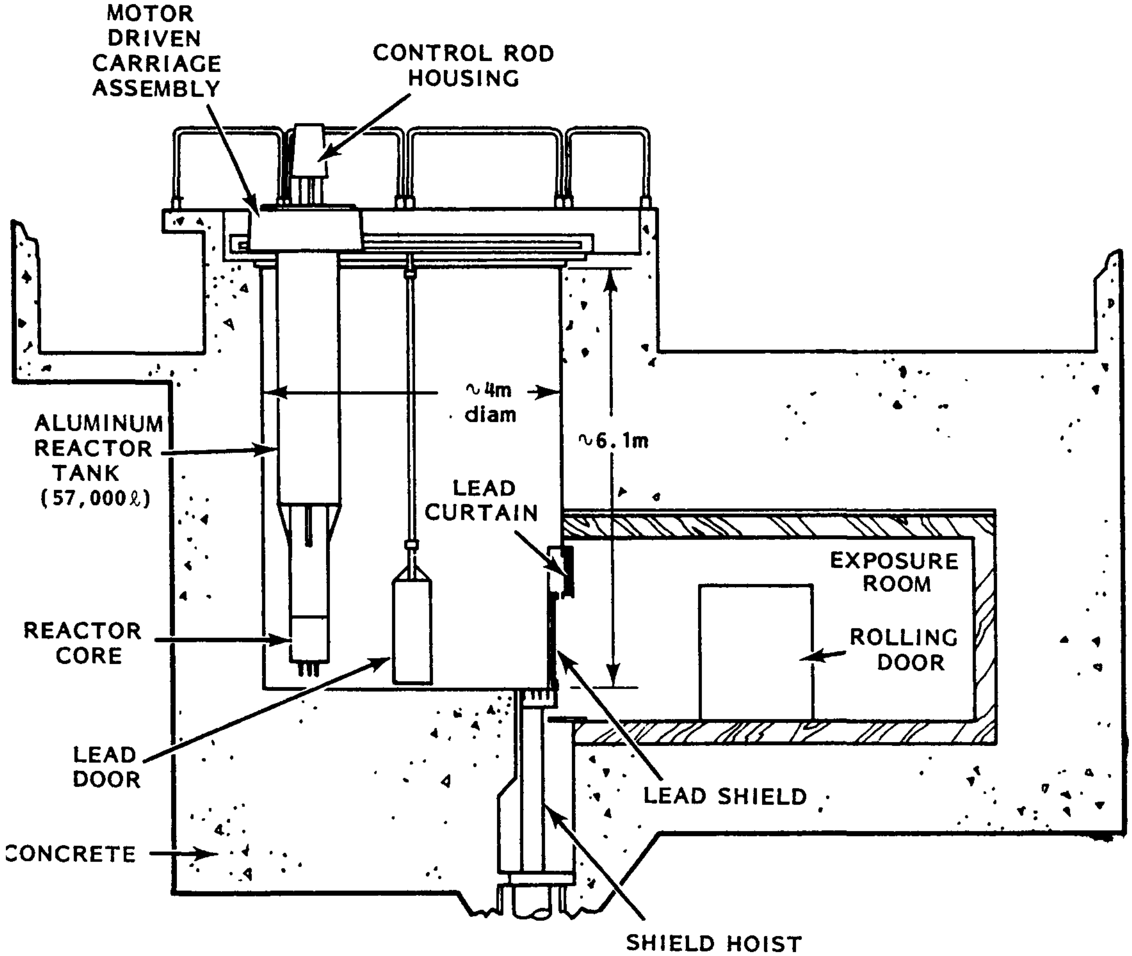


FIGURE A.2-1. Vertical Section View of the Diamond Ordnance Reactor Facility

A.2.1.2 Decommissioning of the DORF

Reactor operations at DORF were terminated in September 1977. The core was removed from the reactor in the spring of 1979 by DORF facility personnel and dispositioned to several universities. The remaining two unirradiated DORF fuel assemblies were accepted by an NRC-licensed, government-owned TRIGA reactor operator.

The Atomics International (AI) Division of the Energy Systems Group (ESG) of Rockwell International was contracted by the Department of the Army to dismantle and decontaminate the DORF. The contract (DAAK 27-79-C-0136) was for a firm fixed price (proprietary information) with a schedule duration of 8 months. The decommissioning was completed within the required schedule and budget.

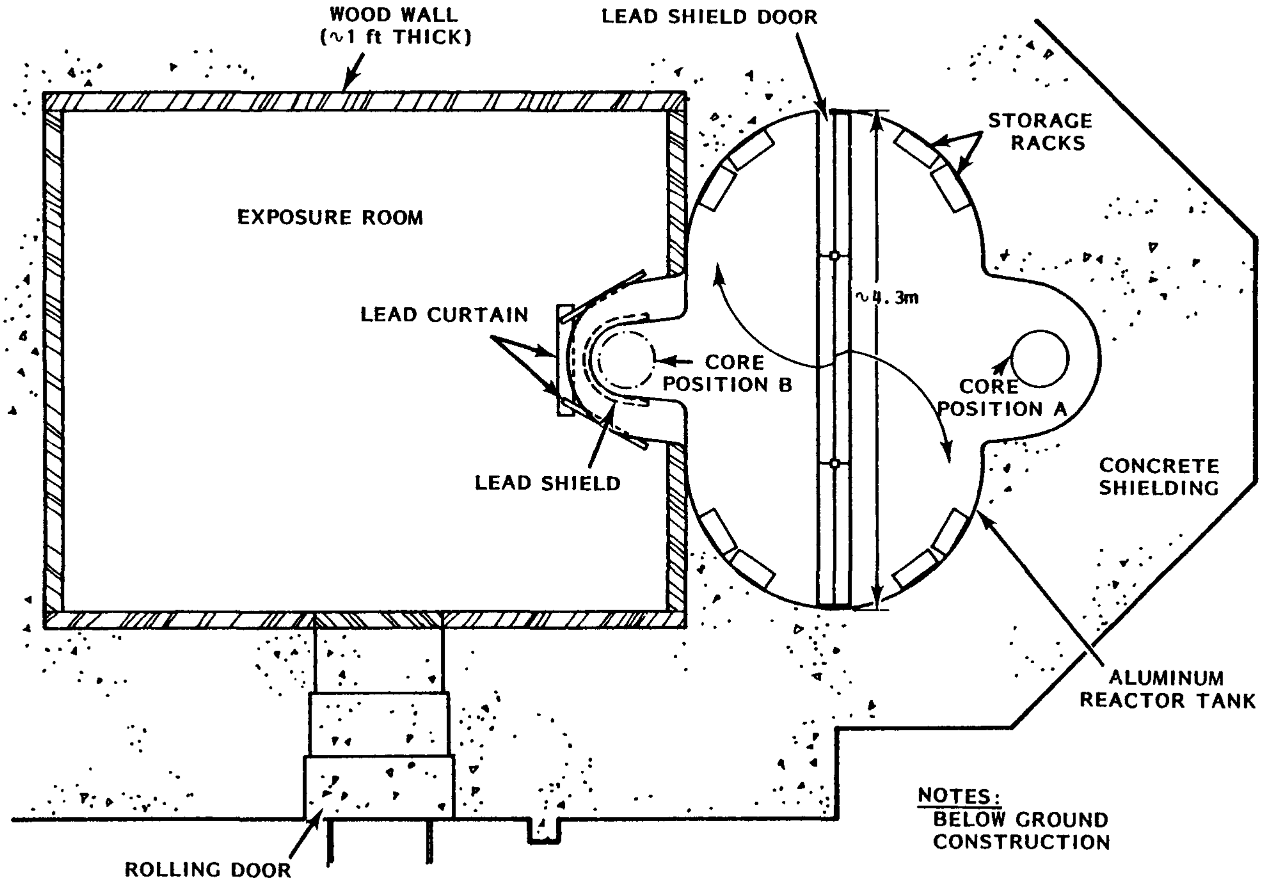


FIGURE A.2-2. Horizontal Section View of the Diamond Ordnance TRIGA Mark F Reactor

Decommissioning Phases. The activities which comprised the decommissioning of the DORF were grouped into three phases. The three phases are listed in Table A.2-3, together with pertinent facts associated with each phase of activities.

Acceptable Radioactivity Levels at DORF. In addition to the acceptable surface contamination levels specified in NRC Regulatory Guide 1.86, the decommissioning contractor established the limits shown in Table A.2-4 as target values to show compliance with ALARA. These limits were based on experience regarding levels that in most cases are reasonably achievable and can be effectively monitored. Radioactive materials and components that exceed R. G. 1.86 limits were removed from the facility. The limits shown in Table A.2-4 were also met in all areas of the facility except in the exposure room where, due to room geometry and the accumulative properties of activation products, the activity ranged from 0.08 to 0.24 mrad/hr as measured with a Technical Associates Mark III Cutie Pie - CP7M. The overall average was slightly higher than

TABLE A.2-3. Summary of the Phases Utilized for Decommissioning the U.S. Army's Diamond Ordnance Reactor Facility

Phase	Description of Phase	Location of Phase Activites	Inclusive Dates of Phase Activities
I	• Planning[a], procurement and staffing activites required to conduct Phases I and II.	- Canoga Park, CA	Sept 21, 1979 - Nov. 21, 1979
II	• Seven activities were completed: (1) site preparation (2) packaging and shipping reactor components to HEDL[b] (3) exposure room dismantlement (4) pool tank removal (5) concrete excavation (6) site survey (7) waste disposal	- Silver Spring, Md	Nov 26, 1979 - Feb. 22, 1980
III	• Demolition (by subcontractors) of nonradioactive portions of the facility	- Silver Spring, Md	Apr. 21, 1980 - May 9, 1980

(a) The resultant Facilities Dismantlement Plan for DORF was subsequently reviewed and approved by the Army Reactor Committee for Health and Safety.
(b) HEDL is Westinghouse's Hanford Engineering Development Laboratories in Richland, Washington.

TABLE A.2-4. Contamination Limits for Decontamination of the Diamond Ordnance Radiation Facility[a]

	Total	Removable
Beta-Gamma Emitters	0.1 mrad/hr average[b] and 0.3 mrad/hr maximum[c] at 1 cm with 7 mg/cm^2 absorber	100 dpm/100 cm^2
Alpha Emitters	100 dpm/100 cm^2	20 dpm/100 cm^2

(a) Data from Reference 2, Table 2.
(b) Measurements of average contaminant should not be averaged over more than 1 m^2. For objects of less surface area, the average should be derived for each such object.
(c) The maximum contamination level applies to an area of not more than 100 cm^2.

0.1 mrad/hr. Individual pieces of concrete from the higher activity areas, when removed from the exposure room, indicated levels below 0.1 mrad/hr. These activity levels were deemed acceptable by the contracting officer's representative and by the United States Army Environmental Health Agency (USAEHA) radiation survey team.

Analyses of the pool tank water were performed to determine compliance with 10 CFR 20.303. These analyses were performed by the decommissioning contractor (Rockwell International), by Teledyne Isotopes, and by the Walter Reed Army Medical Center (WRAMC). The resultant data are presented in Table A.2-5. These data show the water to be well within the allowable limits given in 10 CFR 20, Appendix B, Table 1, Column 2. Walter Reed Hospital's Health and Safety Branch granted Rockwell permission to drain the water through their sanitary sewer svstem.

Concrete Excavation. Following exposure room dismantlement and pool tank removal, a detailed radiation survey was conducted of the exposed concrete structures to establish a map of radioactivity. Concrete samples were cored from selected areas to establish the extent and levels of activation in the concrete structures. The DORF sampling plan identifying the location where core samples were taken is shown in Figure A.2-3. The results of the core sample analysis and a comparison of the results of analysis from two independent laboratories are given in Tables A.2-6 and A.2-7, respectively. The core samples that were provided for comparative analysis were taken from two areas of the exposure room. Sample Nos. 3, 3A, and 3B were taken from the wall and Sample Nos. 34, 34A, and 34B were taken from the floor. Each group of samples were cored as close to each other as possible.

TABLE A.2-5. Analysis of DORF Pool Water

	μCi/ml
Rockwell	4.4×10^{-9} βγ 6.85×10^{-10} α
Teledyne Isotopes	$<1 \times 10^{-9}$ gross β 1.41×10^{-6} H-3
WRAMC	<Detectable gross β 5×10^{-7} H-3

Note: 10 CFR 20 limits were interpreted to be as follows: 4×10^{-7} μCi/mlβγ; 4×10^{-7} μCi/mlα; 3×10^{-3} μCi/ml H-3

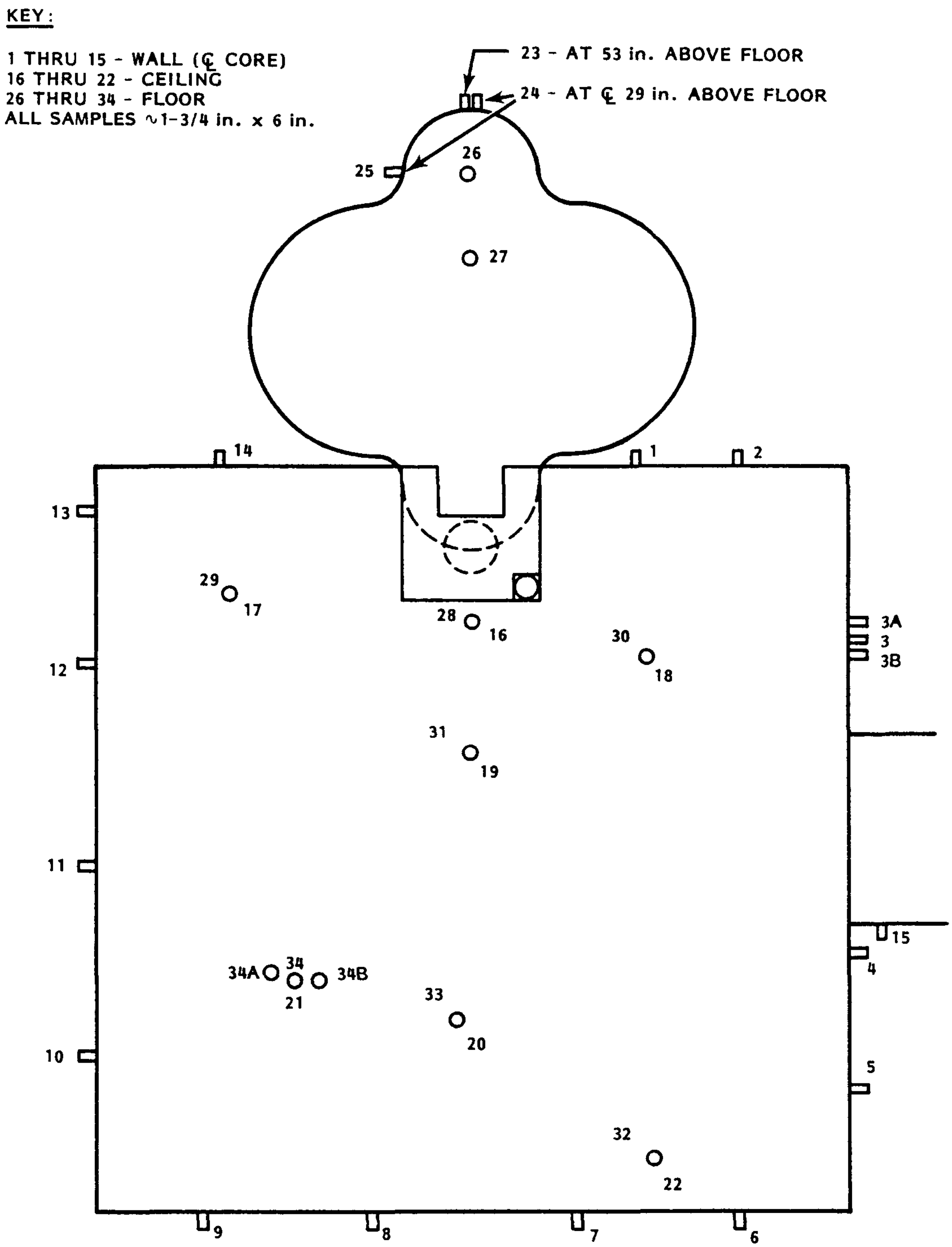


FIGURE A.2-3. DORF Sampling Plan[(a)]

(a) Data from Reference 2, Figure 30.

TABLE A.2-6. Pre-Excavation Analysis of Concrete by Energy Systems Group at the Diamond Ordnance Radiation Facility (gross detectable beta activity)

Core Number	PUG[a]	pCi/g — Distance from Concrete Surface (in.) 0	1	2	3	4	5	6
		Exposure Room Walls						
Ref. 1	Background		3.2	5.2	9.0	LTD[b]	5.0	LTD
Ref. 2	Background	12.4	9.7	LTD	LTD	3.1	LTD	LTD
1	Background	28.0	37.7	23.8	16.6	19.7	10.4	13.3
2	25 cpm	20.5	23.0	11.0	6.8	11.8	8.5	10.6
3	300 cpm	126.8	98.0	63.8	65.8	31.4	36.6	35.8
4	100 cpm	42.1	18.0	22.0	12.0	21.5	18.6	20.1
5	Background	12.8	11.4	9.1	6.0	10.7	4.6	LTD
6	~25 cpm	22.8	8.3	9.5	19.1	5.2	13.1	7.3
7	100 cpm	34.0	27.1	23.4	22.8	13.1	12.8	10.6
8	Background	12.0	19.5	20.1	11.6	8.3	11.8	6.2
9	25 cpm	21.5	10.2	17.0	17.4	14.7	13.7	13.7
10	50 cpm	18.4	16.2	7.0	7.3	5.6	13.3	3.7
11	25 cpm	25.3	22.6	19.1	6.4	12.2	5.6	16.0
12	100 cpm	42.1	33.6	41.0	17.8	14.9	21.1	8.7
13	50 cpm	50.4	27.6	43.3	34.6	18.4	23.8	22.6
14	50 cpm	21.8	15.1	3.1	1.5	LTD	5.8	0.2
15	Background	9.9	7.0	LTD	1.2	4.4	5.4	5.8
		Ceiling						
16	200 cpm	49.9	396.8	26.3	23.8	14.5	17.0	13.9
17	50 cpm	43.9	21.8	27.8	20.1	15.3	6.4	7.5
18	100 cpm	37.7	15.5	35.2	19.5	16.6	17.8	24.2
19	150 cpm	57.2	11.0	20.7	30.9	16.6	14.7	12.6
20	Background	17.4	9.5	15.7	1.0	1.7	8.2	9.9
21	Background	23.8	11.4	7.0	3.5	6.2	9.1	8.1
22	50 cpm	17.0	11.2	8.1	2.3	8.3	9.5	5.4
		Tank						
23	Background	--	11.8	10.3	--	--	--	5.0
24	400 cpm	59.5	28.2	31.3	29.2	12.6	22.8	19.7
25	150 cpm	29.8	14.7	25.5	18.4	5.4	9.9	9.3
26	Background	9.7	15.1	9.5	6.0	1.0	2.9	4.6
27	Background	3.5	0.6	1.2	LTD[b]	LTD	LTD	2.1

(contd on next page)

TABLE A.2-6. (contd)

Core Number	PUG[a]	pCi/g Distance from Concrete Surface (in.) 0	1	2	3	4	5	6
					Floor			
28	100 cpm	43.9	32.9	24.0	26.7	38.3	13.5	18.0
29	100 cpm	20.9	17.6	7.9	11.6	2.3	5.6	12.2
30	50 cpm	18.6	13.3	14.7	14.3	2.5	10.8	10.4
31	50 cpm	19.9	12.6	5.6	9.9	8.3	12.2	LTD
32	Background	7.3	7.7	8.3	3.3	0.6	5.6	11.8
33	25 cpm	19.3	2.3	1.7	7.5	3.7	5.2	LTD
34	Background	15.3	6.0	10.2	11.2	LTD	8.3	5.0

(a) Count rate meter with a 2-in.-thin window pancake G-M detector.
(b) LTD is less than detectable limit.

Core samples were prepared for analysis at DORF and at ESG[a] using existing ESG procedures. The samples were cut with a tungsten carbide saw blade at the appropriate distance from the end designated "the surface." The powder generated by sawing was contained, weighed, and counted on an NMC Model 72, automatic counting system for alpha and beta-gamma simultaneously.

Due to preferential cutting through softer material in the core sample, i.e., binder and soft rock as opposed to the harder rock matrix, this sampling technique did not permit obtaining a fully representative sample of the total activity.

Teledyne Isotopes prepared their samples by cutting through the entire core sample to segment it into 1-in. thick samples. The entire sample was then counted to determine activity. This technique was most representative of the total activity remaining in the concrete at DORF. The results of the concrete sample analysis formed the basis for the concrete excavation plan. Diagrams of the planned excavations are shown in Figures A.2-4 and A.2-5.

Concrete excavation began in the pool tank cavity with the removal of the pedestal which extended under the tank into the exposure room. Jackhammers were used to break this pedestal and the thin wall section between the pool tank cavity and the exposure room. Reinforcing bar (rebar) was removed as necessary to permit further concrete removal or because of activation. Activated concrete in the back of the pool tank cavity was then removed. This area

(a) ESG is the Energy Systems Group of Rockwell International.

TABLE A.2-7. Pre-Excavation Analysis of Diamond Ordnance Radiation Facility Concrete by Teledyne Isotopes

	pCi/g						
Depth	Surface 0-1	1-2	2-3	3-4	4-5	5-6	6-7
3A[a]							
K^{40}	12.7	10.4	5.4	--	12.3	--	--
Co^{60}	154.0	136.0	86.6	443.0	55.3	27.5	20.2
Eu^{152}	281.0	188.0	141	96.6	166.0	93.0	31.2
Eu^{154}	19.0	13.6	5.29	7.3	12.2	7.0	2.3
	466.7	348.0	238.3	546.9	245.8	127.5	53.7
34A[a]							
K^{40}	--	3.8	--	4.0	--	1.9	1.9
Co^{60}	18.2	15.8	6.8	7.8	5.0	4.5	2.2
Eu^{152}	34.6	36.9	14.2	18.1	14.6	9.7	3.2
Eu^{154}	2.9	2.5	0.9	1.2	<0.6	0.9	<0.3
	55.7	59.0	21.9	31.1	20.2	17.0	7.6

ESG Data[b] (Gross $\beta\gamma$ pCi/g)

	0 in.	1 in.	2 in.	3 in.	4 in.	5 in.	6 in.
3B[a]	74.5	70.2	41.3	26.2	24.4	19.0	17.8
34B[a]	12.9	6.7	6.7	11.3	6.3	9.0	4.5

(a) Refer to Figure A.2-3 for location of sample number.
(b) ESG in the Energy Systems Group of Rockwell International.

extended about 2 ft to each side of the core centerline and followed the curvature of the wall. Maximum depth of the excavation was 10 in. at core centerline and tapered to about 2 in. at 2 ft from the centerline. Radiological survey of the pool tank cavity indicated compliance with Regulatory Guide 1.86, stipulations of which are listed in Reference 1, and Table A.2-4, respectively.

Nuclear Controls Corporation (NCC) was contracted to break the activated concrete from the rolling door and to remove the remainder of the door from the site. This operation was supported by the Rockwell staff and took place between January 28 and February 4, 1980. NCC used a rock splitter, a jackhammer, and a mobile hydraulic ram to break up the door and remove it from the facility. The clean rubble from the door was staged onsite for removal during Phase III. The activated rubble was packaged by Rockwell for disposal as radioactive waste.

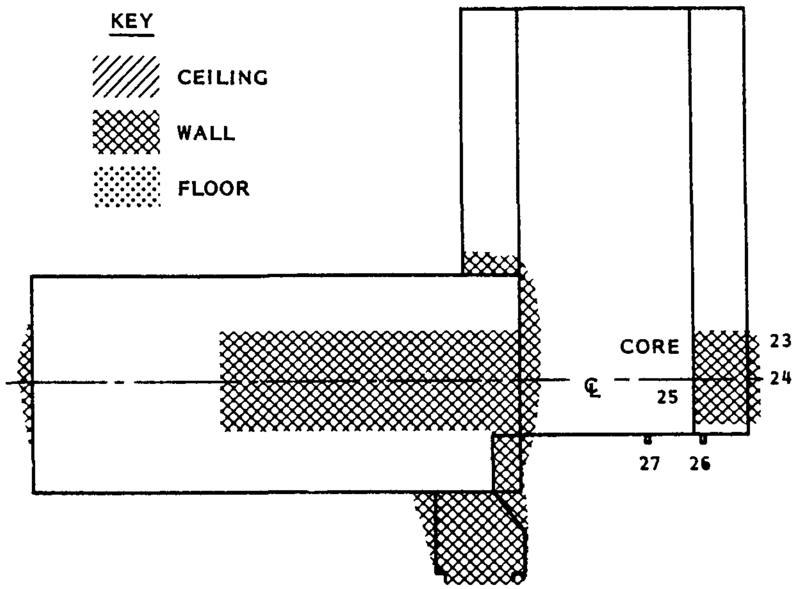


FIGURE A.2-4. Planned Excavation - Side View

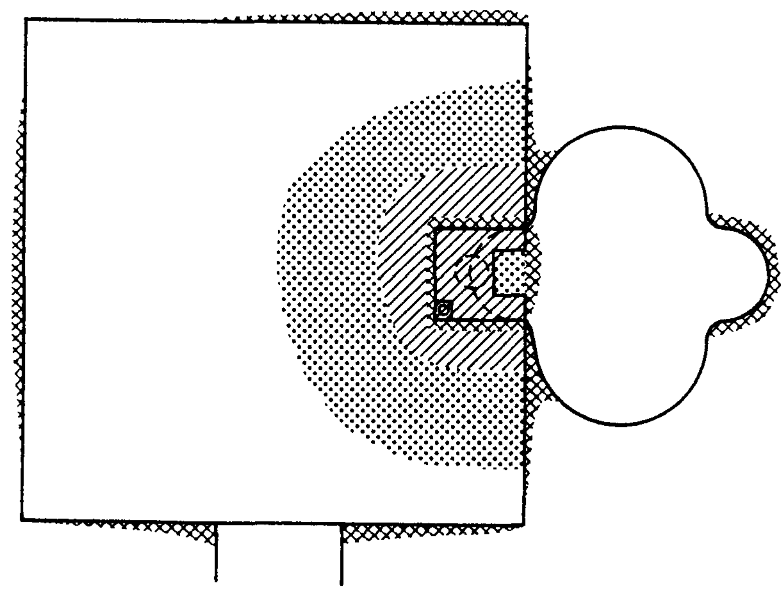


FIGURE A.2-5. Planned Excavation - Top View

The first effort in the exposure room was the removal of some of the phenoline liner (tar paper) from the concrete walls to determine its effect on background radiation in the room. A surface area of about 150 ft^2 of the north and east walls was removed by scabbling with bushing tools in 15-lb chipping hammers. Radiation measurements with a PUG 1 before and after scabbling indicated no difference in reading even to where 1/4 in. of concrete was removed. Based on these results, removal of the phenoline liner from the concrete was terminated.

Based on the core sample analysis and contact radiation readings, there were five areas of the exposure room significantly above background. These areas are identified in Figures A.2-4 and A.2-5 shown previously. Concrete was removed from these areas to depths of 6 to 8 in. using a combination of hydraulic crack forming and impact. A commercial rock splitter was used to hydraulically compress the concrete to form cracks; a jackhammer or chipping hammer was then used to break the concrete from the walls and ceiling. About 40,000 lb of concrete was removed from the exposure room, packaged in DOT-approved shipping containers, and disposed of as radioactive waste.

Radioactive Waste Disposal. The radwastes resulting from dismantling activities included concrete, wood, aluminum, steel, plastic, and rubber. Forty-seven drums (0.21 m^3/each) and eight wooden boxes containing 32.4 m^3, weighing 27.4 Mg, and 1.17 x 10^{-4} Ci were disposed of by land burial. A subcontractor acted as broker for the disposal of the radwastes. In that capcity, the subcontractor handled the arrangements for the transportation and disposal of the waste, taking possession of the radwastes at the DORF site boundary.

Due to the restrictions imposed by the state of South Carolina on the volume of radwastes permitted for burial at the Barnwell site, the earliest space allocation available for acceptance of the DORF radwastes was in April 1980. To ensure completion of the DORF contract on schedule, the decommissioning contractor elected to ship the radwastes to the Beatty, Nevada site instead.

Occupational Radiation Dose for Dismantling Activities. The total external occupational radiation dose for dismantling activities at DORF was <2 man-rem.[a]

Site Survey. Concurrent with and following the removal of radioactive components and materials from the DORF site, radiological surveys were conducted to document the levels of radioactivity left in the facility. Data generated from analyzing concrete for fixed contamination indicated no fixed or removable contamination or activation was detectable outside of the exposure room above NRC Regulatory Guide 1.86 and Table A.2-4 limits. Concrete activation in the exposure room was greater than the Table A.2-4 limits, but less than the limits specified in the NRC Regulatory Guide 1.86.

(a) Based on information supplied by Mr. W. D. Kittinger of the Energy Systems Group of Rockwell International, Canoga Park, California.

Confirmatory (Close-Out) Survey. A close-out survey of the DORF site was conducted between February 25, 1980 and February 27, 1980, by a U.S. Army Environmental Health Agency radiation survey team. This survey was conducted to confirm compliance with NRC Regulatory Guide 1.86 prior to the Army's acceptance of the facility for unrestricted use. The survey team's recommendation, following analysis of the data from the onsite survey, was to accept the facility for unrestricted use and occupancy. Compliance with NRC Regulatory Guide 1.86 was a contracted prerequisite to conducting Phase III tasks. The Army officially notified the decommissioning contractor that the DORF was in compliance with NRC R. G. 1.86 on April 21, 1980. Phase III activities were begun immediately. This phase consisted of the demolition of selected non-radioactive portions of the facility, restoration of any disrupted services to the building, and the repair of facilities damaged by the dismantling activities.

Costs. Inferred costs (1979-80 dollars) of decommissioning DORF are presented in Table A.2-8. The development of these inferentially estimated costs is the result of: 1) applying engineering judgement based on previous decommissioning studies in this series;[(3-5)] and 2) evaluating the limited quantitative data from DORF decommissioning tasks actually completed as described in Reference 2. The best information available suggests the total cost of dismantling the DORF, based on the aforementioned cost development methodology, was about $336,000, not including costs of about $10,000 for transportation of the TRIGA reactor and associated components. The latter costs were paid for by the consignee (i.e., Westinghouse's Hanford Engineering Development Laboratories in Richland, Washington).

A.2.2. Ames Laboratory Research Reactor, Ames, IA

The dismantling of the Ames Laboratory Research Reactor (ALRR) was relatively complex and was well documented in Reference 6 and summarized in Reference 7. It should be recognized that the ALRR is a U.S. Department of Energy (DOE) research reactor; therefore, the licensing activities surrounding it are not necessarily typical of the normal decommissioning activities and criteria of NRC-licensed nuclear R&T reactor facilities. The bulk of the information presented in this subsection on the decommissioning of the ALRR is taken from References 6 and 7. General background information was obtained from the General References given at the end of this appendix.

A.2.2.1 Description and History of the ALRR

The ALRR is located on a 14-hectacre site about 2.4 km from the Iowa State University campus and the rest of the Ames Laboratory. General background information on the 5-MW, tank-type ALRR is presented in Table A.2-9. The arrangement of the structures on the ALRR site is illustrated in Figure A.2-6,

TABLE A.2-8. Summary of Inferred Costs of Dismantling the Diamond Ordnance Radiation Facility in 1979-80

Cost Category	Costs, $	Percent of Total
Labor	144,000	43
Disposal of Radioactive Materials:		
Transportation	8,500	4.1
Burial	5,500	
Tools & Equipment	12,000	3.6
Supplies	14,300	4.3
Specialty Contractors	91,200	27
Misc. Costs:		
G & A[a]	17,800	5.3
Fee	15,200	4.5
Other Expenses	27,500	8.2
Total, Inferred Costs for Dismantlement	336,000	100.0
Other Costs		
Spent Fuel Shipments to Universities	-[b]	
TRIGA Reactor & Components Shipments to DOE-Richland, WA Laboratory	10,000[c]	

(a) G & A is General and Administrative.
(b) These costs were unobtainable.
(c) These costs are assumed to have been paid for by the consignee.

including identification of major structures/areas associated with the site. Auxiliary structures include a waste disposal building and a combination warehouse-laboratory building. A bunker for horizontal and vertical storage of radioactive equipment and material had been constructed near the disposal building.

TABLE A.2-9. General Background Information on the Ames Laboratory Research Reactor

Item	Information
License Number	Not Applicable
NRC Docket Number	Not Applicable
Reactor Address	Iowa State University Ames, Iowa 50011
Reactor Owner/Operator	U.S. Department of Energy/ Ames Laboratory, Iowa State University
Operating Period	1965-1977
Decommissioning Period	January 1978 - September 1981
Current Status	Decommissioned
Reactor Type	Tank Type
Thermal Power	5 MW
Fuel Elements	MTR Type
Reactor and Building Cost Estimate	~$4.5 million (early-1960s)
Support Facilities	~$3.67 million (early-1960s)

The first floor of the Reactor Building (RB) is shown in plan view in Figure A.2-7. The RB has three major regions: the reactor containment room, a laboratory wing, and a staging area. Other features of the RB included a spent fuel storage pool (SFSP), 2.4 m x 4.9 m x 6.4 m deep; a horizontal plug storage facility with a similar capacity to the SFSP was located in the reactor room; and a hot cell was housed within the staging area.

The ALRR was moderated and cooled with heavy water (D_2O) and utilized enriched-uranium MTR-type fuel assemblies. Vertical and horizontal section views, and a simplified flow diagram of the reactor coolant system are shown in Figures A.2-8. -9 and 10, respectively.

The reactor core, 76.2 cm across by 63.5 cm high, was housed in a 1.52-m-diameter aluminum core tank. Six 2.54-cm-thick curved stainless steel plates

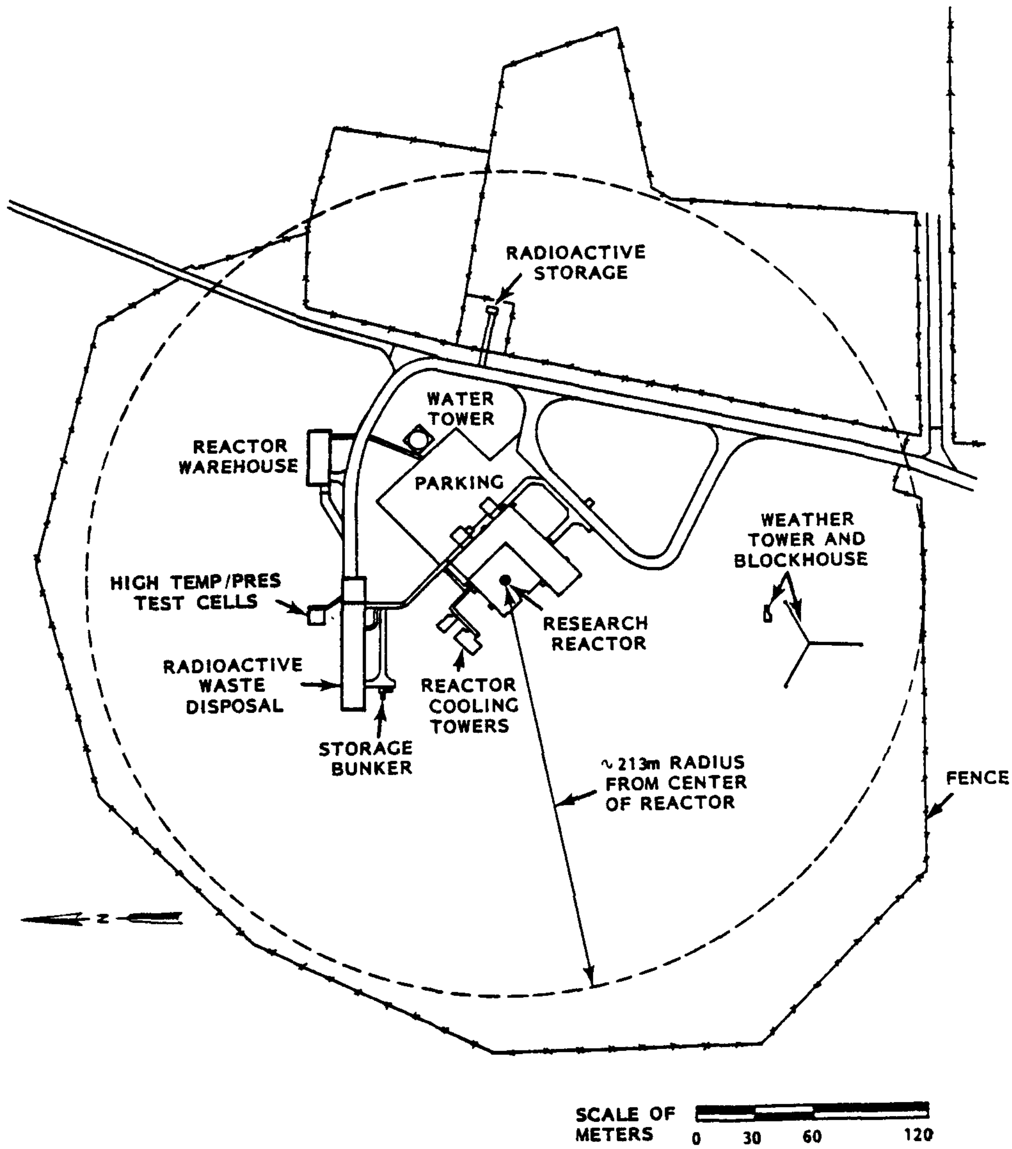


FIGURE A.2-6. Site Plan of the Ames Laboratory Research Reactor

(i.e., the thermal shield) surrounded the core tank on all sides except at the thermal column (see Figure A.2-9). These plates were cooled with light water, which also served as a neutron reflector and circulated through its own heat exchanger in the pump room (see Figure A.2-10). The core tank and thermal shield were contained in a 2.44-m-diameter aluminum tank, which in turn was surrounded by a concrete biological shield.

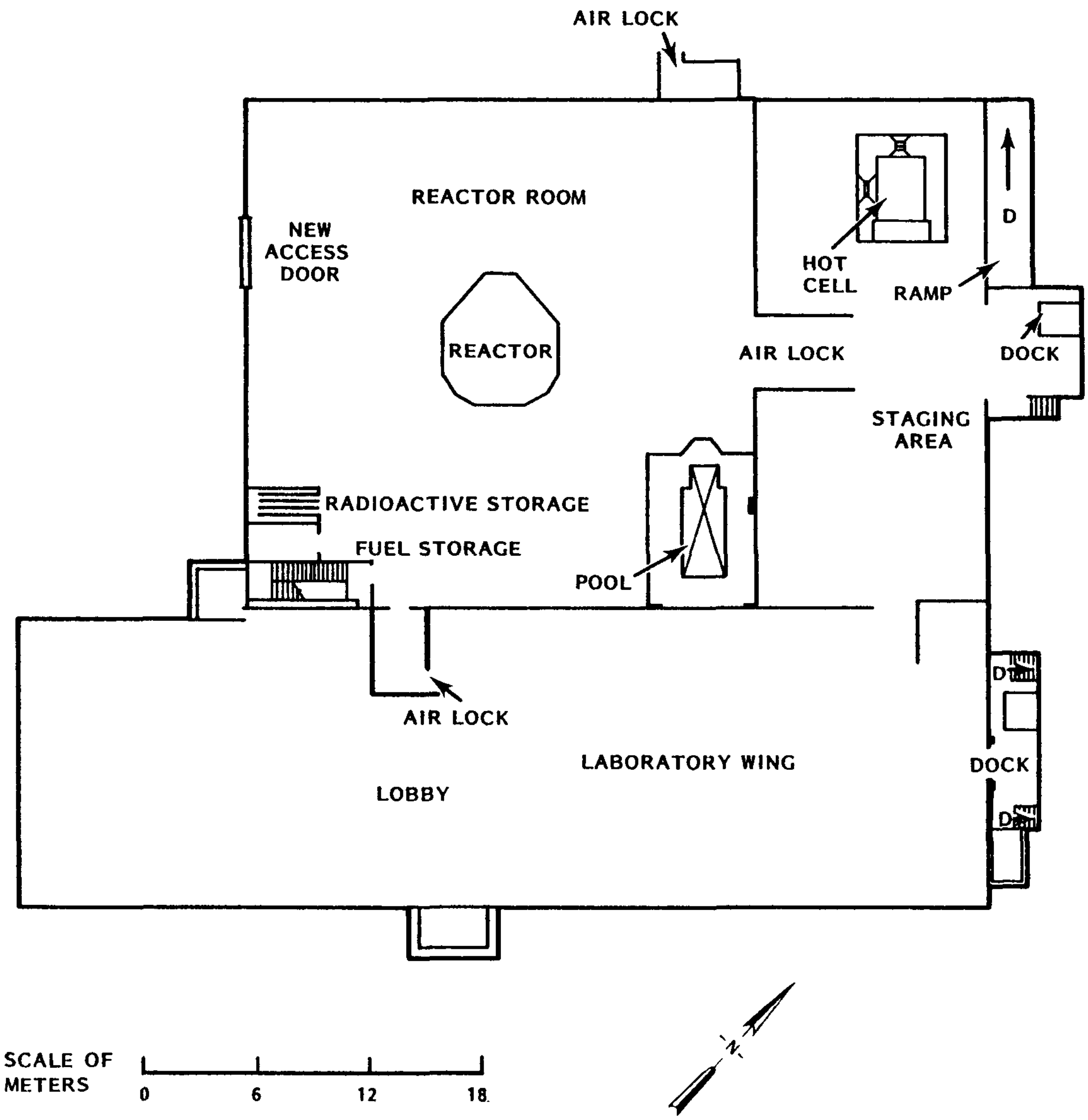
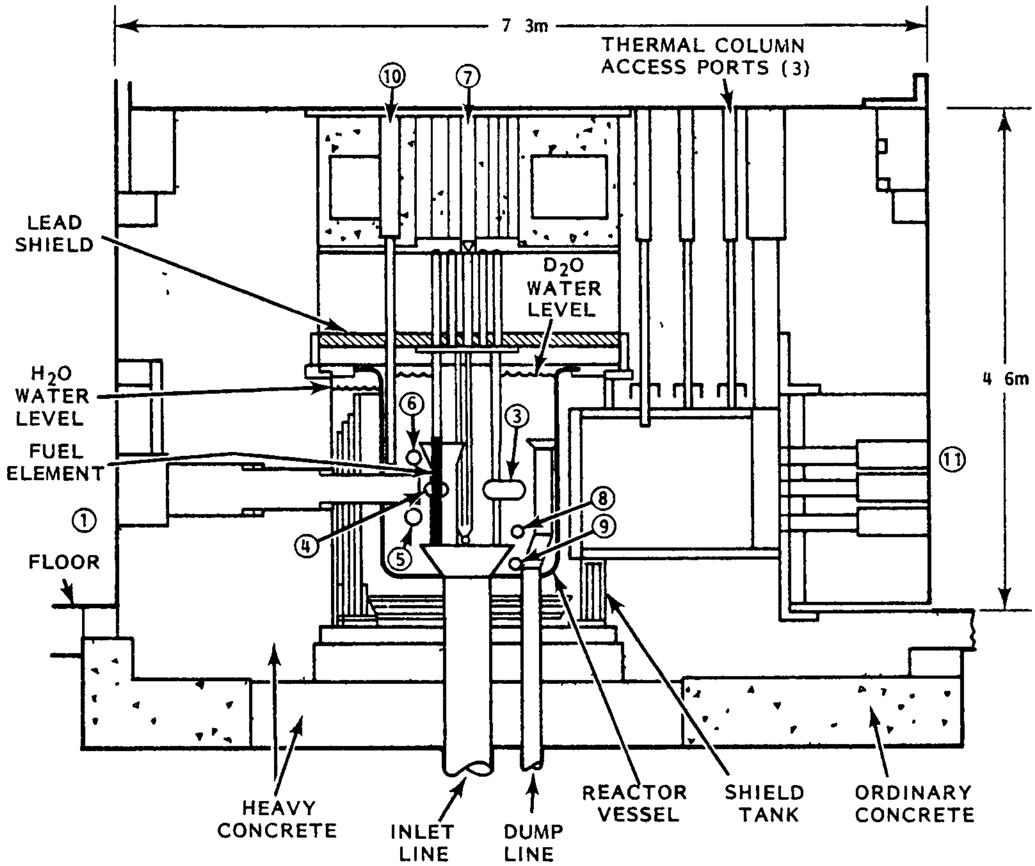


FIGURE A.2-7. First Floor Plan of the Ames Laboratory Research Reactor Building

The ALRR was built between 1961 and 1965. It operated essentially full time (i.e., on a 24-hour, 7-day schedule, excluding refueling, maintenance, etc.). The facility was shut down December 31, 1977, due to a Department of Energy decision regarding consolidation of basic research, which in effect, no longer required many of the ALRR capabilities. The total power produced was 1.52×10^4 MWd.



POSITION	DESIGNATION	NO.
1	HORIZONTAL BEAM TUBES	1
2	HORIZONTAL BEAM TUBES	1
3	HORIZONTAL BEAM TUBES	4
4	HORIZONTAL BEAM TUBES	3
5	HORIZONTAL THROUGH TUBES	1
6	HORIZONTAL THROUGH TUBES	1
7	CENTRAL THIMBLE	1
8	PNEUMATIC TUBES	2
9	PNEUMATIC TUBES	2
10	VERTICAL BEAM TUBES	8
11	THERMAL COLUMN	1

FIGURE A.2-8. Vertical Section View of the Ames Laboratory Research Reactor

A.2.2.2 Decommissioning of the ALRR

In preparation for the timely decommissioning of the ALRR, the ALRR staff prepared an Environmental Impact Assessment. Based on that assessment, the

POSITION	DESIGNATION	NO.
1	HORIZONTAL BEAM TUBES	1
2	HORIZONTAL BEAM TUBES	1
3	HORIZONTAL BEAM TUBES	4
4	HORIZONTAL BEAM TUBES	3
5	HORIZONTAL THROUGH TUBES	1
6	HORIZONTAL THROUGH TUBES	1
7	CENTRAL THIMBLE	1
8	PNEUMATIC TUBES	2
9	PNEUMATIC TUBES	2
10	VERTICAL BEAM TUBES	8
11	THERMAL COLUMN	1

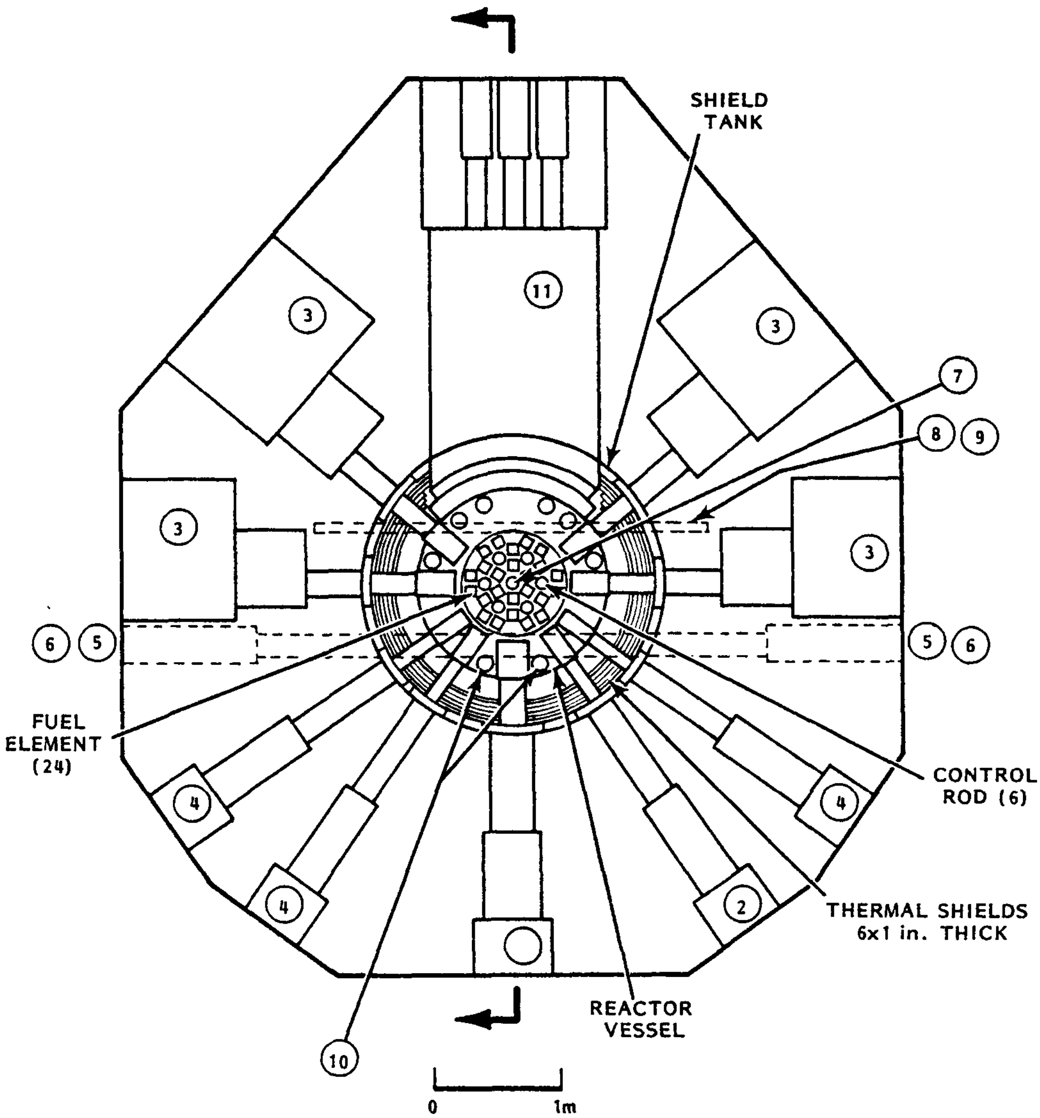


FIGURE A.2-9. Horizontal Section View of the Ames Laboratory Research Reactor

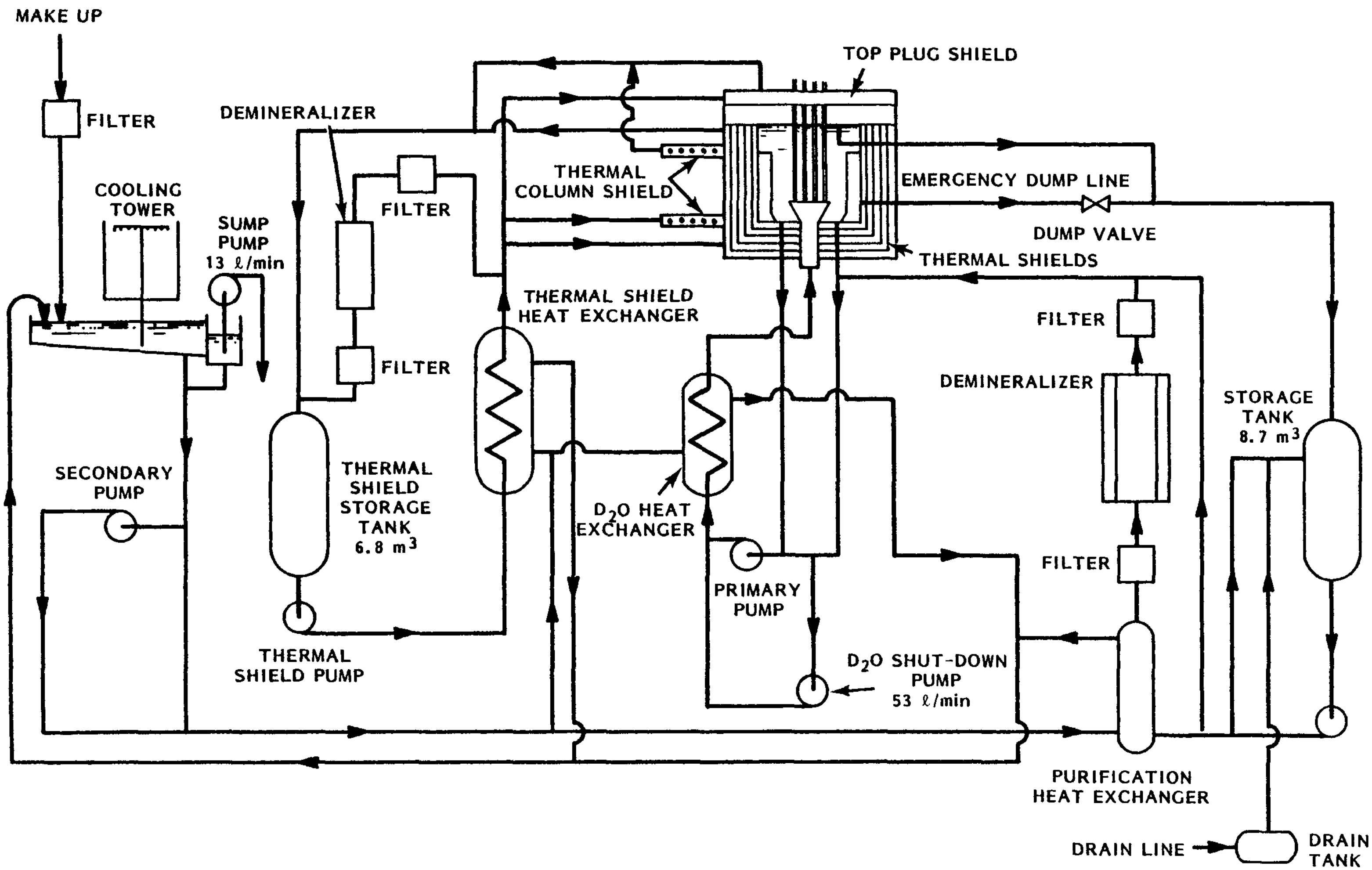


FIGURE A.2-10. Flow Diagram of the Ames Laboratory Research Reactor preparation of an Environmental Impact Statement was considered not to be necessary. The safety aspects of decommissioning the DOE-owned Category B reactor[(a)] were overseen by the Chicago Operations Office (CH). Together with the CH staff, the ALRR staff prepared another document called "Decommissioning Alternatives for the ALRR." The extent of dismantling, i.e., Standby (Alternative 1), Mothballing (Alternative 2), Entombment (Alternative 3), Reactor Pedestal Intact (Alternative 4), Reactor Pedestal Removal (Alternative 5), and Site Restoration (Alternative 6), and the budget proposals were developed in this document.

Analysis of the various alternatives based on total costs, including continued surveillance and escalation, and benefits in the extent of removal of radioactivity showed that Alternative Number 5 best served DOE (then ERDA) and Ames Laboratory objectives.

The dismantling was to be separated into four phases (described later), roughly paralleling the first five alternatives, but avoiding any activities in mothballing or entombment which would not lead toward complete removal of the reactor and residual radioactivity. The objective at this time was to prepare the building for release for "unrestricted use." The sum of $4.5 million was budgeted for the decommissioning and the work was scheduled to take about 3 years.

Alternative Number 5 allowed the existing operations and support staff to begin the work immediately after final reactor shutdown. Also, an immediate start reduced the impact of inflation on costs. The only disadvantage was that it was not possible to include the costs as a line item on a Congressional appropriation, which caused funding problems when schedules had to be slipped across fiscal years.

Decommissioning Phases. As previously mentioned, the dismantling was separated into four phases. The four phases are listed in Table A.2-10, together with pertinent facts associated with each phase of activities and the expected and actual completion dates for the various tasks. The original schedule called for completion of the physical work by the end of calendar year 1980, with the final report to be prepared in the January-June 1981 period. The actual work was completed in September 1981, and the final report was largely completed by that time.

(a) Department of Energy designation as a Category A reactor is based on power level (e.g., 20 MW steady state), potential fission product inventory, and experimental capability. All other DOE-owned reactors (not including Naval Reactors) are designated Category B.

TABLE A.2-10. Summary of Phases and Significant Tasks Utilized for Decommissioning the DOE-Owned Ames Laboratory Research Reactor (ALRR)[a]

Phase	General Description of Phase	Significant Phase Tasks No.	and Description	Scheduled and Actual Completion Dates, month/year: Scheduled	Actual	Remarks
A	Placing the Reactor in Stand-by Status			9/78	9/79	• Scheduled for the period January-September 1978, included shipment of fuel, coolant and previously activated reactor parts, removal of experimantal equipment and leveling of the secondary system cooling tower.
		- A-1	Dispose of fuel	7/78	6/78	
		- A-2,3&4	Dispose of coolants (D_2O and H_2O)	5/78	5/78	
		- A-5	Remove experiments and equipment	5/78	6/78	
		- A-6, B-1,2	Dispose of experimental facilities, control rods, radioactive parts	11/78	9/79	
		- A-11	Remove cooling tower	9/78	6/79	
			Remove water tower	1980	9/78	
			Improve truck access	NS[b]	6/79	
B	Removal of Readily Handled Active Material			3/79	9/81	• Scheduled for the first half of FY 1979, October 1978 - March 1979 included the removal and disposal of control rods, removable parts of the experimental facilities, the top plug, and electrical and electronic systems.
		- B-2, C-5	Seal thermal shield tank, install filter	1/79	6/79	
		- B-3	Remove top plug assembly	7/79	6/79	
		- B-4, C-1	Remove electrical systems	12/78	9/81	
			Restore pool visibility	NS	3/79	
C	Deactivation			3/80	8/80	• Scheduled for the April 1979 - March 1980 period, half each in FY 1979 and 1980. The schedule included removal and disposal of all remaining pump room systems and of the reactor core tank, thermal shield steel and thermal column.
		- C-2,3	Clean out pump room basement	8/79	7/80	
		- C-4	Remove and dispose of core tank	8/79	8/79	
		- C-6	Remove, section, and dispose of thermal shield[c]	12/79	8/80	
		- C-7	Remove thermal column graphite	12/79	3/80	
D	Reactor Removal and Cleanup			12/80	9/81	• Scheduled for the period April - December 1980 with the expectation that little work would remain for the balance of FY 1981. However, delays in completion of earlier contracts and a change in the disposal site delayed the start of this work by six to nine months. In addition to removal of the pedestal and the floor beneath it, Phase D included filling the hole and the spent fuel storage pool and many items of final clean-up.
		- C-8, D-1,2	Remove concrete pedestal (or, biological shield)[d]	7/80	11/80	
		- D-3,4	Remove exhaust systems, stack	12/80	6/81	
		- D-5	Replace concrete in floor, cover pool	9/80	6/81	
		- D-6	Remove hot cell	12/81	4/80	
		- D-7	Remove hot waste tank, lines	12/80	9/81	
		- D-8	Dispose of casks	12/80	3/80	
		- D-9	Dispose of residue, clean up	12/80	9/81	
			Remove acoustic material	NS	3/81	
			Clean up drain lines, storage pool	NS	6/81	

(a) Data presented in this table was compiled from information given in Reference 6.
(b) NS means not scheduled.
(c) This shield was unique to this reactor in the U.S.
(d) This task was both the most visible and the most expensive aspect of decommissioning the ALRR.

A consulting firm, Nuclear Energy Services, Inc., was engaged to provide expertise in planning, since its staff had been involved in earlier decommissioning projects. They provided advice and prepared draft bid specifications for the major operations performed by contractors.

Except for those tasks that had to be done in sequence, efficient use of manpower was considered more important than adherence to a schedule and many deviations from the schedule resulted. Completion of some tasks, e.g., removal of coolant storage tanks and the hot waste line, was purposely delayed so that the systems to be removed could be used in the operations.

The major reasons for the delay in completion were the long preparation period before the work on cutting the stainless steel thermal shield plates could begin and the extra work caused by the existence of unsuspected welds between the plates.

In addition, some delay, no more than a month, was caused by a change in disposal sites from commercial at Barnwell, South Carolina, to DOE at Richland, Washington.

Removal of the Concrete Pedestal, Tank, etc. (Tasks C-8, D-1,2). As reported in Reference 6, the demolition of the concrete pedestal or biological shield of the reactor was the most expensive and most visible aspect of decommissioning. Preparation included estimation of the induced radioactivity by taking three corings of the concrete, two horizontal and one vertical, to obtain profiles of the gamma-emitting activities. The results of the horizontal corings, which covered the full radial thickness of the pedestal, are shown in Figures A.2-11 and A.2-12, calculated for June 1, 1979. Three gamma emitters were identified, ^{60}Co, ^{65}Zn, and ^{54}Mn. In addition to showing rapid decrease in radioactivity with distance out from the center, these corings showed that the concrete near a beam tube was considerably more radioactive than that farther from any tube.

Although the possibility of local disposal of some of the concrete had been considered, it was decided that the difficulty of monitoring and segregating the active and inactive rubble would outweigh any cost advantage in having less rubble to box, transport, and bury.

Extensive sampling was done on the concrete below the reactor pedestal, on both the inside and outside of the pump room wall. Amounts of gamma emitters and tritium were determined in the samples. Low levels of some gamma emitters, particularly ^{60}Co and ^{137}Cs, were found in a few of the samples, but much higher concentrations of tritium as tritiated water or crystallization were found. Tritium was determined by heating the concrete sample to 400°C and collecting the water driven off. The tritium content of the water was determined

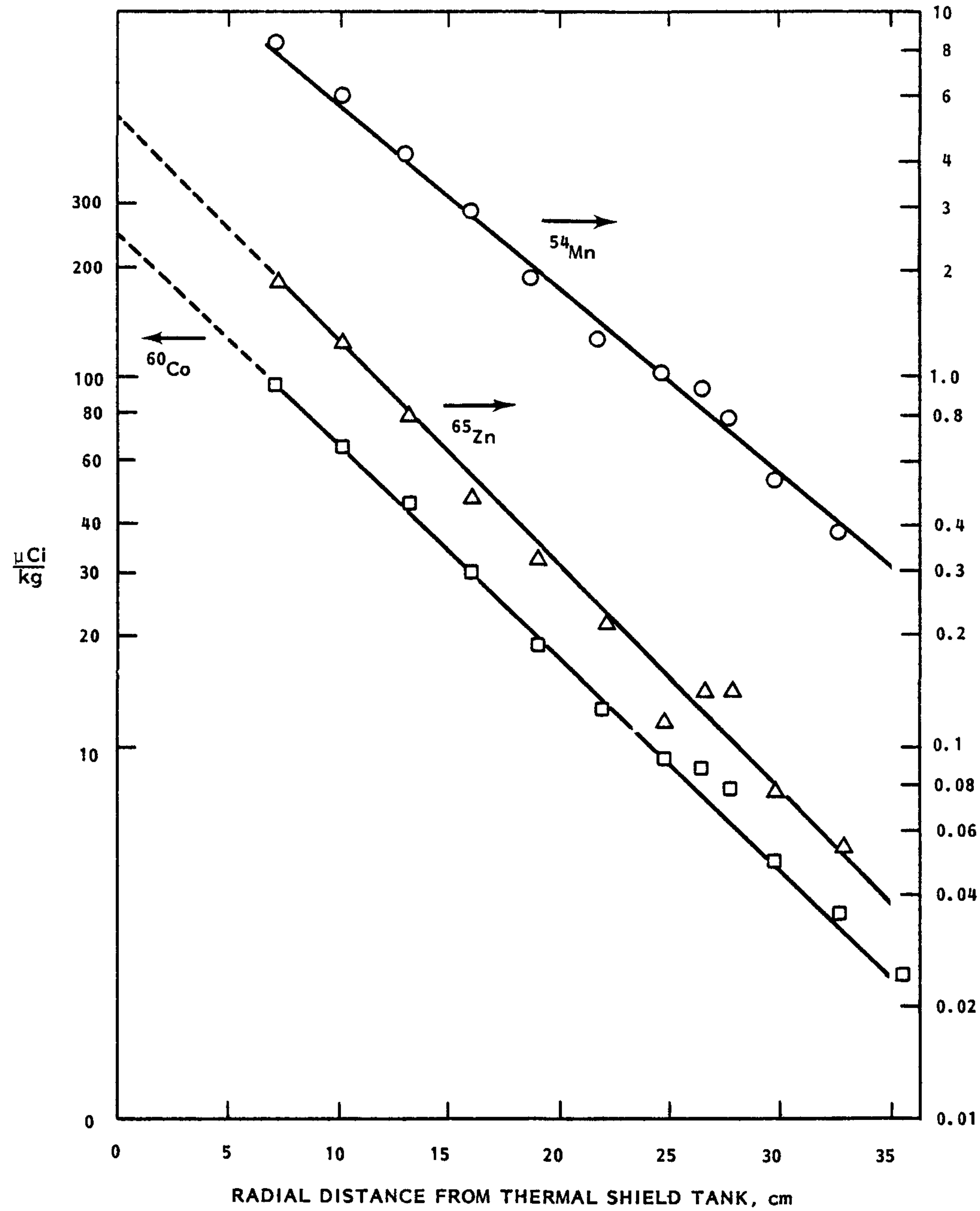


FIGURE A.2-11. Radial Distribution of Three Gamma Emitters in the Inner Concrete at Height of Core Centerline - Concrete Coring Number 1.

with standard liquid scintillation technique, and the weight loss of the sample on heating was used as its water content to provide the tritium content in microcuries per kilogram of concrete.

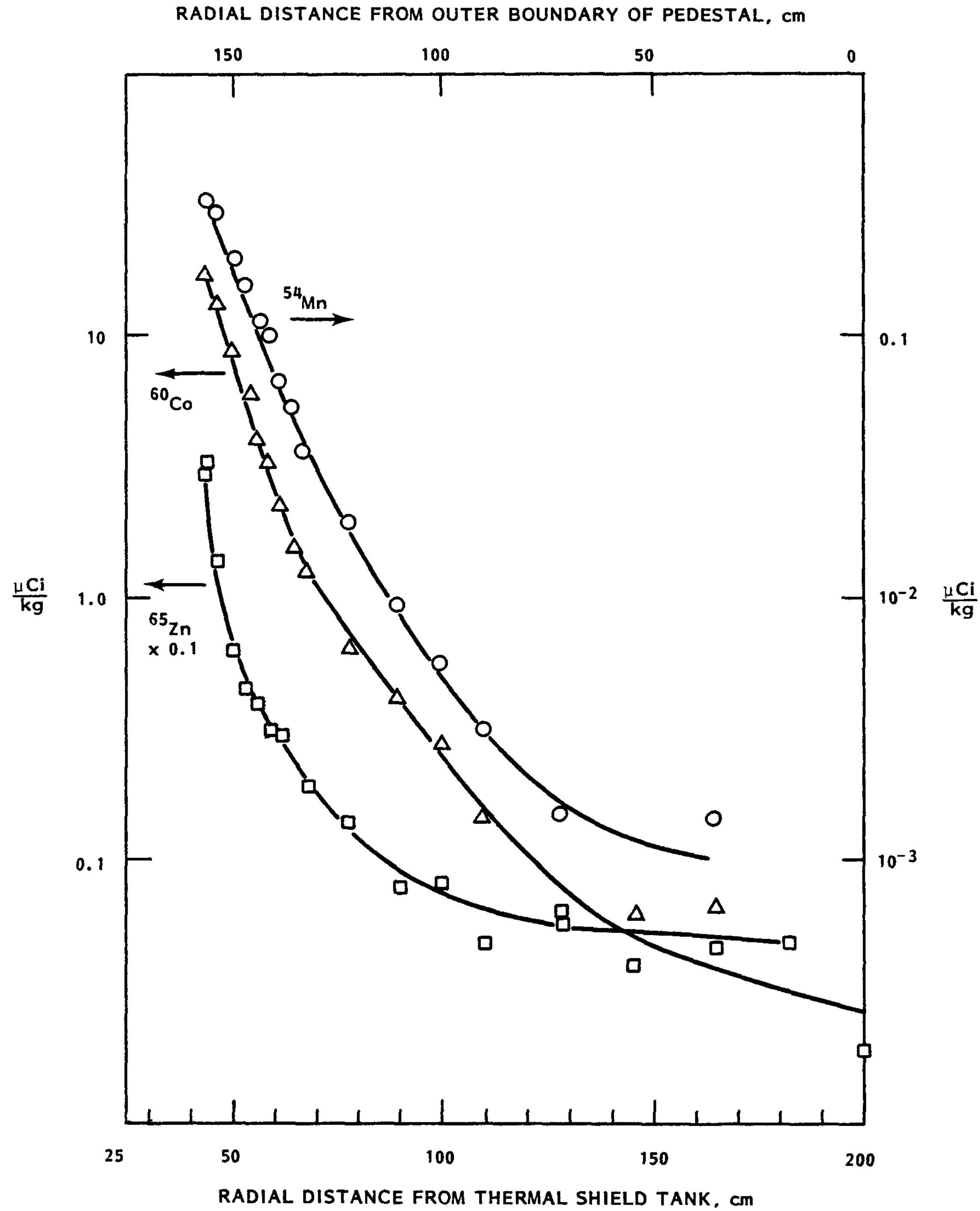


FIGURE A.2-12. Radial Distribution of Three Gamma Emitters in the Outer Concrete at Height of Core Centerline - Concrete Coring Number 2

Leaks that had occurred in the primary coolant system during reactor operation had released substantial quantities of tritium-contaminated heavy water. At that time, heavy water was recovered from the reactor trench and the basement floor. The measured tritium content of the room air (tritiated water vapor) increased, but the problem was not operationally serious. However, aftereffects of these leaks proved more serious for some decommissioning activities than expected. The heavy water, which at that time contained approximately 1.7 Ci of tritium per liter, penetrated into the concrete and exchanged with combined water in the concrete. It remained bound and undetected in the concrete until surfaces were exposed during decommissioning. Tritiated water vapor in the air also exchanged with bound water in the concrete throughout the building. This provided sources of small amounts of tritium that persist in the floors, walls, and ceilings of both levels of the reactor containment area. Tritiated water vapor is slowly being released from the concrete to the room air by exchange and diffusion. The release did not create an exposure problem for reactor personnel during operation, and there is no problem at the present time.

Since tritium contamination in concrete is impossible to measure without taking and analyzing samples, the contamination was not detected until a program to determine residual contamination was begun after the contract for the pedestal removal had been let. The program was expanded considerably as the contamination was found to extend throughout the reactor room. Concentrations of tritium ranged widely from high levels (up to 1 μCi/g of concrete) in areas that had been in direct contact with the primary heavy water to the 10^{-4} μCi/g level in locations where airborne tritiated water vapor had exchanged with the water in the concrete in the floors, walls, and ceiling of the reactor room.

The concentration of tritiated water vapor in the air in the reactor room, pump room, and exhaust stack was measured daily during reactor operation and decommissioning. The tritium content dropped sharply immediately after shutdown, increased to its former levels during demolition of the pedestal and returned to the low values as soon as demolition was complete. Experiments were performed to establish the sources of tritium. It was found that the south face (Face 9) surface was a major contributor to the airborne tritium but that the floor and the other building areas were also important sources. The conclusion was reached that removal of additional concrete from Face 9 or other areas would not reduce the tritium levels enough to justify the effort or cost.

Based on recommendation by the DOE audit team, the Argonne-based MED/AEC Radiological Survey Group, and the Laboratory, DOE decided that unrestricted use of the reactor room was not attainable at this time without major concrete removal. This designation was replaced by that of "monitored use" for that room, which would require continued health physics surveillance and concurrence for future uses of the area. Under these conditions, there would not be any restrictions on the use of the space for laboratories or offices, except that appropriate monitoring of the area would be required, and any building modifications would have to be examined for their potential radiation hazard. Since the Laboratory will continue to maintain a health physics group, this premise does not limit logical future uses of the building.

Removal of the Hot Cell and of the Hot Waste Tank (Tasks D-6, -7). The hot cell in the staging area (see Figure A.2-7) was decontaminated and removed by Laboratory personnel. It contained fairly high-level radioactive scrap which was removed and packaged for disposal. The inside surfaces of the cell, painted concrete block, were decontaminated to the extent possible, removed and boxed for shipment to the disposal site. The remaining material of construction, poured concrete, concrete block and sand, were disposed of locally. The remote manipulators and the large lead glass window and its frame were removed, decontaminated, packaged and shipped to the MIT Reactor, a transfer arranged with DOE by the MITR staff.

Six vertical storage holes into the floor of the cell and a control rod test hole in the staging area were somewhat contaminated. Metal liners and tile casings were removed, and where necessary, earth was removed to reduce radioactivity to undetectable levels. The holes were then filled with sand and capped with concrete.

A concrete bunker and pit had been built outside near the waste disposal building for horizontal and vertical storage of plugs and similar items removed from the reactor. The bunker was built of very high-strength concrete, and its removal required extra effort. The vertical storage holes, steel liners buried in earth, presented difficulties because one of the liners ruptured releasing some radioactivity and requiring removal of earth from the immediate area.

The hot waste systems for the reactor included a 10.6-m^3 holding tank adjacent to the reactor building that received the waste lines from the building and emptied into a 3-inch pipe line to the waste disposal building. The tank was held in a concrete pit below grade. After the pit was uncovered and its top removed, the waste lines from the reactor building were connected directly to the line to the waste disposal building, bypassing the tank which was then removed from the pit. The residual waste water in the tank was removed and processed for disposal and the remaining sludge was dried in place. The tank was filled with acoustic tile from the reactor room walls and included in a shipment to the Rockwell Hanford Operations (RHO) DOE disposal site at Richland, Washington.

Decontamination and Removal of the Spent Fuel Storage Pool (SFSP). The location of most of the cutting operations was the SFSP. The pool was lined with stainless steel sheeting, separated from the concrete surface by a layer of grout. After removal of all material, the water remaining in the pool was transferred to the waste disposal building where it was cleaned by filtration and ion exchange, and the clean water was released to the sewer.

The stainless steel surface was scrubbed and painted to remove and fix any residual contamination. The sheeting was ripped off and cut to fit boxes for disposal. The grout was also chipped off, boxed and shipped, leaving a surface nearly clear of radioactivity. Samples of the concrete of the pool wall and floor were analyzed for tritium and gamma emitters, yielding estimates for the total amounts present of 23 mCi of tritium, 8 Ci each of ^{60}Co and ^{137}Cs, and <1 μCi of other gamma emitters such as ^{65}Zn and ^{134}Cs.

The water circulation lines between the pool and the basement were cleaned to the extent possible by swiping and flushing successively with detergent, acid, alkali, and water. The total residual activity was estimated as less than 4 μCi of ^{60}Co and ^{137}Cs. Permission was obtained to allow this contamination in the pipes to remain, and the outer ends of the pipes were capped. In the performance of the contract for filling the pool as a part of replacing the reactor room floor, two inches of concrete were removed from all areas where any surface radioactivity might have been present.

Radioactive Waste Disposal. Details on shipments of radioactive waste and usable material from dismantling the ALRR are summarized in Table A.2-11, together with the total disposal costs. It can be seen from the table that several subcontractors were utilized. A total of 83 radioactive waste shipments were made to various low-level waste burial grounds. Another 27 "non-waste" shipments were necessary for such items as experimental equipment, unirradiated and spent fuel, heavy water, etc. for a grand total of 110 waste shipments. The sum of the disposal cost is $601,300 which represents about 14% of the total costs of dismantling the ALRR.

Occupational Radiation Dose for Dismantling Activities. The total exposure for the decommissioning was 69.4 man-rem distributed among 92 persons. Approximately three-fourths of this dose was received by reactor personnel, with the remainder being received by the various subcontractors' personnel.

A.2.2.3 Final Site Condition of the ALRR

The original goal for decommissioning the ALRR as stated in the Environmental Impact Assessment was to place the building and site in condition for unrestricted use by removing the reactor-related radioactivity. The radiochemistry laboratories in the laboratory wing (Rooms 118-123), the laboratory part of the Warehouse/Laboratory Building, and the Waste Disposal Building were excluded from the goal of unrestricted use since it was considered that they would be in continued use involving radioactivity. However, removal of reactor-related radioactivity from these areas was included in the decommissioning plan.

TABLE A.2-11. Summary of Waste Shipments and Total Disposal Costs of Dismantling the ALRR[a]

Destination	Originator	No. of Shipments	Wt, tons	Vol, 10^3 ft^3	Act, Ci	Costs, $K: Packaging	Transp. & Cask Rent	Disposal	Total
• Waste Shipments:									
Barnwell	ALRR	17	193.2	8.69	842.5	14.3	53.6	59.2	127.0
	Subcontractor	10	88.7	1.98	5890	0.5	40.3	28.9	69.7
Subtotals		27	281.9	10.67	6732	14.8	93.9	8.1	196.7
NECO	ALRR	1	19.3	0.86	0.26	1.1	3.8	3.3	8.2
RHO	ALRR	11	128.3	9.3	84.4	14.1	69.5	33.9	117.5
	Subcontractor	44	920.5	20.0	64.0	50.0	147.2	44.3	241.5
Subtotals		55	1048.8	29.3	148.4	64.1	216.7	78.2	359.0
TOTAL, Waste		83	1350.0	40.83	6881	80.0	314.4	169.6	563.9
• Non-waste:									
Experimental equipment		6	(b)	(b)	0		8.0		8.0
Excess property		14	(b)	(b)	101.1 (T)		4.4		4.4
Heavy water		1	14	0.42	11,940.0 (T)	0.9	3.4		4.3
Unused fuel		2	0.3	0.005	0.1				0
Spent Fuel		3	0.6	0.01	3.12×10^5	0.7	17.6		18.3
Neutron sources		1	(b)	(b)	6		2.4		2.4
TOTAL, Non-waste		27	14.9	0.44	3.24×10^5	1.6	35.8	—	37.4
OVERALL TOTALS		110			3.31×10^5	81.6	350.2	169.6	601.3

(a) Data are taken from Table 5 of Reference 6.
(b) Weights and volumes not available.

The following writeup on criteria is taken directly from Reference 6. It is indicative of the problem encountered in decommissioning the ALRR while attempting to meet the values of residual levels of radioactivity acceptable for unrestricted use.

Criteria. Guidelines on values of residual levels of radioactivity acceptable for unrestricted use employed during the course of decommissioning the ALRR were those of DOE Order 5480.1 Chapter XI, Table II (also in 10 CFR 20, Appendix B) and the unrestricted use levels of NRC Regulatory Guide 1.86. The former are maximum values averaged over a year for the concentrations of radioactive isotopes in water and air releasable to the general public. The relationship between allowable residual radioactivity in soil and concrete and these values is not clear. The criteria originally suggested were that concentrations of radioactivity in water, soil and concrete of 10% of the Table II value for water could be allowed to remain. This was to be defined on a weight basis, i.e., concentrations in μCi/g of the material in place of μCi/ml of water used in Table II.

In informal discussion with CH, it was indicated that levels in the range of 1-3% of the Table II value should be the goal rather than 10% in guiding the removal of soil in areas which contained low levels on contamination.

The discovery of widespread low-level diffusion of tritiated water into the concrete of the reactor room floors and walls made it obvious that the criterion of 1-3% of the Table II value could not be met for tritium in this part of the building. The ANL-based MED/AEC Radiological Survey Group stated in their report, "Interim Overview/Certification Activities Report for the Ames Laboratory Research Reactor Facility, Ames, Iowa" of February 11, 1981 that "It is also quite evident, from the airborne tritium levels encountered, that the release of this structure for unrestricted use is not possible at this time or in the near future." This conclusion was endorsed by CH and agreed to by the Ames Laboratory and has been used as the basis for decontamination of the reactor room.

However, this decision does not imply that the room cannot be used. Another conclusion by the Survey Group was that it appears possible "to essentially allow uncontrolled access" to the room as long as Health Physics surveillance of airborne tritium is maintained. Exemptions from strict adherence to the unrestricted use criteria for removal of radioisotpes other than tritium were granted for several pipe lines buried in concrete. (The specific aspects of the problem are discussed in detail in Reference 6.)

Final Site Condition. In August and September 1981, soil samples were taken at two depths from 65 sites around the reactor using a grid based on quadrant/radial segment areas centered on the reactor, including areas inside and outside of the reactor fence. Samples were also taken from five control sites. To this date all control site samples and seven of the reactor site samples have been analyzed by gamma spectroscopy. All samples contain ^{137}Cs with no significant difference between reactor site and control samples. One site sample showed ^{95}Zr and ^{95}Nb at levels of approximately 0.1% of the Table II Radioactivity Concentration Guide Values for Unrestricted Areas. Additional samples have been prepared for gamma analysis and sufficient samples will be analyzed to provide adequate documentation.

Traces of radioactivity dating to pre-reactor days remain in a controlled waste holding area on the site which has been used by the Laboratory since 1950. Most of the radioactive material stored in this area has been removed, and much of it was included with decommissioning waste shipments. Surveys show a small residue of slightly contaminated soil, with uranium and thorium the major components.

In summary, the reactor and its associated systems, components and wastes have been removed, and major decontamination has been completed. Only the task of detailed survey and low-level decontamination remains to be completed as of late 1981. Documentation in the form of interim and final addenda to the ALRR Final Report (i.e., Reference 6) will be made as this work progresses.

A.2.2.4 Costs

The original sum budgeted for decommissioning was $4.5 million. During FY 1978 expenses were incurred more slowly than anticipated, freeing approximately $100,000 for work related to but not directly part of decommissioning. In FY 1980 funds amounting to $165,000 could not be spent because the work fell behind schedule. The budget outlay was reduced accordingly and actual total expenditures were $4.335 million. A summary of the costs of dismantling the ALRR (per Alternative Number 5 as previously discussed in Section A.2.2.2) is presented in Table A.2-12. A breakdown of the costs by tasks is given in Table A.2-13. The principal cost item is staff labor, contributing about 42% of the total. About 23.4% of the total dismantling cost is due to the use of contractors for completion of the various tasks.

As can be seen in Table A.2-13, the two most costly dismantling tasks were the removal of the thermal shield (Task C-6) and demolition of the pedestal (Task C-8).

A.2.3 Lynchburg Pool Reactor, Lynchburg, VA

The dismantling of the NRC-licensed Lynchburg Pool Reactor (LPR) was completed on schedule by the Babcock & Wilcox Company (B&W) at the end of March, 1982. Currently, license termination is under consideration by the NRC.

TABLE A.2-12. Summary of Costs of Dismantling the ALRR During the Period of January 1979 - September 1981.

Cost Category		Actual Costs ($ thousands)		Percent of Total
Waste Disposal				
Packaging:	ALRR[a]	31.2		
	Subcontractor	50.5		
Cask Rental,				
Shipping:	ALRR[a]	162.8		
	Subcontractor	187.5		
Disposal:	ALRR	96.3		
	Subcontractor	73.2		
Total Disposal Costs			601.5	13.9
Labor			1,823.7	42.1
Other Subcontracts			741.9	17.1
Supplies and Services:				
Reactor			675.0	26.9
In-House			492.9	
TOTAL, Costs for Dismantling[b]			4,335.0	100.0

(a) Includes non-waste items; see Table A.2-11 for details.
(b) Dismantling the ALRR via Alternative Number 5 is described in detail in Reference 6. It should be recognized that the current end product condition of the reactor is one of "monitored use" which requires concurrence for future uses of the reactor area. Under these conditions, there are no restrictions on the use of the space for laboratories or offices, except that appropriate monitoring of the area is required, and any building modifications have to be examined for their potential radiation hazard. Since the Laboratory continues to maintain a health physics group, this premise does not limit logical future uses of the building.

TABLE A.2-13. A Listing of Costs by Tasks for Dismantling the DOE-Owned ALRR Facility[(a)]

Task No.	Description	Costs ($ thousands): Reactor Salaries	Reactor Supplies, Services	In-house Services	Contracts	Packaging, Shipping Disposal	Total
A-1	Dispose of fuel	13.0	10.0	2.0		18.3	43.3
A-2,3,4	Dispose of coolants	20.0	8.8	2.0		4.3	35.1
A-5	Remove and relocate experiments	57.0	111.6	43.9		8.1	220.6
A-6, B-1,2	Dispose of active parts, waste	201.0	100.4	25.3		150.2	476.9
A-7, etc.	Security	108.9	16.8				125.7
A-8, etc.	Health physics, monitoring	557.3	107.6	7.8			672.7
	Health physics counting equipment		32.0				32.0
A-9, etc.	Reports and supervision	381.1	47.0	82.2			510.3
A-10	Fabricate tools	1.5	6.5	3.1			11.1
A-11	Remove cooling tower		5.0	12.9			17.9
	Remove water tower		5.0		43.6		48.6
	Improve reactor room access		5.0	6.2	23.0		34.2
A-12	Consultant				46.2		46.2
B-3	Remove top plug assembly	26.0	15.0	15.8	28.7		85.5
B-4, C-1	Remove electrical systems	30.0	20.0	175.8			225.8
	Restore pool visibility	23.9	16.1	5.0			45.0
C-2	Remove D20 closet	11.5	7.0			5.0	23.5
C-3, D-9	Clean out reactor room, pump room, basement	157.0	37.6	4.0		30.0	228.6
C-4	Remove core tank	10.0	10.0		67.4		87.4
C-5	Seal Thermal Shield	11.7	5.0				16.7
C-6	Remove, cut, ship, bury TS, plates	11.5	15.0		200.1		226.6
C-7	Remove Thermal Column graphite	7.5	5.0			10.0	22.5
C-8, D-1,2	Remove pedestal, tank, etc.	18.0	10.0	7.6	484.1	44.3	564.0
D-3,4	Remove exhaust system, stack	36.8	10.0	3.0		6.0	55.8
D-5	Replace floor	10.0	5.0	5.3	55.5		75.8
D-6	Remove hot cell and bunker	40.0	15.0	54.6		8.9	118.5
D-7	Remove hot waste tank, lines	25.0	15.0	28.5	2.5	6.0	77.0
	Decommission reactor drain lines	5.0	5.0	1.9			11.9
	Decommission storage pool	20.0	10.0	2.0	7.7	20.5	60.2
	Remove acoustic material	20.0	13.6	2.0	53.3	16.2	105.1
D-8	Dispose of casks	20.0	5.0	2.0		3.5	30.5
	TOTALS	1823.7	675.0	492.9	1012.1	331.3	4335.0

(a) Data are taken from Table 10 of Reference 6.

A.2.3.1 Description and History of the LPR

The LPR was an integral part of the Lynchburg Research Center (LRC). The LRC is located in Campbell County, Virginia, approximately 3 air miles from Lynchburg, the nearest principal city. General background information on the LPR is presented in Table A.2-14. The arrangement of the structures on the LRC site is illustrated in Figure A.2-13, including identification of major structures/areas on the site. The basement floor level of Building "A", which houses the LPR, is shown in Figure A.2-14.

Provisions for radioactive waste storage, liquid waste disposal, cask handling, and a large hot cell complex were available for decommissioning support operations. However, the support facilities were not part of the LPR dismantling project.

The pool-type reactor was light water moderated, cooled, and reflected. It was licensed to be operated up to 1 MW in the forced convection mode and up to 200 kW in the natural convection mode, using MTR-type fuel assemblies. Vertical and horizontal section views are shown in Figures A.2-15 and A.2-16, respectively.

The reactor was operated for about 23 years, starting in September 1958. The operating history for the period 1958 through 1981 is given in Table A.2-15. The LPR had generated a total of about 842 megawatt hours of thermal energy during its operational lifetime.

A.2.3.2 Decommissioning of the LPR

In 1972, the pool was emptied to repair a leak. That repair job provided valuable information on methods of dismantling and experience in working with the components in the pool. During the repair, experiments were removed and radiation levels were obtained for many of the components. Thus, reasonable assurance of the radiation levels of various parts were available later for the purposes of planning and preparation for the dismantling work. At that time, the highest radiation levels were from control rods, which read approximately 2R/hr at 1 ft. The next highest reading dropped significantly to approximately 100 mR/hr at 1 ft for the beam ports. Radiation levels of all other components were less than that of the beam ports.

Reactor operations at the LPR were terminated in late-February, 1981. Application for a "Class IV" license amendment as described in 10 CFR 170.22 was submitted to the NRC in July 1981, together with the dismantling plan for the reactor.[8] The NRC requested additional information regarding technical specifications that would be applicable during the dismantling. Subsequently, the plan was approved on January 12, 1982.

TABLE A.2-14. General Background Information on the Lynchburg Pool Reactor

Item	Information
License Number	R-47
NRC Docket Number	50-99
Reactor Address	The Babcock & Wilcox Company Lynchburg Research Center Lynchburg, Virginia 24505
Reactor Owner/Operator	Babcock & Wilcox Company/ Babcock & Wilcox Company
Operating Period	1958-1981
Decommissiong Period	April 1981 - March 1982[(a)]
Current Status	Dismantled[(b)]
Reactor Type	Pool-type
Thermal Power	Up to 1 MW (Forced convection mode); up to 200 kW (natural convection mode)
Fuel Elements	MTR-type
Reactor and Building Cost Estimate	Not Available

(a) The effort to dismantle the LPR facility took approximately 12 months. The paperwork to allow the dismantling to proceed took 9 months and the actual dismantling took 5 months (shipment of fuel early November to dismantling completion end of March).

(b) Currently, the license termination is under consideration by the NRC.

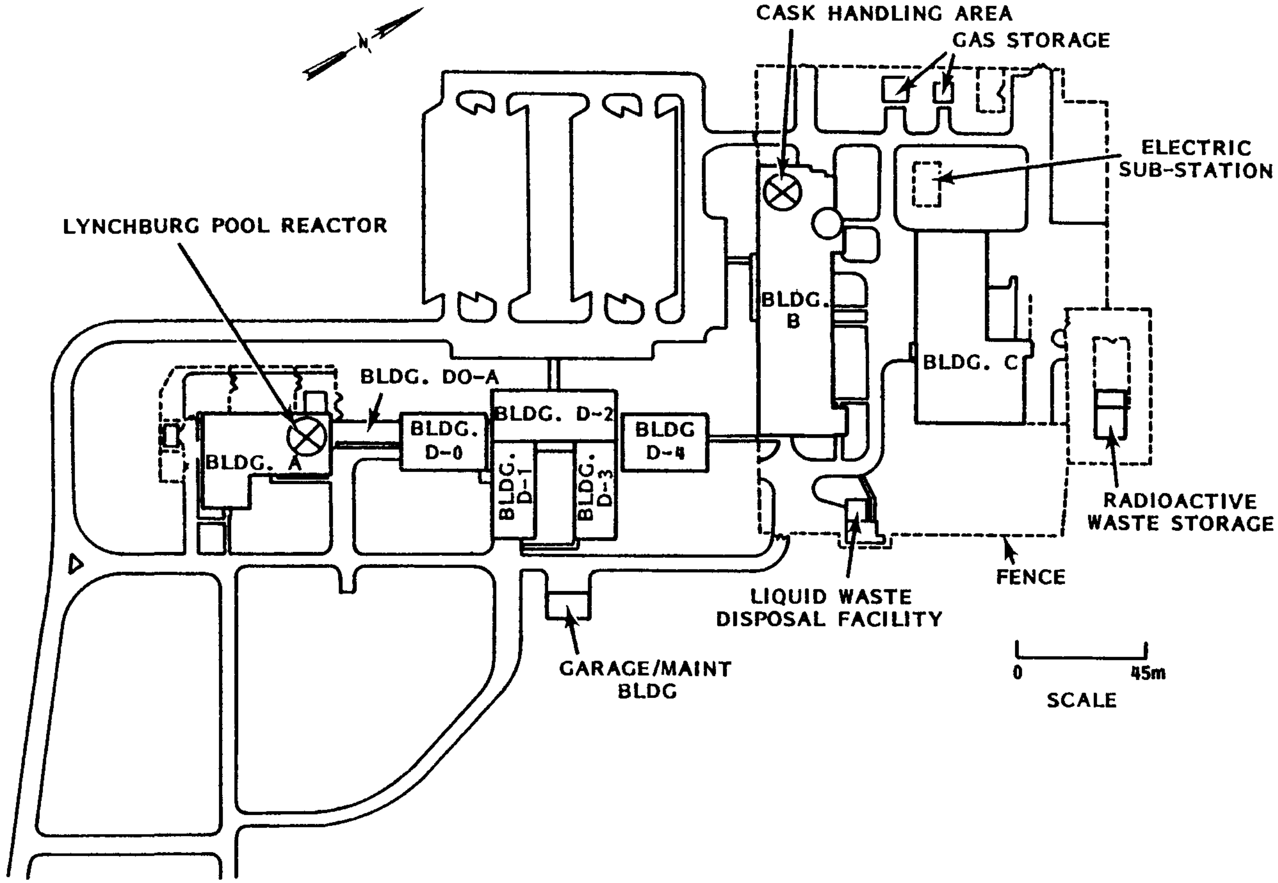


FIGURE A.2-13. Site Plan of the Lynchburg Research Center

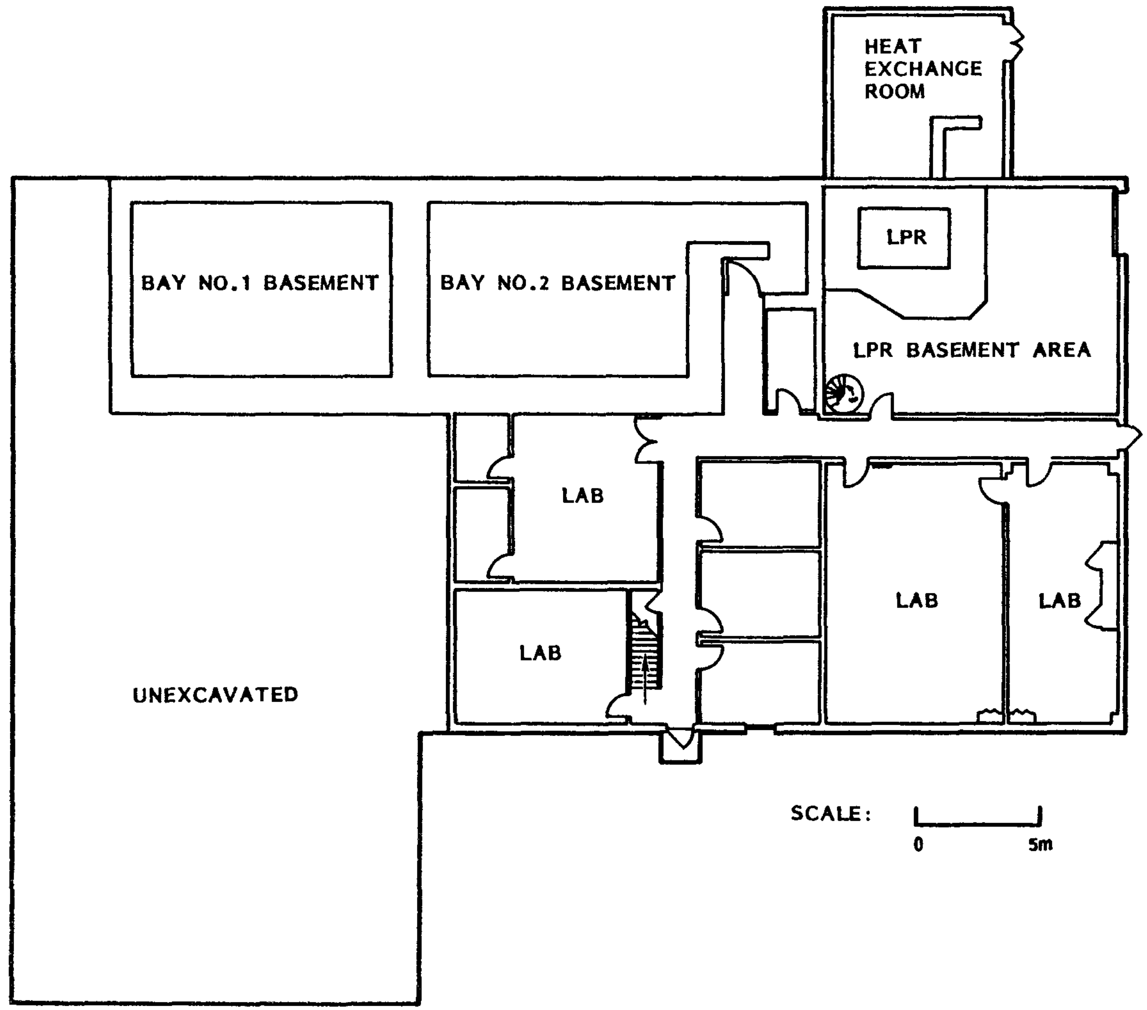


FIGURE A.2-14. Building "A" (LPR Building) - Basement Floor Level

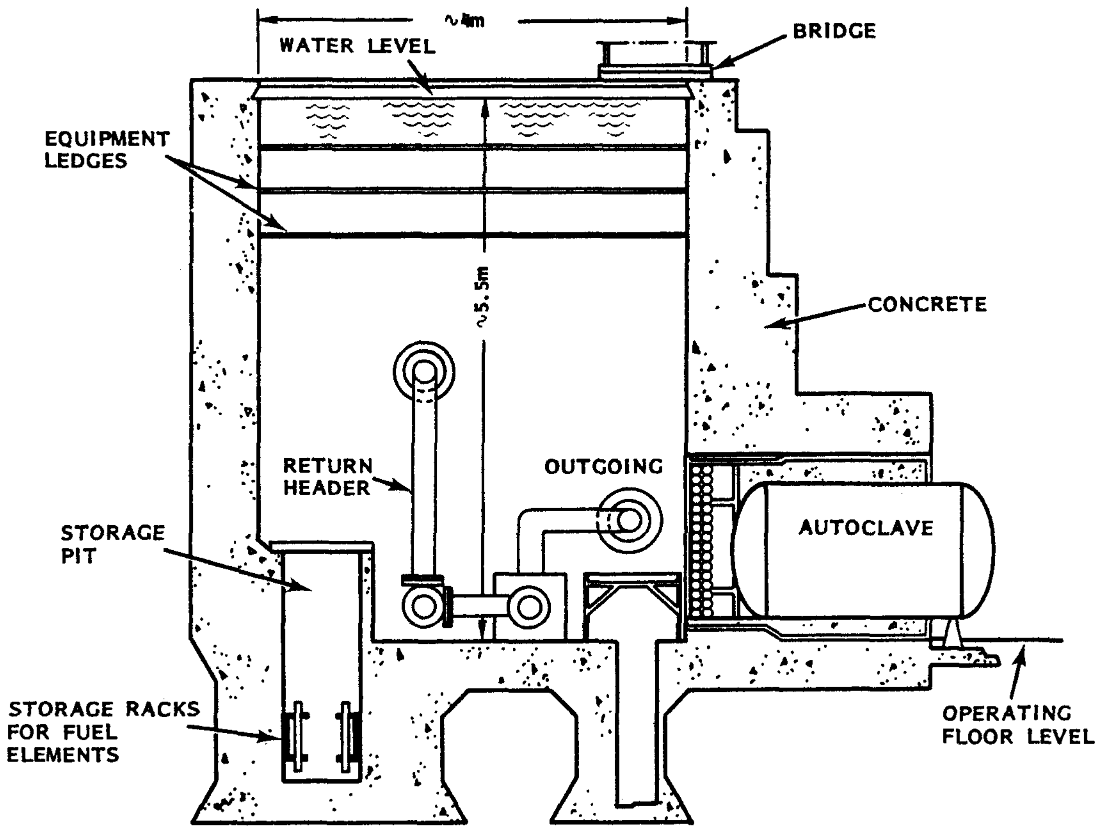


FIGURE A.2-15. Vertical Section View of the Lynchburg Pool Reactor

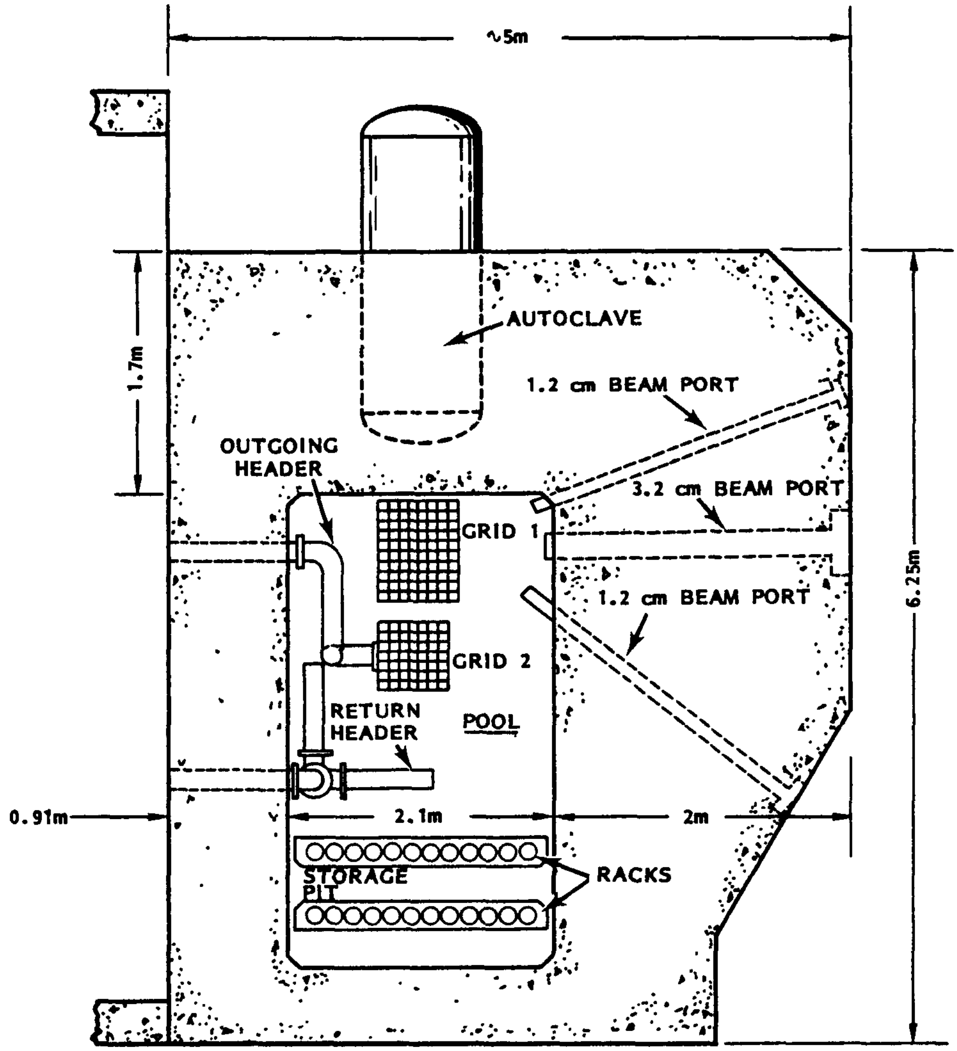


FIGURE A.2-16. Horizontal Section View of Lynchburg Pool Reactor

TABLE A.2-15. LPR Operating History

Period	Megawatt Hours
1958-1973	653.86
1974	11.10
1975	69.40
1976	16.36
1977	18.24
1978	17.60
1979	27.53
1981	1.85
Total	841.85

The overall approach by B&W to dismantling the LPR was as follows:

1. Obtain Corporate approval for dismantling.

2. Submit a Dismantling Plan to the NRC in time to begin dismantling by January 1, 1982.

3. Ship all the fuel (3 shipments) to Savannah River by mid-December 1981. (This was accomplished one month ahead of schedule. Shipping of the fuel was accomplished November 2-17).

4. As soon as the fuel was shipped begin to dismantle those portions of the facility which did not require NRC approval.

5. Invite University of Virginia reactor operations personnel to the LRC to identify components that could be used at their facility.

6. Once NRC approval of the plan is obtained continue dismantling of the facility to completion.

7. Complete the dismantling by March 31, 1982 (the end of the B&W fiscal year).

Dismantling Plan. The dismantling plan for the LPR was organized into five separate tasks, which included a logical order of work to be done in the pool area (Task 1), the autoclave area (Task 2), the heat exchanger room (Task 3), and the control room (Task 4). Task 5 included decontamination, disposal operations, and a final radiation survey.

The two most time consuming activities were the removal of concrete in the pool area and the safe removal and packaging of an asbestos covering in the autoclave area.

Applicable Criteria. B&W reviewed various authorized dismantling plans that suggested maximum levels of radiation that were acceptable to the NRC for the release of a reactor facility to unrestricted access. Those levels are: 1) surfaces decontaminated to levels consistent with Table 1 Regulatory Guide 1.86;[1] and, 2) ^{60}Co, ^{152}Eu, and ^{137}Cs (i.e., radioactive material other than surface contamination) that may exist in concrete, components, structures, and soil removed such that the radiation level from these isotopes is less than 5 μR/hr above natural background[a] as measured at 1 meter from surface.

(a) Radiation from naturally occurring radioisotopes as measured at a comparable uncontaminated structure or exterior soil surface.

It was the intention of B&W to decontaminate the LPR to meet the above criteria. However, since these decontamination limits were developed for the release of facilities to unrestricted access, B&W may elect not to release the LPR facility for unrestricted access but transfer the entire area to the control of their Special Nuclear Material license. Detailed discussions regarding these alternatives are contained in References 8 and 9.

Radioactive Waste Disposal. The total amount of radwastes resulting from dismantling activities were larger than anticipated due to the amount of concrete that had to be removed from the pool area (due primarily to ^{152}Eu). Currently 75 drums (0.21 m^3/each) and three wooden boxes (~1 m x 1 m x 1.2 m/ea.) are awaiting disposal by land burial to the Barnwell, South Carolina site. The disposal of all radioactive material is anticipated to be made through a licensed commercial waste disposal firm.

Except for an occasional fastener, all materials near the core were aluminum 1100 or 6061. (Enriched Uranium was used for fuel, shim rods were 1-1/2 wt% boron stainless steel and the regulating rod was 304 stainless steel.) The most important of the alloy elements is ^{65}Zn (T-1/2 = 244 days) and the most important of the impurities is ^{60}Co (T-1/2 = 5.26 years). These two isotopes comprised the bulk of the radioisotopes after the fuel was shipped. The total curie content was estimated to be <1 curie.[8]

Occupational Radiation Dose for Dismantling Activities. Using in-house, experienced personnel, the total external occupational radiation dose for dismantling activities at the LPR was <0.1 man-rem.[a]

Final Surveys. As illustrated in Figure A.2-14, the LPR is located in Building "A". In turn, Building "A" is part of the much larger Lynchburg Research Center, which continues to operate under B&W's Special Nuclear Materials License. Therefore, the verification survey for license termination may be limited to the LPR facility within Building "A" and not necessarily include a site survey at this time.

Costs. A summary of estimated costs of dismantling the LPR is presented in Table A.2-16. In 1974, when the Federal government stopped leasing enriched uranium fuel, the B&W Company opted to buy the fuel for continued use in the LPR. Later, just prior to dismantling, they decided not to retain the uranium credit resulting from reprocessing, and subsequently sold the uranium (see Table A.2-16) which offset the costs of decommissioning of the LPR.

(a) This information was supplied on May 6, 1982 by Mr. J. W. Cure, Health Physics Supervisor at the LPR, and represents only a preliminary estimate.

TABLE A.2-16. Summary of Estimated Costs of Dismantling the LPR in 1981-82

Cost Category	Estimated Costs, $	Percent of Total
Labor	~40,000[a]	46.5
Disposal of Radioactive Materials	10,000	11.6
License Fees	6,000	7.0
Reduce Nuclear Fuel Inventory Account to Zero	20,000	22.3
Misc. Materials	10,000	11.6
TOTAL, Dismantling Costs	86,000	100.0
Other Costs		
Spent Fuel:		
Shipment	4,000	
Reprocessing	54,000	
Cask Rental	22,000	
TOTAL, Other Costs	80,000	
Credits:		
Fuel (uranium credits)	$158,500	

(a) Includes about $10,000 for the services of two extra people and associated equipment from a rental contractor used to help B&W personnel remove the activated pool concrete.

A.2.3.3 Summary

In summary, the effort to dismantle the LPR facility took approximately 12 months. The paperwork to allow the dismantling to proceed took 9 months and the actual dismantling took 5 months (shipment of fuel early November to dismantling completion end of March). The dismantling and disposal of the facility was readily accomplished in conformity with existing regulatory and inhouse requirements, using experienced B&W personnel to carry out the dismantling.

Application was made to the NRC on 23 April 1982 for a final verification survey, which would lead to termination of the LPR's operating license.

A.2.4 North Carolina State University Reactor, Raleigh, NC

The North Carolina State University research reactor known as the "NCSUR-3"--the third reactor on campus--is being dismantled. The NCSUR-3 has been shut down for 9 years, and has been dry for over 7 years. General background information and dismantling and decommissioning information on the NCSUR-3 is presented in subsequent subsections.

A.2.4.1 Description and History of the NCSUR-3

The NCSUR-3 is located in the southern half of the Court of Ceres on an open quadrangle near the center of the North Carolina State University Campus. General background information on the NCSUR-3 is presented in Table A.2-17. The reactor was placed in the shield and building originally occupied by the NCSR-1 unit and later by the NCSR-2 unit. The NCSUR-3 reactor (NRC license Number R-63) and the North Carolina State University PULSTAR Reactor (NRC License Number R-120), together with adjacent offices and laboratories are integral parts of the Burlington Engineering Laboratories' complex, shown in Figure A.2-17. The NCSUR-3 reactor was operated from 1960 to 1973, at which time the NRC operating license was terminated and a license to "possess but not operate" was issued.

The NCSUR-3 is a 10-kW graphite-reflected pool-type reactor using 18 plate MTR-type fuel elements. The core lattice is a 5 by 5 array of fuel (21) and graphite (4) elements. Vertical and horizontal section views and a simplified flow diagram of the reactor coolant system are shown in Figures A.2-18, -19, and -20, respectively.

A total of 52.5 megawatt hours of operations were performed over the operating period of the reactor. A year-by-year operating history of the NCSUR-3 is summarized in Table A.2-18.

The NCSUR-3 operations were terminated after the completion of the new 1-megawatt PULSTAR research reactor in 1972. This new facility provided all reactor services required at NCSU, and it was not economically feasible to continue operation of the NCSUR-3 reactor.

A.2.4.2 Decommissioning of the NCSUR-3

The NRC operating license for the reactor was terminated in 1973, and a license to "possess but not operate" was issued. Then, the reactor core was unloaded, the fuel placed in storage racks within the reactor tank, the control rods removed to storage, and the electrical controls disconnected to prevent further operation. In February 1974, the fuel was removed from water storage, examined, and placed in dry storage. The reactor system was drained completely at this time. Subsequently, the irradiated fuel assemblies were shipped to

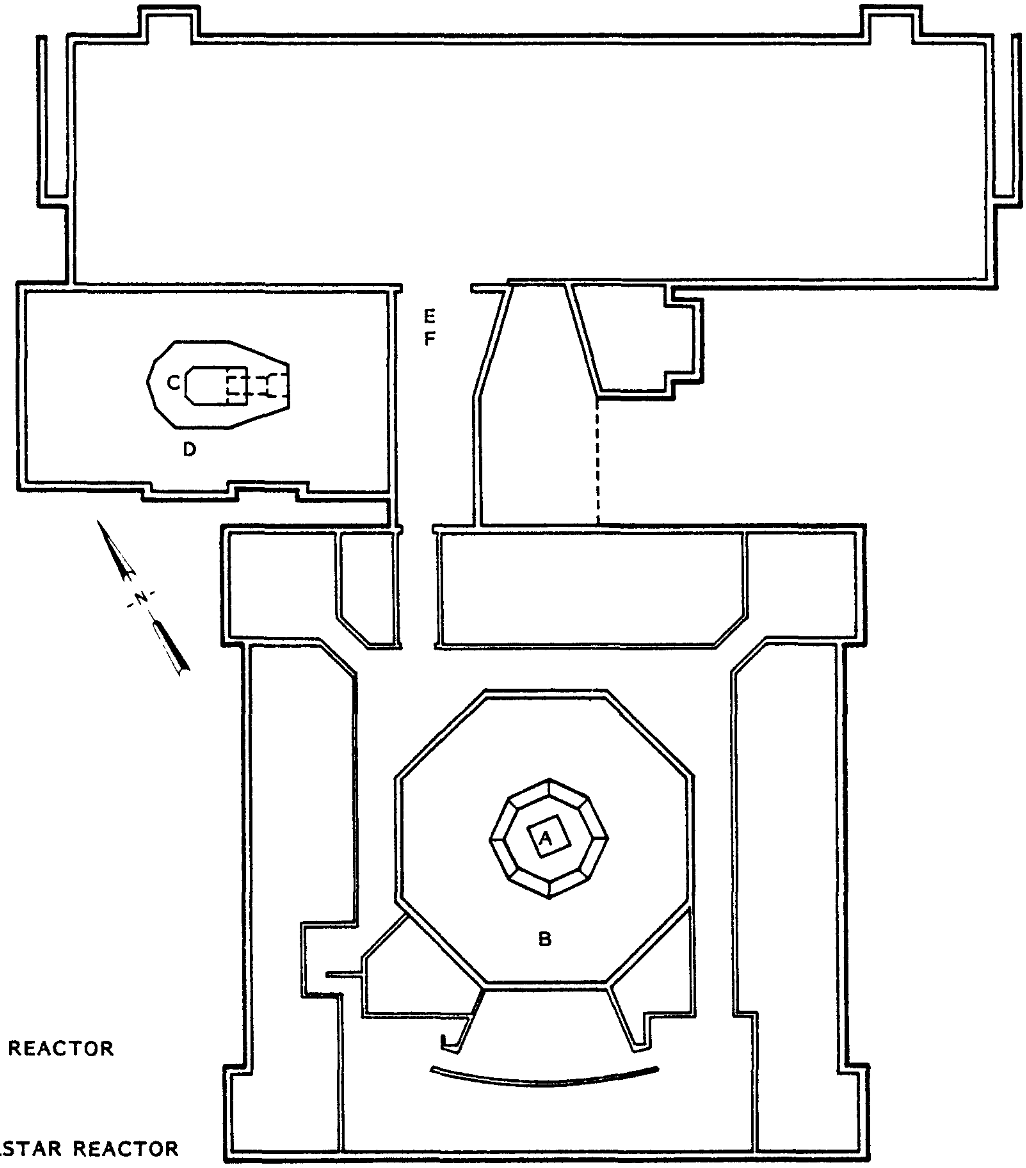
TABLE A.2-17. General Background Information on the North Carolina State University Reactor Number 3 (NCSUR-3)

Item	Information
License Number	R-63
NRC Docket Number	50-11
Reactor Address	Department of Nuclear Engineering North Carolina State University Raleigh, North Carolina 27650
Reactor Owner/Operator	North Carolina State University
Operating Period	1960-1973
Decommissioning Period	1973 - present[a]
Current Status	Amended Nuclear License: Dismantling Order Issued 6-1-81
Reactor Type	Pool-type
Thermal Power	10 kW
Fuel Elements	MTR-type
Reactor and Building Cost Estimate	Not Available

(a) The extended decommissioning period is the result of the licensee's plan to minimize costs while assuring public safety. The decommissioning tasks to date have been safely accomplished in discrete stages by the university staff, together with paid student labor. One of the end product tasks--a fixed-price bid for concrete demolition--is expected to be awarded to a contractor in mid-1982.

Savannah River, South Carolina, and four unused fuel assemblies were moved to the PULSTAR Bay for dry storage. The beam ports and thermal column were closed and safety-locked. The top of the reactor tank was covered by a 2-inch-thick steel plate. The electrical circuit breaker box containing the breaker for the overhead crane was locked, and the reactor electrical controls were disconnected. Thus, the amendment to the facility license "to possess but not operate" had been fulfilled.[10]

Daily (working day) high-volume air sampling and weekly contamination surveys have been conducted since February, 1973. Neither of these actions have evidenced any radioactivity in the NCSUR-3 Bay. A Victoreen Area Monitor



LICENSE R-63

A - NCSU R-3 REACTOR

B - R-3 BAY

LICENSE R-120

C - NCSU PULSTAR REACTOR

D - PULSTAR BAY

E - PULSTAR CONTROL ROOM, 2ND FLOOR

F - PULSTAR MECHANICAL EQUIPMENT ROOM, BAY FLOOR LEVEL

C,D,E,F - PULSTAR REACTOR BLDG.

PLAN VIEW - NO SCALE

FIGURE A.2-17. Burlington Engineering Laboratories Complex at North Carolina State University

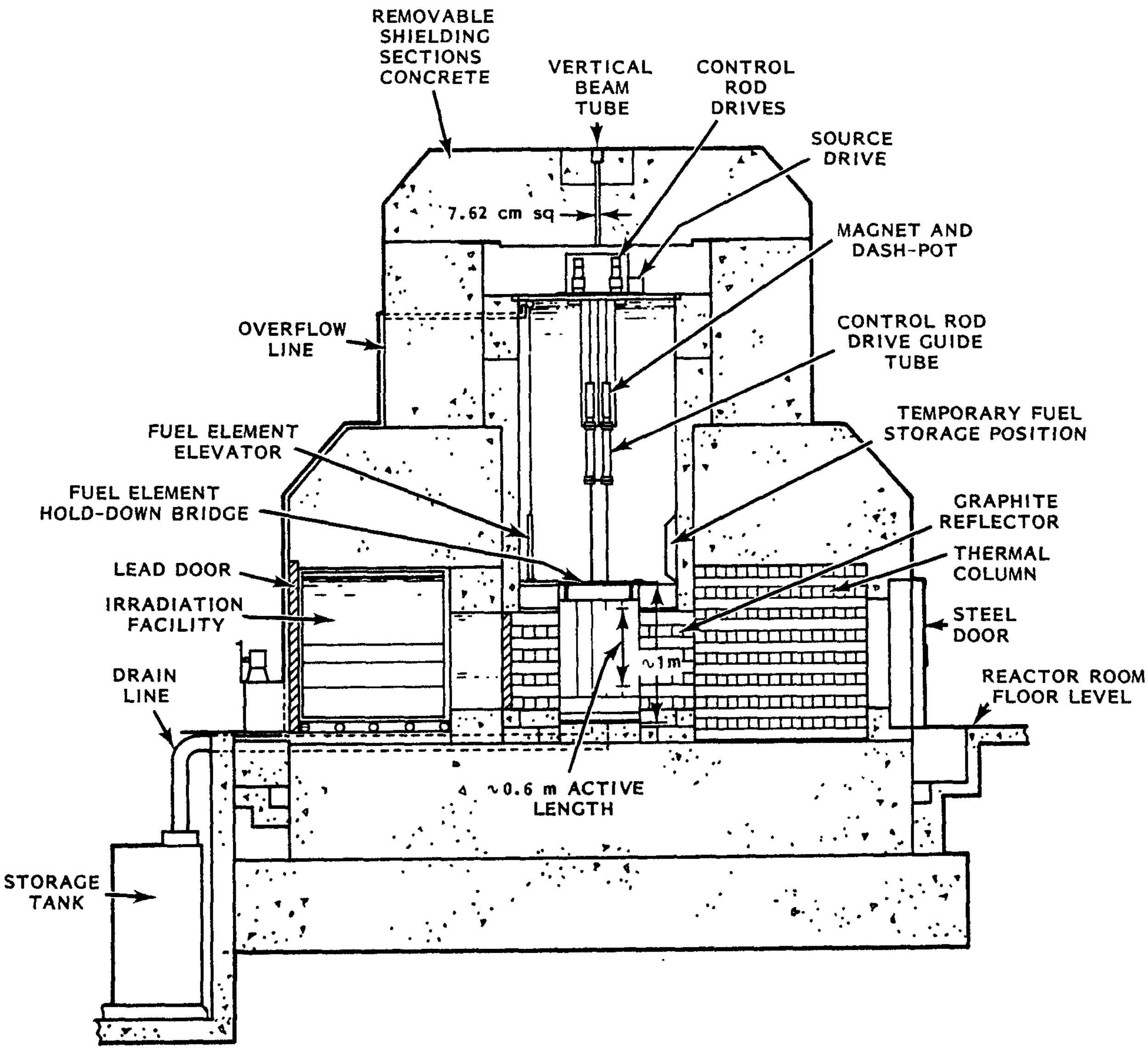


FIGURE A.2-18. Vertical Section View of the North Carolina State University 10-kW Research Reactor

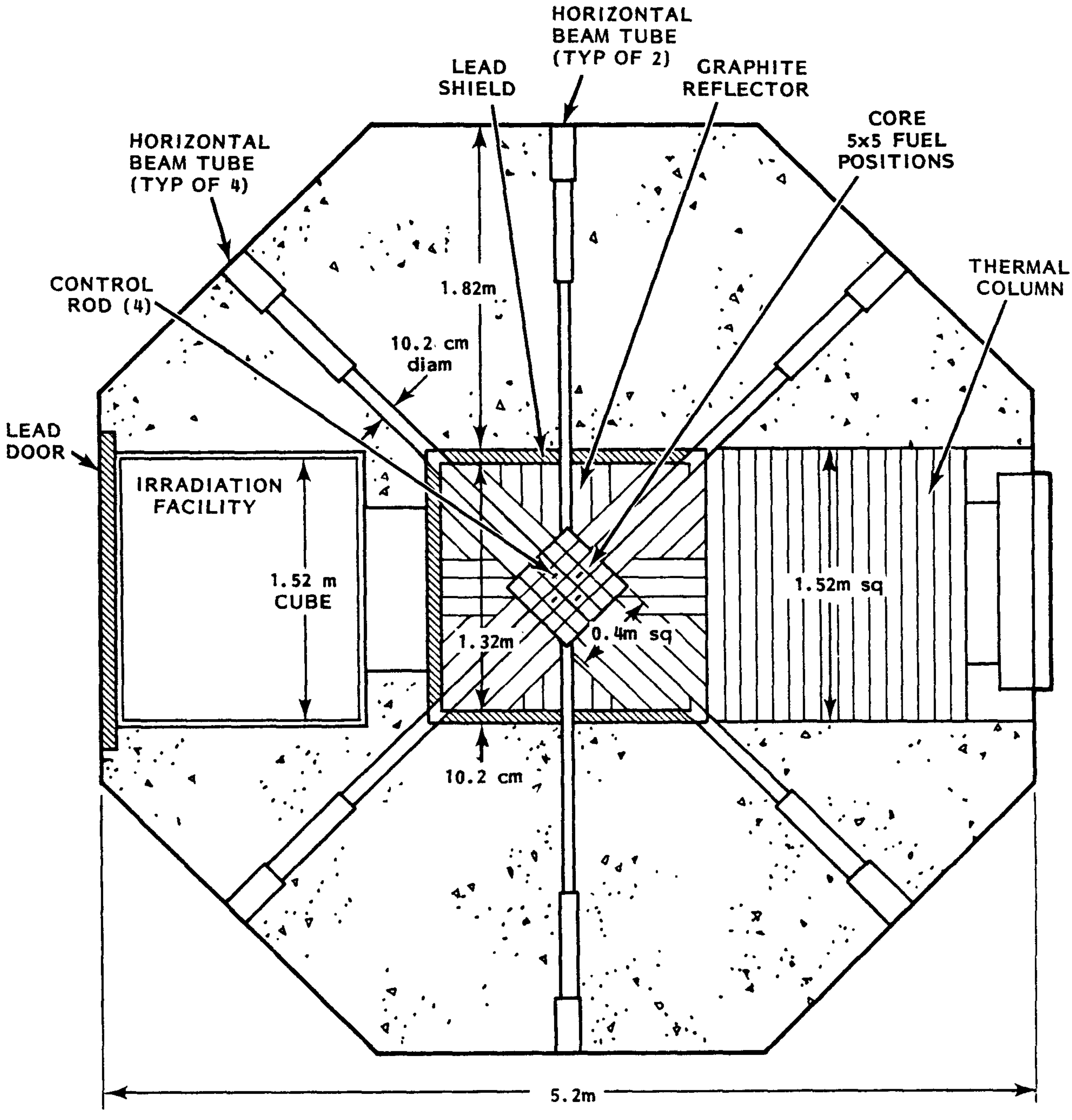


FIGURE A.2-19. Horizontal Section View of the North Carolina State University 10-kW Research Reactor

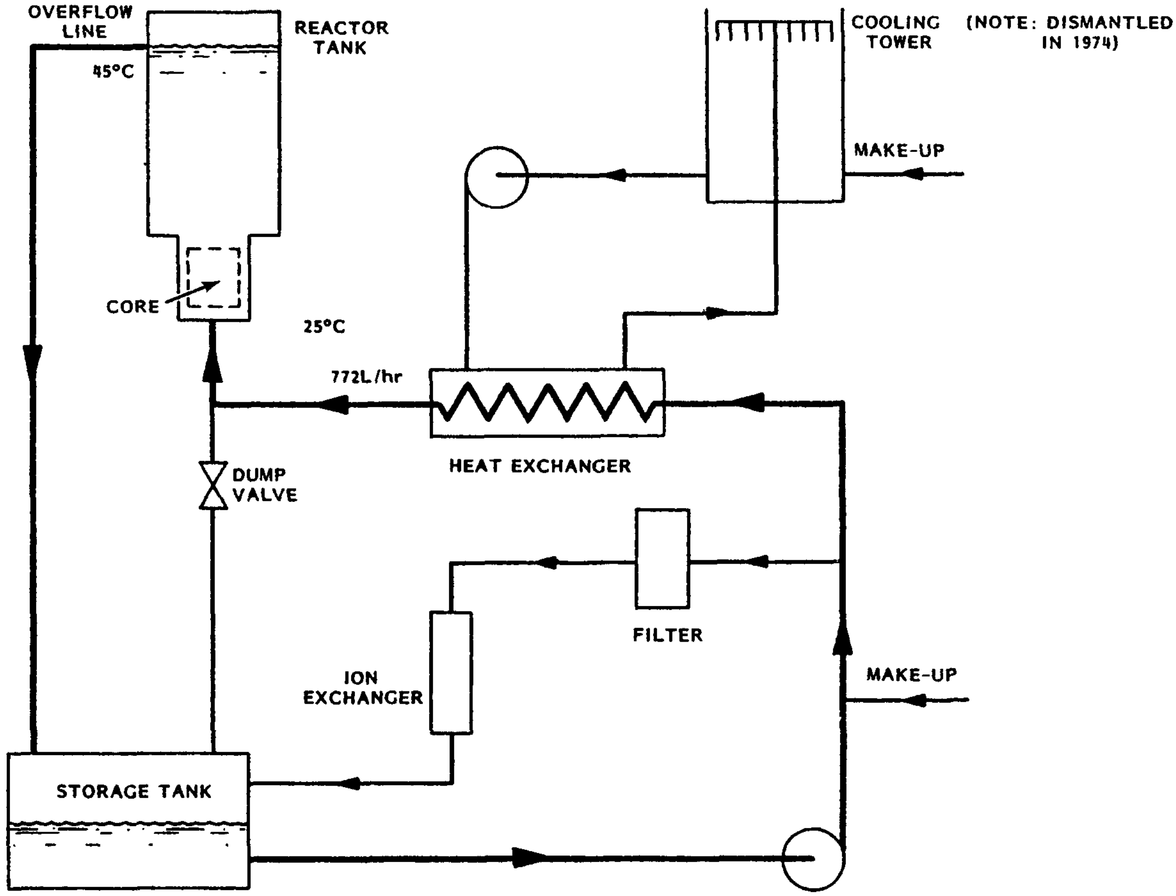


FIGURE A.2-20. Flow Diagram of the North Carolina State University 10-kW Research Reactor

TABLE A.2-18. NCSUR-3 Operating History

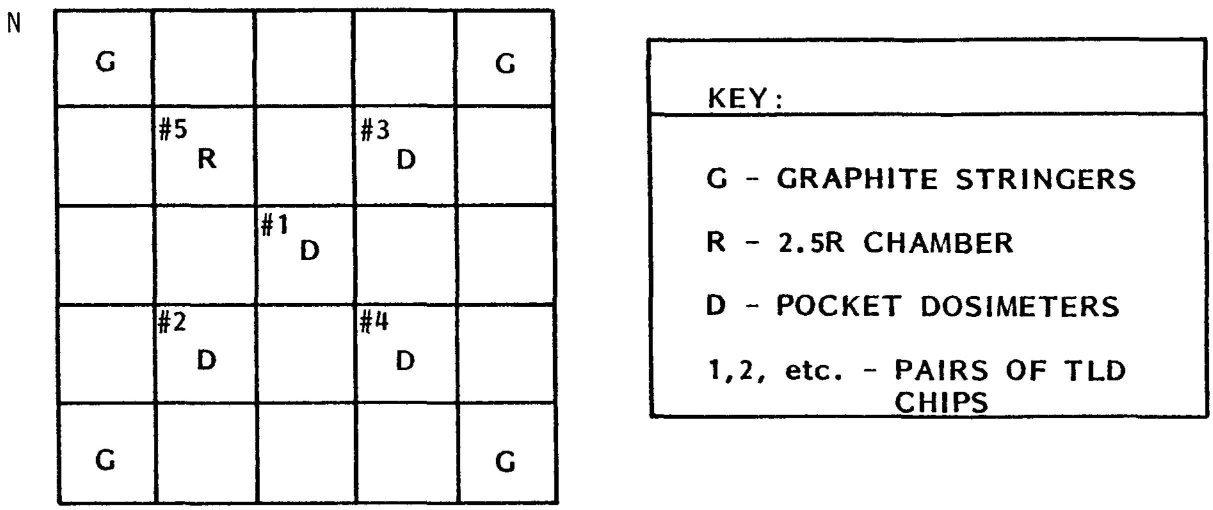
Period	Energy (Megawatt Hours)
1960-1965	18.1
1966	2.65
1967	5.0
1968	5.4
1969	4.2
1970	8.6
1971	5.3
1972	3.2
Total	52.54

Portable, set to alarm at 1 mR/hr, has been on the NCSUR-3 shield or over the Gamma Facility for over 7 years. This instrument continuously reads in order of 0.1 mR/hr or less.

A radiation measurement and swipes were taken in several beam ports in June 1976. For the radiation measurement, a thin-wall GM was attached to a board that was inserted into the beam ports to a point close to the core reflector. In a similar manner, the swipes were taken. The largest dose rate found was 20 mR/hr and the swipe results were less than 120 dpm.

In July 1976, a dismantling plan for the NCSUR-3 was submitted to the NRC. Subsequent to that submittal, a revised plan was submitted.(10) On June 1, 1981, the NRC issued a dismantling order for the NCSUR-3.

In June 1978, the radiation level in the nose grid of the R-3 core was measured by TLD chips, pocket dosimeters, and a 2.5 R chamber of a Condenser R-meter. The location of each and the results of a 2-hour exposure are given below:



	mrem		
Position	TLD	Pocket Dosimeter	2.5R Chamber
N	100	-	101
E	106	109	-
S	122	108	-
W	99.5	100	-
Center	83	79	

Exposure Time - 2 Hours

The components of the NCSUR-3 reactor in which the greatest amount of activation products are anticipated to be found are: core grid, bottom section of the reactor tank, and in the concrete under the reactor core. These components each may contain up to 100 mCi of activation products. This estimate is consistent with that experienced in the dismantling of the IITRI 75-kW research reactor and the 50-kW Walter Reed research reactor.[10]

The principal tasks associated with the dismantling of the NCSUR-3 are presented in Table A.2-19.

TABLE A.2-19. Principal Tasks Associated with the Dismantling of the NCSUR-3[10]

Number of Tasks	Location	Dismantling Information
1	Control Room	• Isolate the Control Room--cut and remove cables • Remove equipment
2	Pipe Pit	• Remove storage tank, IX unit, pumps, HX, pipes, valves, and electrical lines
3	External Piping to Biological Shield	• Remove contaminated and/or activated concrete, as required • Decontaminate, as necessary, trenches, beam catchers and storage tubes in bay walls, and change filter in Filter Room
4	Pool Tank	• The process of decontamination and survey will be continued until all surfaces are acceptable for release to unrestricted usage.
5	Reactor Structure	• Remove Pool Tank drain line and overflow line, Bulk Irradiation Facility, and pipes
6	Biological Shield, (including ends of beam ports)	• Remove Pool Tank and equipment therein, including control rod drive motors and fuel element elevator
7	NCSUR-3 Bay Area	• Remove thermal column and reflector (graphite and lead bricks)
8	Final Radiation Survey	

The radwastes resulting from dismantling work through December 1981 consisted of 25 drums, which were shipped to the LLWBG at Hanford, Washington. The total cost of disposal for these wastes was about $3,250 and includes the cost of the drums, transportation, and burial. Since shutdown, labor costs to September 1981 are estimated at about $7,000 (primarily student labor costs). Equipment costs (e.g., hard hats, gloves, sabre saw, box materials) are estimated at <$2,000. It is estimated that the total dismantling costs that will have been expended by mid-1982 will be approximately $15,000. In mid-1982, a demolition contractor is anticipated to be hired by fixed-cost bid contract to remove the remaining contaminated/activated concrete, beam tubes, and liners.

Assuming additional costs of $10,000 to $15,000 to complete the decommissioning tasks at NCSUR-3, it is estimated that the final total costs of decommissioning (covering a period of almost 9 years of intermittent activity) will be in the range of $25,000 to $32,000. A summary of these estimated dismantling costs is presented in Table A.2-20.

TABLE A.2-20. Summary of Estimated Costs of Dismantling the NCSUR-3 Research Reactor.

Cost Category	Range of Estimated Costs, $	Approximate Percent of Total
Labor	7,000 to 9,000	28 to 28
Disposal of Radioactive Materials (to date)	3,250	25 to 20
Disposal of Radioactive Materials (assumed to project completion)	3,250	
Specialty Contractor (assumed)	10,000 to 15,000	39 to 46
Equipment	~2,000	8 to 6
Estimated Total, Dismantling Costs	~25,500 to 32,500	100
Other Cost		
Spent Fuel Shipment	-(a)	

(a) The fuel was shipped to Savannah River, South Carolina, in the mid-1970s; cost data were unavailable for this activity.

The total external occupational radiation dose for dismantling activities at NCSUR-3 to date is estimated at <1 man-rem. For the purpose of this study, the total occupational radiation dose to completion is assumed to be <1 man-rem, based on current radiation levels remaining at the facility.

A.2.5. Oregon State University's AGN-201 Reactor Facility, Corvallis, OR

The Oregon State University's (OSU) AGN-201 reactor operated for about 16 years before it was removed from service and dismantled. The information presented in this subsection on the dismantling of the reactor was obtained from NRC Docket No. 50-106,[11] and other data supplied by personnel at OSU.

A.2.5.1 Description and History of the OSU/AGN-201

The OSU/AGN 201, Serial 114 research reactor had a maximum design operating power of 0.1 W. The reactor was delivered, installed, and made critical in January 1959, and terminated operation in December 1974. The AGN-201 reactor was moved into its final location in the Radiation Center on 15 July 1964. Actual reactor operating time was 408.6 hours, with a total energy release of 1583.6 watt-min (1.1 watt-day).

The room that housed the AGN-201 is approximately 10.7 m long and 9.1 m wide. It is located in the northeastern corner of the Radiation Center Building, adjacent to the TRIGA Reactor Building.[a] The site is located on the OSU campus in Corvallis, Oregon. General background information on the AGN-201 is presented in Table A.2-21.

A vertical section view of the AGN-201 reactor is presented in Figure A.2-21. A section view of the AGN-201 core tank assembly is illustrated in Figure A.2-22. The reactor was cooled by natural convection. The combined fuel content of the safety and control rods is approximately 45 grams of ^{235}U, and the core itself contained approximately 620 grams of ^{235}U dispersed in polyethylene discs.

A.2.5.2 Decommissioning of the OSU/AGN-201

The last date of reactor operation was December 12, 1974. The control rods were removed and the reactor was placed in long-term shutdown (LTS) on May 28, 1975. It remained in the LTS condition until it was dismantled. Application was made to decommission the reactor on March 8, 1979. Schedules and the necessary approvals for dismantling were submitted and granted and the AGN-201 dismantling was conducted between June 10 and 20, 1980. The monitoring of the dismantling operations and the survey of the radiological conditions of the space after removal of the reactor were described in the licensee's report

(a) The Oregon State University TRIGA reactor is the reference research reactor for the parent document NUREG/CR-1756 and is described in Section 8 and Appendix B of that document.

TABLE A.2-21. General Background Information on the Oregon State University AGN-201 Reactor

Item	Information
License Number	R-51
NRC Docket Number	50-106
Reactor Address	Radiation Center Oregon State University Corvallis, Oregon 97331
Reactor Owner/Operator	Oregon State University/ Oregon State University
Operating Period	January 1959 to December 1974
Decommissioning Period	June 10 to June 20, 1980
Current Status	Dismantled
Reactor type	Closed Vessel
Thermal Power	0.1 W
Fuel Elements	Fuel Discs (standard)
Reactor and Building Modification Cost Estimate (1959 dollars)	~107,000

dated July 9, 1980, entitled, Final Decommissioning Report, Oregon State University AGN-201 Reactor. The costs to dismantle and transfer reactor components to another university were estimated to be less than $10,000. Currently, the reactor is crated and awaiting shipment to a potential customer.

The fuel core and control rods of the OSU/AGN-201 reactor were removed and transported to the OSU TRIGA Facility for secured storage. The other reactor components were thoroughly monitored and surveyed, cleared, and transferred to a university storage facility.

A chronology of the decommissioning of the OSU/AGN-201 reactor is given in Table A.2-22. As indicated in the table, a closeout inspection was conducted on September 9, 1980. The purpose of the closeout inspection was to observe the condition of the facility and to verify that the licensee conducted surveys and documented results as described in the Final Decommissioning Report.

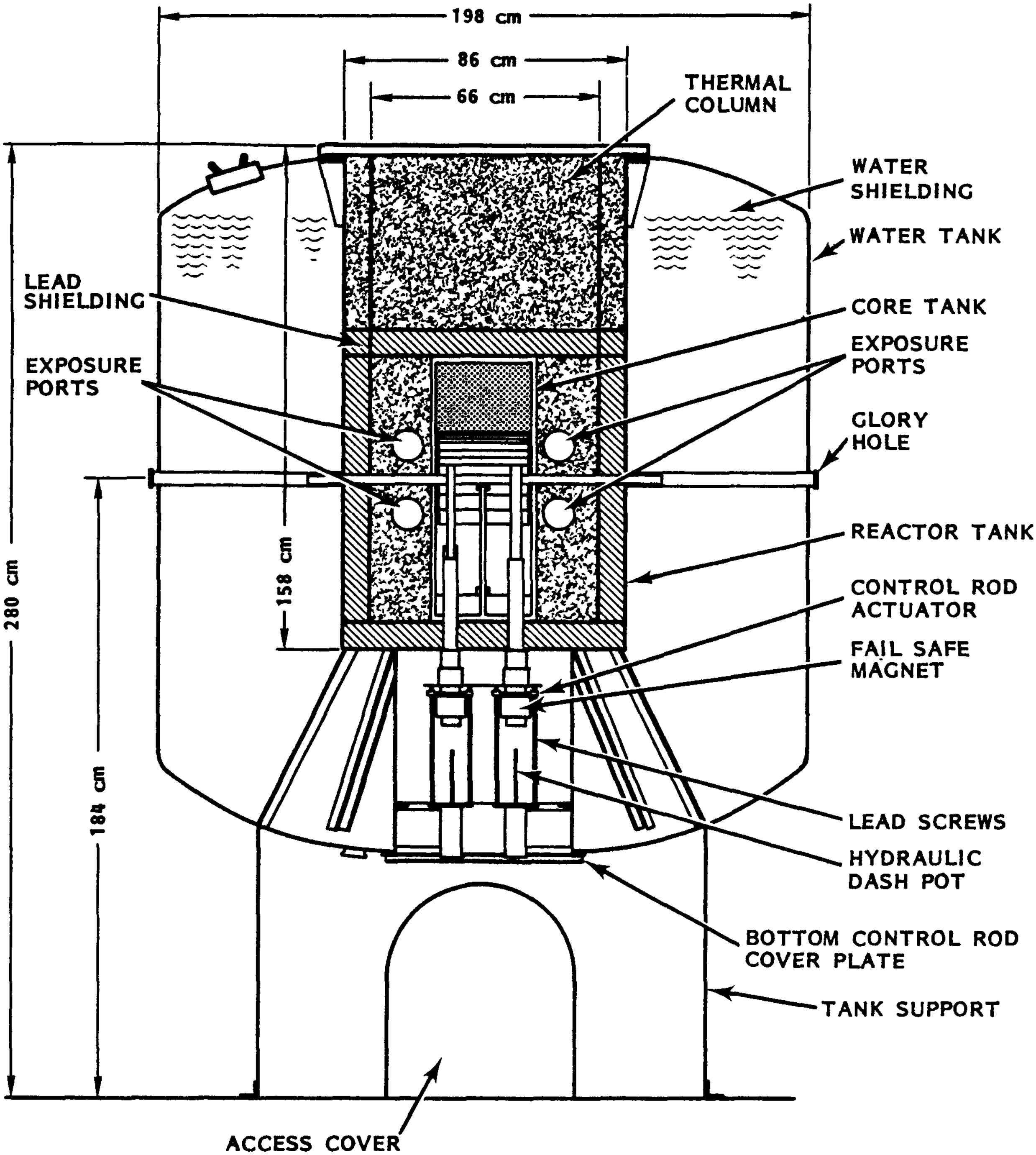


FIGURE A.2-21. Vertical Section View of the AGN-201

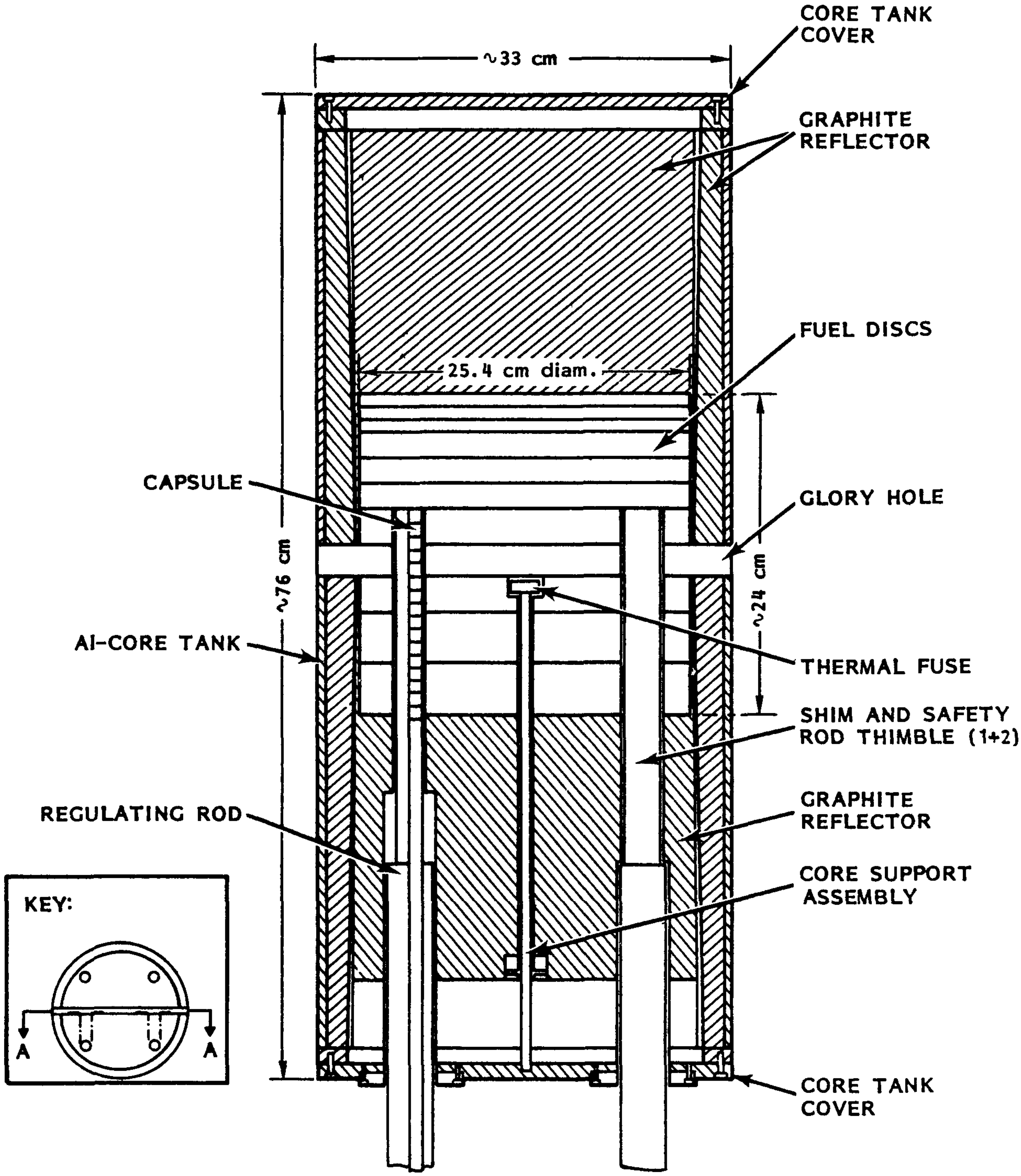


FIGURE A.2-22. View A-A of the AGN-201 Core Tank Assembly

TABLE A.2-22. Chronology of the Decommissioning of the OSU/AGN-201 Reactor

Date	Action Item
12-18-78	OSU sent a request to the NRC to decommission the AGN reactor, along with the proposed Dismantling and Disposal Plan. Also, the Detailed Disassembly Procedures document was developed.
3-8-79	NRC approved the dismantling of the reactor.
4-16-80	The decommissioning timetable for the AGN project was completed (OSU internal document).
7-2-80	The OSU/AGN-201 reactor was successfully decommissioned as of this date.
7-10-80	OSU requested the NRC to terminate the reactor license and submitted their Final Decommissiong Report (dated 7-9-80).
9-9-80	An NRC Region V I&E officer conducted a closeout inspection of the decommissioning project at OSU.

Radiation Surveys Conducted During the Closeout Inspection. The NRC inspector toured the facility with the licensee's senior health physics representative who had participated in the dismantling project, discussed survey techniques and results, examined survey and personnel monitoring records, and then conducted independent radiation level and contamination surveys.

The NRC inspector's radiation level survey consisted of measurement of the gamma radiation levels at approximately 3 feet above the floor throughout the facility and within 6 inches of the floor in specific areas in the immediate area where the AGN-201 reactor was located. No radiation levels above the normal background of 5 to 15 micro r per hour were identified.

The contamination survey consisted of the measurement of removable contamination by taking smears of an area approximately 100 cm^2 with dry filter paper discs at selected locations in the facility, and the measurement of beta-gamma count rates with a thin-window, pancake-type GM tube detector over selected floor surfaces at a distance of 1/2 inch to 1 inch above the surface.

The smear samples were counted in an NRC laboratory-type windowless, gas flow proportional counter and the counting results from all smears were at or below the background count rate of 30 counts per minute. The meter survey of floor surfaces with the pancake GM tube probe indicated no readings above the normal background of 30 to 50 counts per minute.

With the exception of the expected radiation levels detected on the fueled core can and control rods (0.5 to 10 mrem/hr), no radiation levels or radioactivity above normal background levels were detected on reactor components, associated electronic and laboratory equipment, or on floor surfaces in the facility.

NRC Exit Interview After the Closeout Inspection. An exit interview was held at the close of the inspection. An Oregon State Department of Energy representative was present. The inspector reviewed the scope and findings of the inspection and indicated that based on the surveys performed and on the conditions observed, his report would confirm that the AGN-201 Reactor had been dismantled as described in the licensee's dismantling report and the conditions found at the facility met the guidelines of Regulatory Guide 1.86.

Radioactive Wastes. A small volume (estimated at $<0.3\ m^3$) of low-level waste--paper towels, gloves, wipes, etc.--was generated during the disassembly operation.

REFERENCES

1. U.S. Atomic Energy Commission, Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors, June 1974.

2. J. M. Harris, Diamond Ordnance Radiation Facility Decommissioning Program Final Report, ESG-80-23, Rockwell International for Department of the Army, Contract Number DAAK 21-79-C-0136, July 7, 1980.

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

4. H. D. Oak, et al., Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station, NUREG/CR-0672, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1980.

5. G. J. Konzek, et al., Technology, Safety, and Costs of Decommissioning Reference Nuclear Research and Test Reactors, NUREG/CR-1756, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, March 1982.

6. Adolf F. Voigt, et al., FINAL REPORT - Decommissioning of the Ames Laboratory Research Reactor, IS-4789, Prepared for the U.S Department of Energy Under Contract W-7405-ENG-82, January 1982.

7. AMES LAB CHANGING SCENE, Vol. 7 No. 9, September 1981, pp. 1-3, "How to Take Apart a Reactor: With Care." Iowa State University, Ames, Iowa 50011.

8. Docket No. 50-99, Dismantling Plan for the Lynchburg Pool Reactor, NRC License No. R-47, July 1981.

9. Federal Register, Vol. 47, No. 12, Tuesday, January 19, 1982, p. 2802, "Babcock Wilcox Co.; Order Authorizing Dismantling of Facility and Disposition of Component Parts."

10. Docket No. 50-111, Dismantling Plan for the R-3, 10 KW Reactor, NRC License No. R-63, March 15, 1980.

11. Docket No. 50-106, Detailed Disassembly Procedures for the Oregon State University AGN-201 Reactor, NRC License No. R-51, December 1978.

GENERAL REFERENCES

- Directory of Nuclear Reactors, Volume II, Research, Test and Experimental Reactors, Published by the International Atomic Energy Agency, Kärnter Ring, Vienna 1, Austria, 1959.

- The American Nuclear Society Research Training, Test, and Production Reactor Directory, Volumes 1 & II, First Edition, 1980.

APPENDIX B

ADDENDUM STUDY CONTACTS

APPENDIX B

ADDENDUM STUDY CONTACTS

The methodology used in this study (see Section 3.4 for details) for the collection of data is based on the recognized need to address a number of different views and interests to accommodate a range of interest, opinions, and data so that: 1) an overview could be developed to provide direction in conducting this study; and 2) the sensitivity analyses could be performed in those selected areas identified as warranting additional study as a result of the analysis of decommissioning the reference nuclear research and test (R&T) reactors, as reported in NUREG/CR-1756.

Various nuclear R&T reactor owners/operators (both current and former) as well as burial ground operators, state and Federal government officials, and other persons familiar with the subject areas of interest were contacted. The contactees who supplied information useful to the completion of Sections 4, 5 and 6 of this report are listed alphabetically in Tables B.1-1, -2 and -3, respectively, together with their current addresses. The author includes this information to provide a measure of grateful acknowledgment for the information as well as to provide useful, up-to-date contacts to those who may be interested in seeking additional information for their own purposes.

TABLE B.1-1. Contactees Who Supplied Information Useful to the Completion of Section 5 of this Addendum

- Mr. Neil Baldwin
- John W. Cure
- J. Patrick Doran
- Ken Long
  Babcock & Wilcox
  Lynchburg Research Center
  P.O. Box No. 1260
  Lynchburg, VA 24505

- Dr. Bob Cockrell
  Department of Nuclear Engineering
  North Carolina State University
  Raleigh, NC 27650

- Bruce W. Link
  UNC Nuclear Industries
  Office of Surplus Facilities Management
  Richland, WA 99352
  Telephone: (509) 376-9646

- Mark Moore
  Armed Forces Radiobiology Research Institute
  Building 42 National Naval Medical Center
  Bethesda, MD 20814
  Telephone: (202) 295-1290

- John P. Roberts
  U.S. Nuclear Regulatory Commission
  Washington, DC
  Telephone: FTS 427-4205

- Ophelia Williams
  U.S Nuclear Regulatory Commission
  Public Document Room
  1717H Street, N.W.
  Washington, D.C. 20555

TABLE B.1-2. Contactees Who Supplied Information Useful to the Completion of Section 6 of this Addendum

• Arvil Case, Director of Marketing U.S. Ecology, Inc. P.O. Box 7246 Louisville, KY 40207 Telephone: (800) 626-2582	NOTE: The Beatty, Nevada site operator must be contacted for fiscal arrangements prior to shipment of radioactive waste to the site.
• Larry C. Osness, Operations Manager Nevada Inspection Services, Inc. (NIS) 1700 Dell Avenue Campbell, California 95008 Telephone: (800) 538-3093	NOTE: NIS, Inc. is the third party inspector for the State of Nevada
• Mr. Harold K. Peterson, Director Transportation Division Nevada State Public Service Commission 505 East King Street Carson City, Nevada 89710 Telephone: (702) 885-4117	NOTE: A permit is required for motor carriers transporting radioactive waste into Nevada, and they must report when they will enter the State.
• John Vaden, Supervisor Radiological Health Section Nevada Health Division 505 E. King St., Room 103 Carson City, NV 89710 Telephone: (702) 855-4750	

TABLE B.1-3. Contactees Who Supplied Information Useful to the Completion of Section 7 of this Addendum

- Tom Bowden
  Savannah River Plant
  Dept. of Energy
  Aiken, SC. 29801
  Telephone: FTS 239-6371

- Robert Carter
  U.S. Nuclear Regulatory Commission
  Washington, D.C.
  Telephone: FTS 492-9795

- Eugene L. Emerson
- Cheryl K. Haaker
  Transportation & Analysis Information Division 455
  Sandia National Laboratories
  Transportation Technology Center
  Albuquerque, NM 87185
  Telephone: (505) 844-4301

- Thomas Emswiler
  Sr. Specialist, Nuclear Materials Technology Section
  Battelle Memorial Institute
  Telephone: (614) 879-5165

- Diane Harmon
- Bruce Podkurst
  Edlow International
  Telephone: (202) 833-8237

- Roger K. Heusser, Director
  Div. of Materials Processing
  Dept. of Energy
  Washington, D.C. 20545
  Telephone: FTS 233-5496; or (301) 353-5496

- George Lohse, Manager
  Fuel Shipping and Receiving
  Exxon at INEL
  Telephone: FTS 583-3311

- Malcom Teissen
  Oak Ridge National Laboratory
  Oak Ridge, TN 37830
  Telephone: FTS 626-0754

- Tri-State Motor Co.
  Joplin, MO 64801
  Telephone: (800) 641-7591

- Steve C. Vorndran, Chief
  Chemical Processing Production
  Idaho National Engineering Laboratory (INEL)
  Idaho Falls, ID 83401
  Telephone: FTS 583-1396

- Harold H. Young
  Div. of University & Industry Programs
  Office of Energy Research
  Dept. of Energy
  Washington, DC 20545
  Telephone: FTS 252-6833

APPENDIX C

GLOSSARY

Abbreviations, terms, and definitions directly related to research and test reactor facilities decommissioning work and associated technology are defined and explained in this appendix. It is divided into two parts, with the first part containing abbreviations, acronyms, and symbols, and the second part containing terms and definitions (including those used in a special context for this addendum). Common terms covered adequately in standard dictionaries and commonly used chemical symbols are not included.

C.1 GLOSSARY ABBREVIATIONS

Abbreviations and Acronyms

AEC	Atomic Energy Commission (discontinued with the formation of ERDA and NRC on January 19, 1975)
AGN	Aerojet-General Nucleonics (designer and manufacturer of the AGN reactor)[a]
ALARA	As Low as Reasonably Achievable[a]
ALRR	Ames Laboratory Research Reactor
ANSI	American National Standards Institute
B&W	Babcock and Wilcox, Inc. (a McDermott Company)
CFR	Code of Federal Regulations[a]
CH	Chicago Operations Office of the Department of Energy
Ci	Curie[a]
CPM	Counts Per Minute [a, Count Rate]
D_2O	Heavy Water [a]

(a) See Section C.2 for additional information or explanation.

DF	Decontamination Factor [a]
DOE	Department of Energy
DORF	Diamond Ordnance Reactor Facility
DOT	Department of Transporation
dpm (or, d/m)	Disintegrations per minute (a, Disintegration Rate)
EFPY	Effective Full Power Year(s)
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FSAR	Final Safety Analysis Report
FLIP	Fuel Lifetime Improvement Program (special long-life nuclear fuel for TRIGA reactors)
g	grams(s)
H_2O	Ordinary Water (a, Light Water)
HP	Health Physicist [a]
HVAC	Heating, Ventilation and Air Conditioning
HX	Heat Exchanger
INEL	Idaho National Engineering Laboratory
IX	Ion Exchanger
kWt	Kilowatt, thermal
LLWBG	Low Level Waste Burial Ground
LPR	Lynchburg Pool Reactor
LWR	Light Water Reactor
mrad	Millirad[a]
mr	Milliroentgen[a]

(a) See Section C.2 for additional information or explanation.

APPENDIX C

GLOSSARY

mrem	Millirem, see rem also
MTR	Material Test and Research
MWd	Megawatt Days
MWhr	Megawatt Hours
MWt	Megawatts, thermal
NCSCR-1	North Carolina State College Reactor No. 1
NCSUR-3	North Carolina State University Reactor No. 3
NIS	Nevada Inspection Service
NECO	Nuclear Engineering Company (now, U.S. Ecology)
NRC	Nuclear Regulatory Commission (includes the regulatory branch of the former AEC).
ORNL	Oak Ridge National laboratory
OSTR	Oregon State TRIGA Reactor
Q.A.	Quality Assurance[a]
R	Roentgen[a]
rad	Radiation Absorbed Dose[a]
rem	Roentgen Equivalent Man[a]
R&T	Research and Test
SFP	Spent Fuel Pool
SNM	Special Nuclear Material[a]
SSNM	Strategic Special Nuclear Material[a]
SRP	Savannah River Plant
SRL	Savannah River Laboratory
T	Tritium[a]
TI	Transport Index(a)

(a) See Section C.2 for additional information or explanation.

TRTR	Training Research and Test Reactors
TRIGA	Training, Research Isotope Production, General Atomic Company
TTC	Transportation Technology Center[a]
WRAMC	Walter Reed Army Medical Center

Symbols

α	Alpha Radiation[a]
β	Beta Radiation[a]
H^3	Tritium[a]
γ	Gamma Radiation[a]

C.2 GLOSSARY DEFINITIONS

A: See Mass Number.

Abnormal Environmental Occurrence: An event that 1) results in noncompliance with, or is in violation of, an environmental technical specification, or 2) results in uncontrolled or unplanned releases of chemical, radioactive, or other discharges in excess of Federal, state, or local regulations. (See Technical Specifications.)

Acceptable Residual Radioactive Contamination Levels (NRC-Licensed-facilities): Those levels of radioactive contamination remaining at a decommissioned facility or on its site that are acceptable to the NRC for termination of the facility operating license and unrestricted release of the site.

Activity: Sometimes used for the term "radioactivity": (See Radioactivity.)

Adsorption: Adhesion of ions or molecules to the surface of liquids or solid bodies with which they come in contact, adhering to a surface.

Agreement State: A state that has entered into an agreement with the NRC that transfers to the state regulatory responsibility for byproduct material, source material, and quantities of special nuclear material insufficient to form a critical mass.

(a) See Section C.2 for additional information or explanation.

Airborne Radioactive Material:	Radioactive particulates, mists, fumes, and/or gases in air.
Airborne Releases:	The amount of a material of interest dispersed into the air inside a building.
ALARA	An operating philosophy to maintain exposure to ionizing radiation As Low As is Reasonably Achievable. The phrase "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic consideration, and in relation to the utilization of atomic energy in the public interest. (See 10 CFR 20.1(c). The intent of ALARA is to keep the dose to population groups, as well as to the individual, as low as possible.
Alpha Decay:	Radioactive decay in which an alpha particle is emitted. This transformation lowers the atomic number of the nucleus by two and its mass number by four.
Alpha Emitter:	A radionuclide that characteristically undergoes transformation by emission of alpha particles.
Alpha Particle:	A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons; hence it is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, and gamma) emitted by radioactive material.
Anticontamination Clothing:	Special clothing worn in a radioactively contaminated area to prevent personal contamination.
Atmospheric Release:	The amount of a material of interest released to the atmosphere.
Atomic Number (Z):	The number of protons in the nucleus of an atom; also its positive charge. Each chemical element has its characteristic atomic number and the atomic numbers of the known elements form a complete series from 1 (hydrogen) through 109 (not yet named).
Background:	Radiation originating from sources other than the source of interest (i.e., the reactor facility). Background radiation includes natural radiation (e.g., cosmic rays and radiation from naturally radioactive elements), as well as man-made radiation (e.g., fallout from atmospheric weapons testing).

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

Beta Emitter: A radionuclide that characteristically undergoes transformation by emission of beta particles.

Beta Particle: An electron, of either positive or negative charge, that has been emitted by an atomic nucleus in a nuclear transformation.

Broker of Radioactive Waste: For the purposes of this addendum, a broker of radioactive waste is a person who conducts any of the following activities:

a. Packages radioactive waste as a service to the generator of the waste, at the generator's site.

b. Takes possession of packages of radioactive waste either at the generator's site or at the broker's facility.

c. Inspects radioactive waste packages for compliance with the Department of Transportation of State regulations as a service to the generator of the waste.

d. Collects for temporary storage or repacking, radioactive waste generated by others which will eventually be transferred to a radioactive waste disposal site, as authorized in a license issued by an Agreement State or the U.S. Nuclear Regulatory Commission.

Burial Ground: An area specifically designated for shallow subsurface disposal of solid radioactive wastes to temporarily isolate the waste from man's environment.

Byproduct Material: Any radioactive material (except source material and special nuclear material) obtained during the production or use of source or specal nuclear material. Byproduct material includes fisson products and other radioisotopes.

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

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

Chelating Agent: A complexing agent that forms chelates. A chelating agent has two or more groups that attach to a single ion to form a stable (usually 5- or 6-member) ring. Organic chelating agents are compounds containing carbon, hydrogen, nitrogen, and oxygen.

Chemical Limits: Maximum chemical concentrations or quantities imposed upon gaseous or liquid effluents discharged from a facility to the environment, and consistent with known air- and water-quality standards.

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

Complexing Agent: A chemical that combines with some ion to form a stable compound that no longer behaves like the original ion. The usual result of the complexing process is to increase the mobility of the complexed ion.

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

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

Contamination, Fixed: Radioactivity remaining on a surface after repeated decontamination attempts fail to significantly reduce the contamination level. Survey meter readings made on the surface generally indicate the level of fixed contamination.

Contamination, Removable: That fraction of the radioactive contamination present on a surface that can be transferred to a smear test paper by rubbing with moderate pressure.

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

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

Curie: A unit of radioactivity, abbreviated Ci. One curie equals 3.7×10^{10} nuclear transformations per second. Several fractions of the curie are in common usage:

- Millicurie, abreviated mCi. One-thousandth of a curie (3.7×10^7 d/s).
- Microcurie, abbreviated μCi. One-millinth of a curie (3.7×10^4 d/s).
- Nanocurie, abbreviated nCi. One-billionth of a curie (37 d/s).
- Picocurie, abbreviated pCi (replaces the term μμCi). One-millionth of a microcurie (0.037 d/s).

Decay, Radioactive: A spontaneous nuclear transformation in which charged particles and/or gamma radiation are emitted.

Decommissioning: The measures taken following a nuclear facility's operating life to safely remove the property from radioactive service and to dispose of radioactive materials. The level of any residual radioactivity remaining on the property after decommissioning must be low enough to allow unrestricted use of the property.

DECON: A decommissioning alternative that involves the immediate removal of all radioactive materials down to levels which are considered acceptable to permit the property to be released for unrestricted use.

Decontamination: The removal of radioactivity from structures, equipment, or material by chemical and/or mechanical means.

Decontamination Agents: Chemical or cleansing materials used to effect decontamination.

Decontamination Factor (DF): The ratio of the initial amount (i.e., concentration or quantity) of an undesired material to the final amount resulting from a treatment process.

Deep Geologic Disposal: Placement of radioactive materials in stable geologic formations far beneath the earth's surface, to isolate them from man's environment. (Currently, the U.S. does not have this disposal capability.)

Design Basis Accident: A postulated accident believed to have the most severe expected impacts on a facility. It is used as the basis for design and safety analysis.

Detergent: A synthetic cleansing agent that resembles soap in its ability to emulsify oil and hold dirt in solution, and that contains surface active agents (surfactants) that do not precipitate in hard water.

Discount Rate: The rate of return on capital that could be realized in alternative investments if the money were not committed to the plan being evaluated (i.e., the opportunity cost of alternative investments), equivalent to the weighted average cost of capital.

Disintegration, Nuclear: The spontaneous (radioactive) transformation of an atom of one element to that of another, characterized by a definite half-life and the emission of particles or radiation from the nucleus of the first element.

Disintegration Rate: The rate at which disintegrations (i.e., nuclear transformations) occur, in events per unit time (e.g., disintegrations per minute [dpm]).

Dismantlement: Those actions required to disassemble and remove sufficient radioactive or contaminated material from a facility to permit release of the property for unrestricted use.

Dispersion: A process of mixing one material within a larger quantity of another, causing the first material to be diluted (i.e., reduced in concentration). For example, material released to the atmosphere is dispersed in (mixed with) air, reducing the released material's concentration with distance from the source.

Disposal: The disposition of materials with the intent that they will not enter man's environment in sufficient amounts to cause a significant health hazard.

Dose, Absorbed: The mean energy imparted to matter by ionizng radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad equals 0.01 joules/kilogram in any medium (100 ergs per gram).

Dose, Equivalent: Expresses the amount of ionizing radiation that is effective in the human body, in units of rems. Modifying factors associated with human tissue and body are taken into account. Equivalent dose is the product of absorbed dose, a quality factor, and a distribution factor. Referred to as Dose in this study.

Dose, Occupational: An individual's exposure to ionizing radiation (above background) as a result of his employment, expressed in rems.

Dose, Radiation: As commonly used, the quantity of radiation absorbed in a unit mass of a medium, frequently a human organ, expressed in rems.

Dose Rate: The radiation dose delivered per unit time, expressed in units of rems per hour.

Dosimeter: A device, such as a film badge or an ionization chamber, that measures radiation dose.

Drum: A metal or composition cylindrical container used for the transportation, storage, and disposal of waste materials.

ENTOMB: A decommissioning alternative that involves the encasement and maintenance of property in a strong and structurally long-lived material (e.g., concrete) to assure retention until radioactivity decays to a level acceptable for releasing the facility for unrestricted use.

Environmental Surveillance: A program to monitor the impact of discharges from industrial operations on the surrounding region. As used in this study, it is the program to monitor the extent and consequences of releases of radioactivity or chemicals from the nuclear facility.

Exhumation: The process of removing buried waste from the earth by digging.

Exposure: A measure of the ionization produced in air by x-ray or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the roentgen. (See Roentgen.)

Facility:	The physical complex of buildings and equipment on a research of test reactor plant site. Also see Reactor Facility.
Fission:	The splitting of a heavy atomic nucleus into two or more nearly equal parts (nuclides of lighter elements), accompanied by the release of a relatively large amount of energy and (generally) one or more neutrons. Fission can occur spontaneoulsy, but usually it is caused by nuclear absorption of gamma rays, neutrons, or other particles.
Fission Products:	The lighter atomic nuclides (fission fragments) formed by the fission of heavy atoms. It also refers to the nuclides formed by the fission fragments' radioactive decay.
Food Chain:	The pathways by which any material (such as radioactive material) passes through the environment through edible plants and/or animals to man.
Formula Quantity:	Means strategic special nuclear material in any combination in a quantity of 5,000 grams or more computed by the formula, grams=(grams contained U-235) + 2.5 (grams U-233 + grams plutonium). [See 10 CFR 73.2 (bb)].
Fuel Assembly:	An assembly of fuel elements.
Fuel Cycle:	The series of steps involved in supplying fuel for nuclear reactors, handling the spent fuel and the radioactive waste, including transportation.
Fuel Element:	A tube, rod, plate or other form into which fissionable material is fabricated for use in a reactor.
Fume Hood:	Ventilated containment space, enclosed of five sides, with the sixth side covered by a movable glass or plastic window to allow access and to maintain sufficient inflow or air and splash control to protect the worker from the hazardous materials handled inside.
Gamma Rays:	Short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials such as lead or uranium. The rays are similar to x-rays, but are nuclear in origin, i.e., they originate from within the nucleus of the atom.

Gaseous: Material in the vapor or gaseous state, but can include entrained liquids and solids.

Geiger-Muller (G-M) Detector: A gas-filled tube used as a detector of beta particles and gamma rays. The tube acts as an ionization chamber and produces a voltage pulse each time an energetic particle or gamma photon deposits energy in the tube.

Germanium Lithium [Ge(Li)] Detector: A solid-state detector of gamma radiation. The detector produces a voltage pulse proportional to the energy dissipated by the gamma photon in the germanium crystal.

Glove Box: A box, usually made of stainless steel and large panes of glass or transparent rigid plastic, in which workers using gloves attached to, sealed, and passing through openings in the box can safely handle radiactive materials from the outside by inserting their hands into the gloves and manually performing manipulations.

Greenhouse: In nuclear terms, a temporary structure, frequently constructed of wood and plastic, used to provide a confinement barrier between a radioactive work area and a nonradioactive area.

Half-Life, Biological: The time required for a biological system (such as a man or animal) to eliminate, by natural processes, half the amount of a substance (such as a radioactive material) that it has absorbed.

Half-Life, Effective: The time required for radioactivity contained in a biological system (such as a man or animal) to be reduced by half as a combined result of radioactive decay and biological elimination.

Half-Life, Radioactive: The time in which half the atoms of a particular radioactive susbstance disintegrate to another form. Each radionuclide has a unique half-life. Measured half-lives vary from millionths of a second to billions of years.

Health Physicist: A person trained to perform radiation surveys, oversee radiation monitoring, estimate the degree of radiation hazard, and advise on operating procedures for minimizing radiation exposures.

Health Physics: The science concerned with recognition, evaluation, and control of health hazards from ionizing radiation.

Heavy Water (D_2O): Water containing significantly more than the natural proportions (one in 6500) of heavy hydrogen (deuterium) atoms to ordinary hydrogen atoms. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively and also has a low probability for absorption of neutrons.

High Efficiency Particulate Air (HEPA) Filter: An air filter generally rated as being capable of removing at least 99.97 percent of the particulate material in an air stream.

High-Level Waste: Radioactive waste from the first-cycle solvent extraction (or equivalent) during spent nuclear fuel reprocessing. Also applied to other concentrated wastes of various origins.

Hood: See Fume Hood.

Hot Cell: A heavily shielded enclosure in which radioactive materials can be viewed through shielding windows and handled remotely with manipulators to limit exposure to operating personnel.

Hot Spot: An area of radioactive contamination of higher than average concentration.

HTO: Chemical symbol for a molecule of water in which one of the ordinary hydrogen atoms has been replaced by an atom of tritium (tritiated water).

Immobilization: Treatment and/or emplacement of materials (e.g., radioactive contamination) so as to impede their movement.

Intermodal: A transportation scenario that uses a succession of different devices (e.g., cranes, trucks, and/or other propelled mechanisms) that moves, carries, or transports irradiated fuel assemblies and/or casks (either loaded or unloaded).

Intrusion Alarm: A security device that detects intrusion into a protected area and initiates a visible and/or audible alarm signal.

Ion Exchange: A chemical process involving the selective adsorption or desorption of certain chemical ions in a solution onto a chemical compound or solid material.

Isotope: Any of two or more forms of an element having the same or very closely related chemical properties but different radioactive properties. Isotopes of an element have the same atomic number but different atomic weights.

Laboratory: A type of facility used for experimentation, observation, or practice in a particular field of study. The term "laboratory" is used broadly in this document to include parts of research facilities.

License: Written authorization issued to the research or test reactor licensee by the NRC to perform specific activities related to the possession and use of byproduct, source, or special nuclear material.

Licensed Material: Byproduct material, source material, or special nuclear material received, possessed, used, or transferred under a license issued by the NRC or a state regulatory agency.

Licensee: The holder of a license issued by the NRC or a state regulatory agency to perform specific activities related to the possession and use of byproduct, source, or special nuclear material.

Light Water: Ordinary water (H_2O) as distinguished from heavy water (D_2O).

Liquid Radioactive Waste: Solutions, suspensions, and mobile sludges contaminated with radioactive materials.

Long-Lived Nuclides: For this study, radioactive isotopes with long half-lives, typically taken to be greater than about 10 years. Most nuclides of interest to waste management have half-lives on the order of one year to millions of years.

Long-Term Care: The period following initial decommissioning activities during which institutional control of a facility or site is maintained. Activities performed during this period include environmental monitoring and routine surveillance and maintenance.

Low-Level Waste: Waste containing low but not hazardous quantities of radionuclides and requiring little or no biological shielding; low-level waste generally contains no more than 10 nanocuries of transuranic material per gram of waste.

Man-rem:	Used as a unit measure of population radiation dose, calculated by summing the dose equivalent in rem received by each person in the population. Also, it is used as the absorbed dose of one rem by one person, with no rate of exposure implied.
Mass Number (A):	The number of nucleons (protons and neutrons) in the nucleus of a given atom.
Maximum-Exposed Individual:	The hypothetical member of the public who receives the maximum radiation dose to an organ of reference. For the common case where exposure from airborne radionuclides result in the highest radiation exposure, this individual resides at the location of the highest airborne radionuclide concentration and eats food grown at the location.
Maximum Permissible Concentration (MPC):	The average concentration of a radionuclide in air or water to which an individual may be continuously exposed without exceeding an established standard of radiation dose limitation.
MeV:	Million electron Volts. One MeV is equal to 1.6 x 10^{-13} joules.
Millirad:	A unit of absorbed dose (one-thousandth of a rad).
Milliroentgen:	A submultiple of the roentgen, equal to one-thousandth of a roentgen. (See Roentgen.)
Monitoring:	Making measurements or observations so as to recognize the status or adequacy of, or significant changes in, conditions or performance of a facility or area.
Neutron Source:	Any material, combination of materials, or device that emits neutrons, including materials undergoing fission.
Normal Operating Conditions:	Operation (including startup, shutdown, and maintenance) of systems within the normal range of applicable parameters.
Nuclear Reaction:	A reaction involving a change in an atomic nucleus, such as fission, fusion, particle capture, or radioactive decay.
Nuclear Reactor:	Any apparatus, other than an atomic weapon, designed or used to sustain nuclear fission in a self-supporting chain reaction. (See 10 CFR 140.3(f) and 10 CFR 170.3(d).) Also see Reactor Facility.

Nuclear Reactor Types:

AGN-201 Training: General Description. The AGN-201 consists of two basic units, the reactor unit and the control console. The reactor unit consists of the reactor core surrounded by a graphite reflector which in turn is enclosed by lead and water shielding. Control and safety rods are installed vertically in the bottom of the reactor unit and pass through the shields and graphite reflector into the uranium-polyethylene core. The control console consists of instruments and appropriate control mechanisms for measuring the power level of the core and for actuating the control and safety rods so as to provide safe and efficient operation of the nuclear reactor.

Reactor Core. The AGN-201 reactor core is comprised of a series of discs formed from a mixture of polyethylene and UO_2 (the uranium content 20 percent enriched in the isotope U-235). The estimated critical mass of the reactor is 600 + 50 gm of U-235. The design volume of the core allowing for the void resulting from the glory hole and the fuse assembly is 12,000 cm^3. The core is loaded initially with a U-235 density of 54 milligrams cm^{-3} and will thus contain about 650 grams of U-235.

Experimental Reactor: A reactor operated primarily to obtain reactor physics or engineering data for the design or development of a reactor or type of reactor. Reactors in this class include: zero-power reactor (may also be a research reactor), reactor experiment, and prototype reactor.

Heavy Water Moderated Reactor: A reactor that uses heavy water as its moderator. Heavy water is an excellent moderator and thus permits the use of inexpensive (unenriched) uranium as a fuel.

Heterogeneous Reactor: A reactor in which the core materials are segregated to such an extent that its neutron characteristics cannot be accurately described by the assumption of homogeneous distribution of the materials throughout the core.

Homogeneous Reactor: A reactor in which the core materials are distributed in such a manner that its neutron characteristics can be accurately described by the assumption of homogeneous distribution of the materials throughout the core.

Nuclear Reactor Types: (contd)

Irradiation Reactor: A reactor used primarily as a source of nuclear radiation for irradiation of materials or for medical purposes. Reactor types in this class include: isotope-production reactor, food-irradiation reactor, chemonuclear reactor, materials processing reactor, biomedical irradiation reactor, and materials testing reactor (may also be a research reactor).

Light Water Reactor: A term used to designate reactors using ordinary water as coolant, including boiling water reactors (BWRs) and pressurized water reactors (PWRs), the most common types used in the United States.

Materials Processing Reactor: A reactor employed for the purpose of changing the physical characteristics of materials by utilizing the reactor-generated ionizing radiation. Such characteristics may be color, strength, elasticity, dielectric qualities, etc. (See nuclear reactor, irradiation.)

Materials Testing Reactor: A reactor employed for testing materials and reactor components in intense radiation fields.

Pool Reactor: A reactor whose fuel elements are immersed in a pool of water which serves as moderator, coolant, and biological shield. (Also called swimming pool reactor.)

Power Reactor: A nuclear reactor used to provide steam for electrical power generation.

Pressurized Reactor: A reactor whose primary liquid coolant is maintained under such a pressure that no bulk boiling occurs.

Pressurized Water Reactor: A reactor whose primary coolant, water, is maintained under such a pressure that bulk boiling does not occur.

Prototype Reactor: A reactor that is the first of a series of the same basic design. Sometimes used to denote a reactor having the same essential features but of a smaller scale than the final series.

Pulsed Reactor: A reactor designed to produce intense bursts of neutrons for short intervals of time.

Nuclear Reactor Types:
(contd)

Research Reactor: A reactor used for scientific, engineering, or training purposes which operates at:

1. A thermal power level of 1 megawatt or less; or
2. A thermal power level of 10 megawatts or less and does not contain:

   a. A flow loop through the core in which fueled experiments are conducted; or
   b. A liquid fuel loading; or
   c. An experimental facility in the core in excess of 16 $in.^2$ (103.2 cm^2) in cross-section.

Test Reactor: A testing facility (i.e., a test reactor) is a nuclear reactor licensed for operating at:

1. A thermal power level in excess of 10 megawatts; or
2. A thermal power level in excess of 1 megawatt, if the reactor is to contain:

   a. A circulating loop through the core in which the licensee plans to conduct fueled experiments; or
   b. A liquid fuel loading; or
   c. An experimental facility in the core in excess of 16 $in.^2$ (103.2 cm^2) in cross-section.

Offsite: Beyond the boundary line marking the limits of facility property.

Onsite: Within the boundary line marking the limits of facility property.

Operable: Capable of performing the required function.

Overpack: Secondary (or additional) external containment or cushioning for packaged nuclear waste that exceeds certain limits imposed by regulation.

Package: The packaging plus the contents of radioactive materials.

Packaging: The assembly of radioactive material in one or more containers and other components as necessary to ensure compliance with applicable regulations.

Possession-only License: An amended operating license issued by the NRC to a nuclear facility owner entitling the licensee to own but not operate the facility.

Present Value of Money: The present value of a future stream of costs is the present investment necessary to secure or yield the future stream of payments, with compound interest at a given discount or interest rate. Inflation can be taken into account in this calculation.

Protective Clothing: Special clothing worn in a radioactively contaminated area to prevent personal contamination.

Protective Survey: See Radiation Survey.

Quality Assurance: The systematic actions necessary to provide adequate confidence that 1) a material, component, system, process, or facility performs satisfactorily or as planned in service, or 2) that work is performed according to plan.

Quality Control: The quality assurance actions that control the attributes of the material, process, component, system, facility, or work in accordance with predetermined quality requirements.

Rad: The unit of absorbed dose. The energy imparted by ionizing radiation to a unit mass of irradiated material at the place of interest. One rad equals 0.01 joules/kilogram.

Radiation: 1) The emission and propagation of radiant energy: for instance, the emission and propagation of electromagnetic waves or photons. 2) The energy propagated through space or through a material medium; for example, energy in the form of alpha, beta, and gamma emissions from radioactive nuclei.

Radiation Area: Any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive a dose in excess of 5 millirem in any one hour, or a dose in excess of 100 millirem in any 5 consecutive days. (See 10 CFR 20.202).

Radiation Survey: An evaluation of radiation and associated hazards incidental to the production, use, or existence of radioactive materials. It normally includes a physical survey of the arrangement and use of equipment and measurements of the radiation dose rates under expected conditions of use. Also called protective survey.

Radioactive Material:	Any material or combination of materials that spontaneously emits ionizing radiation and has a specific activity in excess of 0.002 microcuries per gram of material. (See 49 CFR 173.389(e).)
Radioactive Series:	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nonradioactive nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product."
Radioactivity:	The property of certain nuclides of spontaneously transforming to other nuclides by emitting particles and/or gamma radiation. Also used to describe the number of nuclear transformations occurring in a given quantity of material per unit time. Often shortened to "activity."
Radioactivity, Artificial:	Man-made radioactivity produced by particle bombardment or electromagnetic irradiation, as opposed to natural radioactivity.
Radioactivity, Induced:	Radioctivity produced in a substance after bombardment with neutrons or other particles. The resulting radioactivity is "natural radioactivity" if formed by nuclear reactions occurring in nature and "artificial radioactivity" if the reactions are caused by man.
Radioactivity, Natural:	Radioactivity exhibited by more than 50 naturally occurring radionuclides.
Radiochemical:	A molecule or a chemical compound or substance containing one or more radioactive atoms.
Radioisotope:	A radioactive isotope of a chemical element. Each radioisotope decays with a characteristic half-life and with the emission of characteristic radiation.
Radiological Protection:	Protection against the effects of internal and external human exposure to ionizing radiation and radioactive materials.
Reactor:	See Nuclear Reactor

Reactor Facility: 1) The term reactor, unless it is modified by words such as containment, vessel, or core, means the entire reactor facility including the housing and equipment and associated areas devoted to the operation and maintenance of one or more reactor cores. Any apparatus that is designed or used to sustain nuclear chain reactions in a controlled manner, including critical and pulsed assemblies and research, test and power reactors, is defined as a reactor. All assemblies designed to perform subcritical experiments which could potentially reach criticality are also to be considered reactors.

2) Critical assemblies are special nuclear devices designed and used to sustain nuclear reactions. Critical assemblies may be subject to frequent core and lattice configuration changes, and may be used frequently as mockups of reactor configurations. Therefore, requirements for modifications do not apply unless the overall assembly room is modified, a new assembly room is proposed, or a new configuration is not covered in previous safety evaluations (i.e., Safety Analysis Reports, Safety Analysis Report Addenda, or Technical Specifications).

Reactor Vessel: The principal vessel surrounding at least the reactor core.

Reagent: A chemical substance used to detect or measure another substance or to convert one substance into another by means of the chemical reaction that it causes.

Reflector: A material or a body of material which reflects incident radiation. In nuclear reactor technology, this term is usually restricted to designate part of a reactor placed adjacent of the core to scatter some of the escaping neutrons back into the core.

Regulatory Guides: Documents that describe and make publicly available methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide other guidance to applicants for nuclear operations. Guides are not substitutes for regulations, and compliance with them is not explicitly required. Methods and solutions different from those set out in the guides may be acceptable if they provide a basis for the finding requisite to the issuance or continuance of a permit or license by the NRC. (Government agencies other than the NRC have regulatory guides pertaining to non-nuclear matters.)

Rem: A unit of radiation dose equivalent. The dose equivalent in rem is numerically equal to the absorbed dose in rad multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

Remote Maintenance: Maintenance by remote means, i.e., the human is separated by a shielding wall from the item being maintained. Used in the nuclear industry to reduce the occupational radiation doses to maintenance personnel.

Reporting Levels: Those levels or parameters called out in the environmental technical specifications, the dismantling order, and/or the possession-only license that do not limit decommissioning activites, but that may indicate a measurable impact on the environment.

Repository (Federal): A site owned and operated by the Federal government for long-term storage or disposal of radioactive materials.

Reprocessing: Chemical processing of irradiated nuclear reactor fuels to remove desired constituents.

Research Reactor: See Nuclear Reactor Types, Research Reactor.

Restricted Area: Any area to which access is controlled for protection of individuals from exposure to ionizing radiation and radioactive materials.

Roentgen(R): The unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions. One roentgen equals 2.58×10^{-4} coulomb per kilogram of air. (See Exposure)

Roughing Filter: A prefilter with high efficiency for large particles and fibers but low efficiency for small particles. Usually used to protect a subsequent HEPA filter from high dust concentration.

SAFSTOR: A decommissioning alternative that involves those activities required to place (preparations for safe storage) and maintain (safe storage) a radioactive facility in such condition that the risk to safety is within acceptable bounds and that the facility can be safely stored for as long a time as desired. SAFSTOR is completed by subsequently decontaminating the facility to levels which permit release of the facility for unrestricted use (deferred decontamination).

Sealed Source: Any radioactive material that is encased in a capsule designed to prevent leakage or escape the radioactive material.

Scintillation Detector: A crystal or phosphor used to detect ionizing radiation by the flash of light (scintillation) produced when the radiation enters the crystal. The crystal is normally coupled with a photomultiplier tube that detects and measures the scintillation.

Shield: A body of material used to reduce the passage of ionizing radiation. A shield may be designated according to what it is intended to absorb (as a gamma-ray shield or neutron shield), or according to the kind of protection it is intended to give (as a background, biological, or thermal shield). A shield may be required to protect personnel or to reduce radiation enough to allow use of counting instruments.

Shutdown: The time during which a site is not in production operation.

Site: The geographic area upon which the facility is located, subject to controlled public access by the facility licensee (includes the restricted area as designated in the NRC license).

Site Stabilization: The use of engineered procedures to restrict the migration of stored radioactive waste or contaminated soil and to protect the waste or soil from the effects of potential transport mechanisms.

Sodium Iodide [NaI(Tl)] Detector: A scintillation detector consisting of a thallium-activated sodium-iodide crystal optically coupled to a photomultiplier tube. Used to detect and measure gamma radiation.

Solid Radioactive Waste: Radioactive waste material that is essentially solid and dry, but may contain sorbed radioactive fluids in sufficiently small amounts as to be immobile.

Solidification: Conversion of radioactive wastes (gases or liquids) to dry, stable solids.

Source Material: Thorium, natural or depleted uranium, or any combination thereof. Source material does not include special nuclear material. (See 10 CFR 40.4(h).)

Special Nuclear Material (SNM): Plutonium, ^{233}U, uranium containing more than the natural abundance of ^{235}U, or any material artifically enriched with the foregoing substances. SNM does not include source material. (See 10 CFR 40.4 (i).)

Strategic Special Nuclear Material (SSNM): Means ^{235}U (contained in uranium enriched to 20 percent or more in the ^{235}U isotope), ^{233}U or plutonium.

Spent Fuel Storage Pool: A pool full of water that provides storage and servicing facilities for nuclear fuel elements.

Surface Contamination: The deposition and attachment of radioactive materials to a surface, also, the resulting deposits.

Surveillance: Those activities necessary to ensure that the site remains in a safe condition (includes periodic inspection and monitoring of the site, maintenance of barriers preventing access to radioactive materials remaining on the site, and prevention of activities that might impair these barriers).

Survey Meter: An instrument used to monitor the presence of radioactivity by detecting the radiation (alpha, beta, or gamma) emitted during radioactive decay.

Technical Specifications: Requirements and limits encompassing environmental and nuclear safety that are simplified to facilitate use by plant operation and maintenance personnel. They are prepared in accordance with the requirements of 10 CFR 50.36, and are incorporated into the operating and/or possession-only license issued by the NRC.

Test Reactor: See Nuclear Reactor Types, Test Reactor.

Transport Index (TI): The TI is the "number placed on a package to designate the degree of control to be exercised by the carrier during transportation." It is determined by "the highest radiation dose rate in millirem per hour at three feet from any accessible external surface of the package," or, for Fissile Class II packages only, the "number calculated by dividing the number '50' by the number of similar packages which may be transported together" (49 CFR 173.390).

Transport Mechanism:	Any mechanism that results in the movement of radioactivity away from a site where it is intended to be confined. Examples include water or wind erosion, percolation of water through the soil, the burrowing of animals, or human activity such as farming or excavation.
Transportation Scenario:	A sequence in which an empty cask is transported to a site in which fuel is stored, the cask is loaded with irradiated fuel, and the cask is transported to another site where the cask is unloaded.
Transportation Technology Center:	The Transportaion Technology Center at Sandia National Laboratories is a component of the Department of Energy's Nuclear Waste Management Program. The TTC provides technical management and support for programs which cover a broad range of technical problems related to the transportation of nuclear materials.
Transuranic Elements:	Elements above uranium in the periodic table, that is, with an atomic number greater than 92. All 17 known transuranium elements are radioactive and are produced artifically. Examples: neptunium, plutonium, curium, californium.
Transuranic Waste:	Solid radioactive waste containing primarily alpha emitters.
Tritium:	A radioactive isotope of hydrogen with two neutrons and one proton in the nucleus. It is heavier than deuterium (heavy hydrogen). Tritium (T or ^3H) is used in industrial thickness gages, as a label in tracer experiments, in controlled nuclear fusion experiments, and in thermonuclear weapons. It is produced primarily by neutron irradiation of lithium-6. It decays by emitting a low-energy beta particle.
Unrestricted Release:	Release of property from regulatory control such that subsequent use is no longer restricted in any way.
Waste Management:	The planning and execution of essential functions relating to radioactive wastes, including treatment, packaging, interim storage, transportation, and disposal.
Waste, Radioactive	Equipment and materials (from nuclear operations) that are radioactive and have no further use. Also called radwaste.

X-Ray: A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (characteristic x-rays) or when a metal target is bombarded with high-speed electrons. X-rays are always nonnuclear in origin (i.e., they originate external to the nucleus of the atom).

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Additional analyses of decommissioning at the reference research and test (R&T) reactors and analyses of five recent reactor decommissionings are made that examine some parameters not covered in the initial study report (NUREG/CR-1756). The parameters examined for decommissioning are: 1) the effect on costs and radiation exposure of plant size and/or type; 2) the effects on costs of increasing disposal charges and of unavailability of waste disposal capacity at licensed waste disposal facilities; and 3) the costs of and the available alternatives for the disposal of nuclear R&T reactor fuel assemblies.

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