NUREG/CR-0130
Addendum 4

Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station

Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule

Prepared by G. J. Konzek, R. I. Smith

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory
Commission

NOTICE

Availability of Reference Materials Cited in NRC Publications

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

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7082
3. The National Technical Information Service, Springfield, VA 22161

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

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

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

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

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

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

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Information Support Services, Distribution Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-0130
Addendum 4

Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station

Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule

Manuscript Completed: May 1988
Date Published: July 1988

Prepared by G. J. Konzek, R. I. Smith

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B2902

ACKNOWLEDGMENTS

The authors wish to acknowledge and thank the following utility contacts who provided information that was essential to the completion of this project: Douglas F. Johnson, Thomas G. Malanowski, Ronald D. Seizert, David B. Tate, and James J. Zach, all of the Wisconsin Electric Power Company; Douglas L. Dill, Ron E. Denney, and Bruce Meyer, all of the Carolina Power and Light Company; and Thomas D. Walt and Gary Zimmerman, both of the Portland General Electric Company. Only through their assistance and cooperation was it possible to complete this project.

Programmatic guidance for the project was provided by Dr. Carl Feldman of the Nuclear Regulatory Commission. His input contributed significantly to the successful completion of this project.

The editorial review prior to publication was provided by Donna B. Klan and David R. Payson, both of the Pacific Northwest Laboratory.

FOREWORD
BY
NUCLEAR REGULATORY COMMISSION STAFF

The Nuclear Regulatory Commission (NRC) staff is reappraising its regulatory position relative to the decommissioning of nuclear facilities.[1] As 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 first series of studies covers the technology, safety, and costs of decommissioning reference nuclear facilities.[2-23] Light water reactors (LWRs) and fuel-cycle and nonfuel-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 second series of studies covers supporting information on the decommissioning of nuclear facilities.[24-28] This series includes an annotated bibliography on decommissioning and studies on facilitation and radiation survey methods appropriate for decommissioning, as well as an examination of regulations applicable to decommissioning.

This report contains information concerning technical support provided by Pacific Northwest Laboratory staff for decommissioning matters related to preparation of the final Decommissioning Rule by the NRC staff.

The information provided in this report on decommissioning of a reference PWR, 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
Materials Branch
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

REFERENCES

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

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

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

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

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

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

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

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

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

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

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

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

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

14. Technology, Safety and Costs of Decommissioning Reference Light Water Reactors Following Postulated Accidents. 1982. NUREG/CR-2601, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

16. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. 1983. NUREG/CR-0672, Addendum 1, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

17. Technology, Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors. 1983. NUREG/CR-1756 Addendum, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

18. Technology, Safety and Costs of Decommissioning Reference Independent Spent Fuel Storage Installations. 1984. NUREG/CR-2210, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

19. Technology, Safety and Costs of Decommissioning Reference Nuclear Fuel Cycle and Non Fuel Cycle Facilities Following Postulated Accidents. 1985. NUREG/CR-3293, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

20. Technology, Safety and Costs of Decommissioning Nuclear Reactors at Multiple-Reactor Stations. 1985. NUREG/CR-1755, Addendum 1, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

22. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station - Classification of Decommissioning Wastes. 1984. NUREG/CR-0672, Addendum 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

23. Technology, Safety and Costs of Decommissioning Reference Nuclear Fuel Cycle Facilities - Classification of Decommissioning Wastes. 1986. NUREG/CR-4519, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

24. Decommissioning of Nuclear Facilities - An Annotated Bibliography. 1979. NUREG/CR-0130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

25. Decommissioning of Nuclear Facilities - A Review and Analysis of Current Regulations. 1979. NUREG/CR-0671, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

26. Facilitation of Decommissioning of Light Water Reactors. 1979. NUREG/CR-0569, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

28. Technology and Cost of Termination Surveys Associated with Decommissioning of Nuclear Facilities. 1982. NUREG/CR-2241, U.S. Nuclear Regulatory Commission Report by Oak Ridge National Laboratory, Oak Ridge, Tennessee.

ABSTRACT

Preparation of the final Decommissioning Rule by the Nuclear Regulatory Commission (NRC) staff has been assisted by Pacific Northwest Laboratory (PNL)[a] staff familiar with decommissioning matters. These efforts have included updating previous cost estimates developed during the series of studies on conceptually decommissioning reference licensed nuclear facilities for inclusion in the Final Generic Environmental Impact Statement (FGEIS) on decommissioning; documenting the cost updates; evaluating the cost and dose impacts of post-TMI-2 backfits on decommissioning; developing a revised scaling formula for estimating decommissioning costs for reactor plants different in size from the reference pressurized water reactor (PWR) described in the earlier study; defining a formula for adjusting current cost estimates to reflect future escalation in labor, materials, and waste disposal costs; and completing a study of recent PWR steam generator replacements to determine realistic estimates for time, costs and doses associated with steam generator removal during decommissioning.

This report presents the results of recent PNL studies to provide supporting information in four areas concerning decommissioning of the reference PWR:

- updating the previous cost estimates to January 1986 dollars
- assessing the cost and dose impacts of post-TMI-2 backfits
- assessing the cost and dose impacts of recent steam generator replacements
- developing a scaling formula for plants different in size than the reference plant and an escalation formula for adjusting current cost estimates for future escalation.

(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute.

CONTENTS

ACKNOWLEDGMENTS iii

FOREWORD v

ABSTRACT ix

1.0 INTRODUCTION 1.1

1.1 REFERENCES 1.2

2.0 SUMMARY 2.1

2.1 STUDY BASES 2.2

2.2 UPDATED DECOMMISSIONING COSTS 2.2

2.3 ESTIMATED IMPACTS OF POST-TMI-2 BACKFIT REQUIREMENTS ON THE ESTIMATED COST AND DOSE OF DECOMMISSIONING THE REFERENCE PWR 2.3

2.3.1 Estimated Additional Decommissioning Costs 2.3

2.3.2 Radiation Exposure Estimates 2.4

2.3.3 Conclusions from the Backfit Analysis 2.5

2.4 REASSESSMENT OF COST AND DOSE ESTIMATES FOR REMOVAL OF STEAM GENERATORS DURING DECOMMISSIONING OF THE REFERENCE PWR 2.6

2.4.1 Additional Decommissioning Costs 2.6

2.4.2 Radiation Exposure Estimates 2.6

2.4.3 Conclusions 2.7

2.5 SCALING AND ESCALATION FORMULAE DEVELOPED FOR THE DECOMMISSIONING RULE 2.7

3.0 COST UPDATING BASES, METHODOLOGY AND RESULTS 3.1

3.1 APPLICATION METHODOLOGY 3.1

3.2 ESTIMATED DECOMMISSIONING COSTS 3.1

3.3 REFERENCES 3.6

4.0 ESTIMATED IMPACTS OF POST-TMI-2 REQUIREMENTS AND OTHER SELECTED REGULATORY CHANGES ON DECOMMISSIONING OF THE REFERENCE PRESSURIZED WATER REACTOR 4.1

4.1 SUMMARY OF STUDY RESULTS 4.1

4.1.1 Study Bases 4.1

4.1.2 Additional Decommissioning Costs Associated with Backfit Assessment 4.2

4.1.3 Additional Decommissioning Radiation Doses Associated with Backfit Assessment 4.3

4.1.4 Conclusions and Recommendations 4.5

4.2 STUDY OBJECTIVE, APPROACH, ALTERNATIVES, BASES AND ASSUMPTIONS 4.6

4.2.1 Study Objective 4.6

4.2.2 Technical Approach 4.6

4.2.3 Decommissioning Alternatives 4.6

4.2.4 Study Bases and Assumptions 4.7

4.3 SOURCES OF INFORMATION 4.7

4.3.1 Licensee Visitation 4.8

4.3.2 Discussion Concerning Information Sources Used in this Study 4.8

4.4 RESULTS OF THE BACKFIT IMPACT ASSESSMENT FOR THE REFERENCE PWR 4.10

4.4.1 Estimated Additional Costs for Decommissioning the Reference PWR 4.10

4.4.1.1 Estimated Additional Costs for Immediate Dismantlement 4.12

4.4.1.2 Estimated Additional Costs for Entombment 4.17

4.4.1.3 Estimated Additional Costs for Preparations for Safe Storage 4.18

4.4.1.4 Estimated Additional Costs for Deferred Dismantlement 4.19

4.4.2 Estimated Additional External Occupational Radiation Doses for Decommissioning the Reference PWR 4.21

4.4.2.1 Estimated Additional External Occupational Radiation Doses for Immediate Dismantlement 4.21

4.4.2.2 Estimated External Occupational Radiation Doses for Entombment 4.21

4.4.2.3 Estimated Additional External Occupational Radiation Doses for Preparations for Safe Storage and Continuing Care 4.23

4.4.2.4 Estimated Additional External Occupational Radiation Doses for Deferred Dismantlement 4.23

4.4.3 Estimated Additional Radiation Doses from Routine Transportation Tasks 4.24

4.5 REFERENCES 4.25

5.0 REASSESSMENT OF COST AND DOSE ESTIMATES FOR REMOVAL OF STEAM GENERATORS DURING DECOMMISSIONING OF THE REFERENCE PRESSURIZED WATER REACTOR 5.1

5.1 SUMMARY OF STUDY RESULTS 5.2

5.1.1 Additional Decommissioning Cost Estimates 5.2

5.1.2 Radiation Dose Estimates 5.2

5.1.3 Observations 5.2

5.2 STUDY OBJECTIVE, APPROACH, BASES AND ASSUMPTIONS 5.3

5.3 SOURCES OF INFORMATION 5.4

5.4 REVIEW OF PAST ESTIMATES AND RECENT PWR NUCLEAR EXPERIENCE 5.5

5.4.1 Review of Pertinent Past Estimates 5.5

5.4.2 Review of Recent PWR Nuclear Experience 5.8

5.4.2.1 Surry 1 and 2, Gravel Neck, Virginia 5.8

5.4.2.2 Turkey Point 3 and 4, Florida City, Florida 5.8

5.4.2.3 Point Beach 1, Two Creeks, Wisconsin 5.10

5.4.2.4 H. B. Robinson 2, Hartsville, South Carolina 5.10

5.4.3 Discussion of Previous Estimates and of Recent Changeout Programs 5.10

5.4.4 Additional Major Work Involving Steam Generators 5.11

5.5 STUDY RESULTS 5.12

5.5.1 Estimated Additional Costs for Steam Generator Removal During Immediate Dismantlement of the Reference PWR 5.12

5.5.2 Results of the Reassessment of the Radiation Dose Estimate 5.13

5.6 CONCLUSIONS, OBSERVATIONS AND COMMENTS 5.16

5.7 REFERENCES 5.26

6.0 DEVELOPMENT OF SCALING AND ESCALATION FORMULAE FOR THE DECOMMISSIONING RULE 6.1

6.1 DEVELOPMENT OF SCALING FORMULAE FOR ESTIMATING DECOMMISSIONING COSTS OF PWRs DIFFERENT IN SIZE FROM THE REFERENCE PWR 6.1

6.2 DEVELOPMENT OF A COST ESCALATION FORMULA FOR DECOMMISSIONING COSTS 6.3

6.3 REFERENCES 6.5

APPENDIX A - COST UPDATING BASES AND METHODOLOGY A.1

APPENDIX B - REVISED ASSUMPTIONS AND FORMULAE FOR ESTIMATING COSTS AS A FUNCTION OF PLANT SIZE B.1

FIGURES

4.1 Post-TMI-2 Backfit Impacts Study Methodology 4.6

4.2 Reference PWR Plant Layout Showing the Extension to the Fuel Building 4.12

5.1 Steam Generator Removal Reassessment Study Methodology 5.3

TABLES

2.1 Summary of Updated Decommissioning Costs Estimated for the Reference PWR 2.3

2.2 Total Estimated Additional Costs for Possible Decommissioning Alternatives for the Reference PWR 2.4

2.3 Summary of Estimated Additional External Occupational, Transport, and Public Radiation Doses for Decommissioning the Reference PWR 2.5

3.1 Summary of Estimated Costs for Immediate Dismantlement of the Reference PWR 3.2

3.2 Summary of Estimated Costs for Preparations for Safe Storage of the Reference PWR 3.3

3.3 Summary of Estimated Costs for Entombment of the Reference PWR 3.5

4.1 Summary of Estimated Additional Costs for Possible Decommissioning Alternatives for the Reference PWR 4.3

4.2 Summary of the Estimated Additional External Occupational, Transport, and Public Radiation Doses for Decommissioning the Reference PWR 4.4

4.3 Summary of Information Regarding Additional Potentially Contaminated Materials at the Reference PWR 4.11

4.4 Summary of Estimated Additional Costs for Immediate Dismantlement of the Reference PWR 4.13

4.5 Two Cases of Estimated Costs for Disposal of Spent Fuel Pool Storage Racks from the Reference PWR 4.14

4.6 Summary of Estimated Costs for the Disposal of Additional Contaminated Materials from the Reference PWR 4.15

4.7 Estimated Costs for Staff Labor During Immediate Dismantlement of the Reference PWR 4.16

4.8 Estimated Costs for Additional Miscellaneous Supplies During Immediate Dismantlement of the Reference PWR 4.16

4.9 Summary of Estimated Additional Costs for Entombment of the Reference PWR 4.17

4.10 Summary of Estimated Additional Costs for Preparations for Safe Storage of the Reference PWR 4.18

4.11 Estimated Additional Volumes and Costs of Contaminated Material Disposed of During the Various Decommissioning Options for the Reference PWR 4.20

4.12 Estimated Additional Occupational Radiation Doses for Immediate Dismantlement of the Reference PWR 4.22

4.13 Estimated Additional External Occupational Radiation Doses for Deferred Dismantlement for the Reference PWR 4.24

4.14 Estimated Additional Accumulated Radiation Doses from Truck Transport of Radioactive Wastes from the Reference PWR 4.25

5.1 Generic Assessment Factors Considered in this Study 5.6

5.2 Recently Completed Steam Generator Replacement Projects 5.9

5.3 Recent Steam Generator Tube Sleeving Repairs 5.12

5.4 Estimated and Actual Personnel Radiation Doses from the Steam Generator Replacement Operations at PBNP-1 . . . . 5.14

5.5 Summary of Occupational Radiation Doses from the Point Beach Steam Generator Replacement Project 5.15

5.6 Estimated Occupational Dose for the Postulated Removal of Four Steam Generators Similar to PBNP-1 Units During Immediate Dismantlement With and Without Chemical Decontamination of the Reactor Coolant System 5.17

6.1 Revised Estimated Decommissioning Costs for Trojan and R. E. Ginna Reactors 6.1

6.2 Distribution of Radioactive Waste Disposal Costs into Components that Escalate Proportional to Labor, Energy, and Burial Costs 6.4

6.3 Derivation of the Coefficients A, B, and C in the Decommissioning Cost Escalation Formula 6.5

1.0 INTRODUCTION

Preparation of the final Decommissioning Rule by the NRC staff has been assisted by PNL staff familiar with decommissioning matters. These efforts have included updating previous cost estimates developed during the series of studies of conceptually decommissioning reference licensed nuclear facilities for inclusion in the Final Generic Environmental Impact Statement (FGEIS) on Decommissioning; documenting the cost updates; evaluating the cost and dose impacts of post-TMI-2 backfits on decommissioning; developing a revised scaling formula for estimating decommissioning costs for reactor plants different in size from the reference pressurized water reactor (PWR) described in the earlier studies[1,2]; defining a formula for adjusting current cost estimates to reflect future escalation in labor, materials, and waste disposal costs; and completing a study of recent PWR steam generator replacements to determine realistic estimates for time, costs, and doses associated with steam generator removal during decommissioning.

This report presents the results of recent PNL studies to provide supporting information in the following four areas concerning decommissioning of the reference PWR:

- updating the previous cost estimates to January 1986 dollars
- assessing the cost and dose impacts of post-TMI-2 backfits
- assessing the cost and dose impacts of recent steam generator replacements
- developing a scaling formula for plants different in size than the reference plant and an escalation formula for adjusting current cost estimates for future escalation.

For consistency, the analyses for the impact of post-TMI-2 backfits and for the assessment of the imp ct of recent steam generator replacements follow the same basic structure, content, and study approach delineated in the original . 'R study.[1]

Because of rising costs and a changing regulatory climate, the NUREG/CR-0130 generic cost estimates, originally developed in 1978 dollars, were updated to reflect 1984 cost conditions in a report prepared by PNL for the Electric Power Research Institute.[3] Using the new cost estimates as a base, revised generic cost estimates were developed for several alternatives identified to increase decommissioning costs, including additional licensing fees and extra staff to keep personnel radiation exposure below 5 rem/year.

In addition to the EPRI cost update, three addendums[2,4,5] to the original PWR report (NUREG/CR-0130) have been prepared which examined the effects on costs and safety of decommissioning plants 1) different in size than the reference plant, 2) of encountering higher radiation dose rates than were postulated in the reference plant analysis, 3) of being unable to dispose of wastes offsite, and 4) of classifying the wastes resulting from decommissioning.

This fourth addendum, which examines the topics listed above, was prepared in support of the FGEIS on Decommissioning and the final Decommissioning Rule.

Following this introductory chapter, a summary of the information and findings concerning the four areas of interest to this study is presented in Chapter 2. Chapter 3 contains the supporting information associated with updating the previous cost estimates to January 1986 dollars. The assessment of the impact of post-TMI-2 backfits on decommissioning the reference PWR is given in Chapter 4. Based on recent steam generator replacement projects at operating nuclear power stations, Chapter 5 covers the assessment of steam generator removal activities that are needed and appropriate for decommissioning the reference plant. The methodology used to develop scaling and escalation formulae for the Decommissioning Rule is presented in Chapter 6. Two appendixes to the report provide supporting information for cost updating bases and methodology (Appendix A) and revised assumptions and formulae for estimating costs as a function of plant size (Appendix B).

1.1 REFERENCES

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

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

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

4. G. M. Holter and E. S. Murphy. 1983. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130, Addendum 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

2.0 SUMMARY

The results of this study sponsored by the U.S. Nuclear Regulatory Commission (NRC) to provide technical support for decommissioning matters related to preparation of the Final Decommissioning Rule are summarized in this chapter. The purpose of this study is to provide supporting information related to decommissioning a reference pressurized water reactor (PWR), as described previously in NUREG/CR-0130 and subsequent addendums. The four areas considered in this report are:

- updating the previous cost estimates to January 1986 dollars
- assessing the cost and dose impacts of post-TMI-2 backfits
- assessing the cost and dose impacts of recent steam generator replacements
- developing a scaling formula for plants different in size than the reference plant and an escalation formula for adjusting current cost estimates for future escalation.

The principal results are given, in brief, in the following paragraphs, with more complete summaries presented in subsequent sections.

Immediate dismantlement of the reference PWR is estimated to cost $103.5 million (in January 1986 dollars) under the utility-plus-contractor option or $88.7 million under a utility-only option. Based on the results of the assessment of the data from recent steam generator replacements, estimated radiation doses to decommissioning workers for the removal of steam generators during immediate dismantlement remain essentially unchanged from those doses estimated previously in NUREG/CR-0130.

Preparing the reference PWR for safe storage, safe storage for 30 years, and dismantlement after 30 years is estimated to cost a total of $100.5 million (in January 1986 dollars). Continuing care during the safe storage period is estimated to cost $128,000 per year and would continue until the facility is dismantled. The cost of deferred dismantlement, starting after intervals of 10, 30, 50 and 100 years after final shutdown has been estimated in January 1986 dollars to be $69.4 million, $69.4 million, $40.5 million, and $40.4 million, respectively, and to require a time span equivalent to immediate dismantlement.

Entombing the reference PWR after removing the highly activated reactor vessel internals is estimated to cost $70.4 million (in January 1986 dollars) under the utility-plus-contractor option. Entombing the reference PWR with the highly activated reactor vessel internals left in place is estimated to cost $60.1 million under the utility-plus-contractor option.

Costs of continuing care during entombment of the reference PWR are estimated to be $64,000 per year. Federal and state licensing/inspection costs are estimated to cost an additional $10,000 per year. These costs would continue until either the radioactivity can be shown to have decayed to unrestricted release levels, or until the facility is dismantled should an earlier release of the property become necessary.

No detailed estimates of cost and radiation dose are made for dismantlement of an entombed facility. However, it is anticipated that these parameters will have values similar to those for dismantlement following safe storage.

The incremental costs and radiation doses associated with decommissioning the modifications and additions to the reference plant facilities that resulted from post-TMI backfit requirements and from changes in the policy and schedule for the federal radioactive waste management program are about $788,000 and about 32 man-rem, respectively. Over half of these incremental additions are due to the decommissioning of the storage racks in the spent fuel pool at the reference plant. (The number of storage racks has been greatly expanded since the reference study was performed.) However, the original immediate dismantlement decommissioning cost estimate could be expected to increase only slightly overall (less than 1% in January 1986 dollars), due to the slightly expanded scope of decommissioning activities associated with changes in the reference plant's characteristics.

An important part of the Decommissioning Rule related to commercial power reactors developed by the NRC is the section dealing with assurance that funds will be available for decommissioning when the time comes to accomplish that effort. The NRC has placed into the Rule a formula for estimating the amount of funds required to provide reasonable assurance of adequate funding as a function of the power rating of the reactor. Since the actual date of decommissioning for most plants is as yet undefined, an additional formula has been developed for adjusting that cost estimate to include escalation from the time the Rule was issued to the time of actual decommissioning.

2.1 STUDY BASES

For consistency, the major study bases are the same as those used in the original PWR decommissioning studies with two exceptions: 1) costs are in January 1986 dollars and 2) occupational radiation doses to decommissioning workers shall not exceed 5 rem per person per year. It should be recognized that revisions to 10 CFR 20.101 since NUREG/CR-0130 was published in 1978 have tended to reduce annual cumulative radiation dose allowable to persons working in the nuclear industry. Under normal circumstances, the allowable quarterly radiation dose is now 1 - 1/4 rem (rather than the 3 rem per quarter dose postulated in NUREG/CR-0130 for decommissioning workers), with an annual cumulative dose of 5 rem.

2.2 UPDATED DECOMMISSIONING COSTS

All costs are given in terms of January 1986 dollars, with 25% contingencies included.

The total cost in January 1986 dollars for each of the decommissioning alternatives is summarized in Table 2.1. In addition to the values escalated

TABLE 2.1. Summary of Updated Decommissioning Costs Estimated for the Reference PWR[a,b]

Decommissioning Option	Estimated Costs in Millions of 1986 Dollars: Decontamination	Preparations for Safe Storage	SAFSTOR[c]: 10 Years	30 Years	50 Years	100 Years	ENTOMB[d]: Internals Included[e]	Internals Removed
Utility-Only (Internal) Staffing	88.7	21.8	97.7	100.5	73.5	80.3	47.9	57.2
Utility-Plus-Contractor (External) Staffing	103.5	27.5	--	--	--	--	60.1	70.4

(a) Values include the cost adders described in Section 2.2 and the effects of TMI-2 backfits, plus a 25% contingency, and are in January 1986 dollars.
(b) Values exclude cost of disposal of last core, exclude cost of demolition of nonradioactive structures, and exclude cost of deep geologic disposal of dismantled, highly activated components.
(c) The values shown for SAFSTOR include the costs of the preparations for safe storage, continuing care, and deferred dismantlement.
(d) The cost of surveillance and maintenance for the entombed structure is estimated to be about $0.064 million per year. Values listed do not include any costs for post-entombment period actions.
(e) Does not include the costs associated with the eventual removal, packaging, and disposal of the entombed radioactive materials, the demolition of the entombment structure, or demolition of the reactor building.

from the parent documents, the costs in Table 2.1 reflect several new cost adders (i.e., predecommissioning engineering, additional staff to assure meeting the 5 rem/year dose limit for personnel, extra supplies for the additional staff, and the additional costs associated with the option of utilizing an external contractor to conduct the decommissioning effort. These cost adders, initially developed in a PNL decommissioning cost update done in 1984 for the Electric Power Research Institute (EPRI NP-4012), are included in this analysis. Furthermore, the estimated impacts on the decommissioning cost of post-TMI-2 backfit requirements for the reference PWR, described in Chapter 4, are included in the overall totals shown in the table, where applicable.

2.3 ESTIMATED IMPACTS OF POST-TMI-2 BACKFIT REQUIREMENTS ON THE ESTIMATED COST AND DOSE OF DECOMMISSIONING THE REFERENCE PWR

Since the original PWR decommissioning reports were prepared, a number of post-TMI-2 backfit requirements have been imposed on operating nuclear power stations. These requirements were actions judged necessary by the NRC to correct or improve the safety of operation of nuclear power plants based on the experience from the accident at TMI-2. The results of the analyses to examine and assess, in quantitative terms, the impacts of all NRC-initiated post-TMI-2 backfit requirements on the estimated cost and dose of decommissioning the reference PWR are summarized in the following subsections.

2.3.1 Estimated Additional Decommissioning Costs

The total additional cost in January 1986 dollars for each of the decommissioning alternatives is summarized in Table 2.2.

TABLE 2.2. Total Estimated Additional Costs for Possible Decommissioning Alternatives for the Reference PWR

Decommissioning Alternative	Additional Decommissioning Costs ($ thousands)[(a)] Number of Years After Shutdown Dismantlement is Deferred				
	0	10	30	50	100
Immediate Dismantlement	789	--	--	--	--
Preparations for:					
Safe Storage	10	10	10	10	10
Continuing Care	--	--	--	--	--
Deferred Dismantlement	--	678	678	13[(b)]	13[(b)]
Total Additional Cost	--	688	688	23	23
Entombment	260	260	260	260	260
Continuing Care	--	--	--	--	--
Deferred Dismantlement	--	--	--	--	--
Total Additional Cost	--	260	260	260	260[(c)]

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) These reduced values result from lesser amounts of contaminated materials for burial in a licensed disposal site.
(c) It is assumed that the entombed radioactive material decays to the unrestricted release level in 100 years.

2.3.2 Radiation Exposure Estimates

The additional accumulated occupational radiation doses are estimated to be 31.5 man-rem for immediate dismantlement and for entombment, and about 3.3 man-rem for placing the facility in safe storage, with essentially no increase in occupational radiation dose for surveillance and maintenance staff during continuing care. Relatively little additional reduction in accumulated occupational radiation dose is estimated to result from deferring the dismantlement sequence beyond 30 years for those items identified in this backfit assessment, and virtually no reduction results from deferment beyond 50 years.

The individual estimates of additional occupational radiation dose for the various decommissioning alternatives are summarized in Table 2.3. The radiation dose rates are based on the maximum allowable dose rates for each shipment in exclusive-use trucks, just as analyzed in the parent study, and are thus conservatively high. The estimated additional external radiation dose for routine transportation operations for immediate dismantlement is 0.73 man-rem to transport workers and 0.15 man-rem to the general public.

TABLE 2.3. Summary of Estimated Additional External Occupational, Transport, and Public Radiation Doses for Decommissioning the Reference PWR

Decommissioning Mode	Time After Reactor Shutdown (years)	Estimated Additional Dose (man-rem)		
		Occupational	Transport Workers[(a)]	Public[(a)]
Immediate Dismantlement[(b)]	0	31.5	0.73	0.15
Safe Storage:[(c)]				
Preparations for Safe Storage[(b)]	0	3.4	0	0
Continuing Care	10	0	0	0
	30	0	0	0
	50	0	0	0
	100	0	0	0
Deferred Dismantlement	10	8.5	0	0
	30	0.6	0	0
	50	<0.05	0	0
	100	<0.0001	0	0
Total for Safe Storage[(c)] with Deferred Dismantlement in year:	10	11.9	0	0
	30	4.0	0	0
	50	3.4	0	0
	100	3.4	0	0

(a) Based on the radiation doses per shipment delineated in Table 11.4-2 in NUREG/CR-0130.
(b) Total additional shipments: 10 for immediate dismantlement; zero for preparations for safe storage.
(c) Safe Storage consists of three phases: preparations for safe storage, continuing care, and deferred dismantlement.

Based on this study, there are no additional radiation doses to workers or to the public during the preparations for safe storage, since no additional truck shipments are contemplated.

2.3.3 Conclusions from the Backfit Analysis

The changes at the reference PWR that have resulted to date, as well as those changes anticipated to result from full implementation of post-TMI-2 regulatory requirements, will have only a minor impact on decommissioning costs and occupational radiation doses for that facility. For any given plant, however, site-specific issues will have to be addressed to assess the actual impact of the backfits on decommissioning.

One unexpected result of this assessment is the identification of the positive effect that the Technical Support Centers (TSCs), required in the aftermath of TMI-2, will eventually have on decommissioning activities. TSCs are required to provide up-to-date, as-built drawings for the purpose of emergency preparedness. The availability and use of those drawings will facilitate planning and preparation of decommissioning activities and subsequently will support implementation of those activities.

A number of plant modifications have been made for which no specifics could be obtained (and thus no quantification of potential impacts on decommissioning could be made). These modifications pertain to safeguards and/or plant security areas or equipment, and this type of information is not available without appropriate need-to-know. However, it is unlikely that these modifications would have any significant effect on the safety or cost of decommissioning.

2.4 REASSESSMENT OF COST AND DOSE ESTIMATES FOR REMOVAL OF STEAM GENERATORS DURING DECOMMISSIONING OF THE REFERENCE PWR

The results of this analysis to evaluate and compare the occupational radiation doses of recent PWR steam generator changeout programs with the dose estimates previously developed for immediate dismantlement of the reference PWR described in NUREG/CR-0130 are summarized in this section. The principal results are given, in brief, in the following subsections.

2.4.1 Additional Decommissioning Costs

For the reference PWR, the original immediate dismantlement decommissioning cost estimate given in NUREG/CR-0130 could be expected to increase about $8.7 million (in January 1986 dollars), due to the incremental cost adjustments associated with two of the cost adders developed in the 1984 EPRI cost update (EPRI NP-4012). These cost adders are: 1) the additional staff ($7.5 million) to assure meeting the 5 rem/year dose limit for personnel associated with all immediate dismantlement tasks, and 2) the extra supplies ($1.2 million) for the additional staff. These adders have been escalated from 1984 to January 1986 for this study and include a 25% contingency. The fraction of the additional $8.7 million that is attributable to the removal of the reference PWR's four steam generators is conservatively estimated to be about $1.4 million.

2.4.2 Radiation Exposure Estimates

The comparison of the reported exposures for the steam generator removal project at the Point Beach Nuclear Power Plant No. 1 (PBNP-1), which was selected for examination in this study, considers in detail the tasks involved to determine their applicability to decommissioning under the immediate dismantlement alternative. Data on the occupational exposure for this removal/replacement project were obtained from the literature as well as from personal communication with utility personnel. Analysis of these data involved assessing the reported doses concerning all specified tasks and then eliminating those doses associated with tasks determined to be unrelated to decommissioning. In addition, dose adjustments were made where it was determined that the task was performed in a different sequence or manner than envisaged during decommissioning. These adjusted doses were then compared to the doses previously estimated in NUREG/CR-0130. This comparison shows that the estimated total radiation dose to decommissioning workers for the removal of steam generators during immediate dismantlement remains essentially unchanged from the total dose initially estimated in NUREG/CR-0130 for this task.

2.4.3 Conclusions

It should be emphasized that the dose consequences for any decommissioning alternative in which the steam generators are to be physically removed are quite different from the dose consequences associated with the replacement of steam generators during reactor outages. This is because, during a replacement effort, significant additional activities are necessary to assure continued operation, including preservation of building structures, concern for capital equipment, materials, continuing use of air, water, etc. On the other hand, large-component removal (such as steam generator removal) during decommissioning does not require any activities to assure future operability, and thus involves a much smaller commitment of resources than does removal and replacement of the steam generators.

Specific steam generator repair/replacement cost data were generally not available, due to the inherently proprietary nature of this highly competitive type of reactor outage work in the U.S.

2.5 SCALING AND ESCALATION FORMULAE DEVELOPED FOR THE DECOMMISSIONING RULE

The formulae for evaluating financial assurance for decommissioning that the NRC has placed into the Decommissioning Rule are summarized in this section.

The formulae for estimating decommissioning costs incorporate the effects of post-TMI-2 backfits, as documented in Chapter 4 of this report, and account for the situations when the utility employs an external decommissioning contractor and when the utility acts as its own decommissioning contractor. These formulae were developed using data from plants ranging in size from about 1200 MW_t to 3500 MW_t. The formula for the utility-plus-contractor option is:

$$\text{Estimated PWR Decommissioning Cost} = 75 + 0.0088\ MW_t \text{ (millions January 1986\$)}$$

where the cost for plants smaller than 1200 MW_t is set equal to the cost for a 1200-MW_t plant, and the cost for plants larger than 3400 MW_t is set equal to the cost for a 3400-MW_t plant.

This formula provides reasonable cost estimates for immediate dismantlement of reactor plants that are smaller than the reference plant examined in the original PWR decommissioning analysis (NUREG/CR-0130). Since immediate dismantlement (DECON) is generally the more expensive of the acceptable decommissioning possibilities, if funds for DECON are available, the other possibilities are also covered.

As a result of performing several cost updates over the years since 1978 (the most recent update is given in Chapter 3 of this report), it became apparent that the total cost of decommissioning could be divided into three principal components, as regards to cost escalation. These components are:

- Labor and other components that escalate at the same rate as labor
- Energy: electricity, fuel, and other components that escalate at the same rate as energy
- Waste Disposal: handling and burial charges at a low-level waste disposal site

Assuming that the escalation factors for each of these components can be derived for any point in the future, relative to the 1986 data base used in the aforementioned formula used in the Decommissioning Rule, then the escalated decommissioning cost is given by:

$$\text{Estimated Cost (year X)} = \text{January 1986 Cost } (0.65\ L_x + 0.13\ E_x + 0.22\ B_x)$$

where L_x is the escalation factor for labor and related components between January 1986 and year X, E_x is the escalation factor for energy and related components over the same period, and B_x is the escalation factor for waste disposal over the same time period. L_x and E_x are to be based on regional data of the U.S. Department of Labor's Bureau of Labor Statistics. The waste disposal factor, B_x, is to be taken from NUREG-1307, a report that will be developed especially for this purpose and will contain the bases and the derived escalation factors for each disposal site operating in the U.S. at the time of issue. The report will be updated and reissued on some reasonable frequency, to provide reliable factors at any point in time.

3.0 COST UPDATING BASES, METHODOLOGY AND RESULTS

The cost adjustment factors used to update the decommissioning costs for the reference PWR to a January 1986 cost base for the Final Generic Environmental Impact Statement (FGEIS) on Decommissioning are described in detail in Appendix A of this report. The results of the application of the cost adjustment factors given in Appendix A are presented in this chapter.

3.1 APPLICATION METHODOLOGY

The application methodology consisted of a detailed review of all elements that make up each of the major cost categories given in the parent documents(1,2) for the three decommissioning alternatives--immediate dismantlement (DECON), safe storage (SAFSTOR), and entombment (ENTOMB). The appropriate cost adjustment factors were then applied to the respective line items and the items were added to form updated cost categories for each of the decommissioning alternatives. In addition to the values escalated from the parent documents, several new cost adders were included in the update. These were: predecommissioning engineering; additional staff to assure meeting the 5 rem/year dose limit for personnel; extra supplies for the additional staff; and the additional costs associated with using an external contractor to conduct the decommissioning effort. These cost adders were developed in the PNL decommissioning cost update done in 1984 for the Electric Power Research Institute.(3) Furthermore, the estimated cost impacts of post-TMI-2 requirements on the reference PWR decommissioning costs, described in Chapter 4, are included in the overall cost update. In each case, a 25% contingency is applied to the sum of the categories to establish the estimated costs of decommissioning the reference PWR in January 1986 dollars.

3.2 ESTIMATED DECOMMISSIONING COSTS

Immediate dismantlement of the reference PWR is estimated to cost $103.5 million under the utility-plus-contractor option. The major contributors to the total cost of immediate dismantlement are summarized in Table 3.1. The cost for shipment and disposal of radioactive materials is about 38% of the total decommissioning cost. About 25% of the total decommissioning cost is due to utility staff labor (i.e., the cost categories of Staff Labor plus Additional Staff Needed to Reduce Average Annual Dose to 5 rem/year, shown in Table 3.1). Approximately 21% of the total decommissioning cost is due to the use of an external decommissioning contractor. Energy, supplies, and equipment costs constitute about 8%, 4%, and 2%, respectively, of the total dismantlement cost.

Preparing the reference PWR for safe storage is estimated to cost $27.5 million under the utility-plus-contractor option. The major contributors to the total cost of preparations for safe storage are summarized in Table 3.2. The principal cost item is attributable to the use of an external decommissioning contractor, which accounts for about 33% of the total cost of

TABLE 3.1. Summary of Estimated Costs for Immediate Dismantlement of the Reference PWR (millions of 1986 dollars)

Cost Category	Estimated Costs ($ millions)[a,b]		Percent of Total
Disposal of Radioactive Materials			
Activated Materials Disposal	6.446		
Contaminated Internals Disposal	4.032		
Other Building Internals Disposal	18.996		
Radioactive Waste Disposal	2.073		
Total Disposal Costs		31.547	38.1
Staff Labor		14.378	17.4
Energy		6.650	8.0
Special Equipment		1.315	1.6
Miscellaneous Supplies		2.494	3.0
Specialty Contractors		0.624	0.8
Nuclear Insurance		1.520	1.8
Environmental Surveillance		0.246	0.3
License Fees		0.112	0.1
Cost Adders[c]			
Additional Staff Needed to Reduce Average Annual Dose to 5 rem/year		6.000	7.2
Use of External Decommissioning Contractor		10.320	12.5
Predecommissioning Engineering by an External Contractor		5.920	7.1
Supplies for Extra Staff		0.960	1.2
Post-TMI-2 Impacts by an External Contractor		0.720	0.9
Subtotal		82.806	100.0
25% Contingency		20.702	
Total, Immediate Dismantlement Costs		103.508	

(a) Costs adjusted to January 1986.
(b) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(c) See text for details concerning this category.

TABLE 3.2. Summary of Estimated Costs for Preparations for Safe Storage of the Reference PWR (millions of 1986 dollars)

Cost Category	Estimated Costs ($ millions)[a,b]	Percent of Total
Disposal of Radioactive Materials	1.655	7.5
Staff Labor	5.842	26.6
Energy	3.544	16.1
Special Tools and Equipment	0.119	0.5
Miscellaneous Supplies	1.426	6.5
Specialty Contractors	0.489	2.2
Nuclear Insurance	0.559	2.6
License Fees	0.084	0.4
Cost Adders[c]		
Additional Staff Needed to Reduce Average Annual Dose to 5 rem/year	0.880	4.0
Use of External Decommissioning Contractor	3.680	16.8
Predecommissioning Engineering by an External Contractor	3.600	16.4
Supplies for Extra Staff	0.080	0.4
Post-TMI-2 Impacts by an External Contractor	Negligible	--
Subtotal	21.958	100.0
25% Contingency	5.490	
Total, Preparations for Safe Storage Costs	27.448	

(a) Costs adjusted to January 1986.
(b) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(c) See text for details concerning this category.

preparations for safe storage. Utility staff labor (i.e., the cost categories of Staff Labor plus Additional Staff Needed to Reduce Average Annual Dose to 5 rem/year, shown in Table 3.2) contributes about 31% of the total cost. Energy, disposal of radioactive wastes, and supplies contribute about 16%, 7.5%, and 6.5%, respectively, to the total cost.

The cost of continuing care during safe storage of the reference PWR is estimated to be about $128,000 per year.

The cost of deferred dismantlement of the reference PWR, starting after intervals of 10, 30, 50 and 100 years after final reactor shutdown, is estimated in January 1986 dollars to be $69.4 million, $69.4 million, $40.5 million and $40.4 million, respectively. The lesser cost after 100 years is the result of having less contaminated material for packaging, shipment, and burial due to decay of the residual radionuclides.

Entombing the reference PWR via the scenario that calls for the removal and disposal of reactor vessel internals is estimated to cost $70.4 million under the utility-plus-contractor option. The major contributors to the total cost of entombment are summarized in Table 3.3. The principal cost item is attributable to the use of an external decommissioning contractor, which accounts for about 27% of the total cost for this scenario. Utility staff labor (i.e., the cost categories of Staff Labor plus Additional Staff Needed to Reduce Average Annual Dose to 5 mrem/year, shown in Table 3.3) contributes about 27% of the total. Disposal of radioactive materials, energy, miscellaneous supplies, and entombment staff labor contribute 18%, 11.8%, 4.4%, and 3.4%, respectively, to the total cost.

With the reactor internals left in place, which is really a form of hardened safe storage, entombment of the reference PWR is estimated to cost about $60 million (see Table 3.3).

The cost of continuing care during entombment of the reference PWR is estimated to be about $74,000 per year for either of the aforementioned scenarios, which includes an estimated $10,000 per year for various federal and state licensing/inspection costs.

Because of the many variables involved, PNL made no firm estimate of the costs for possible deferred dismantlement of the entombment structure. However, these costs are anticipated to be at least of the same order of magnitude as those discussed previously for deferred dismantlement of the reference PWR after a period of safe storage.

TABLE 3.3. Summary of Estimated Costs for Entombment of the Reference PWR (millions of 1986 dollars)

Cost Category	Entombment (with internals)		Entombment (internals removed)(c)	
	Estimated Costs ($ millions)(a,b)	Percent of Total	Estimated Costs ($ millions)(a,b)	Percent of Total
Disposal of Radioactive Materials				
Neutron-Activated Materials	N/A		5.890	
Contaminated Containment Material Disposal	N/A		N/A	
Other Buildings Contaminated Material Disposal	2.124		2.124	
Radioactive Wastes	2.073		2.073	
Total Disposal Costs	4.197	8.7	10.087	18.0
Dismantlement Staff Labor	11.056	23.0	11.866	21.1
Entombment Staff Labor	1.914	4.0	1.914	3.4
Energy	6.650	13.8	6.650	11.8
Special Equipment	1.315	2.7	1.315	2.3
Miscellaneous Supplies	2.494	5.2	2.494	4.4
Nuclear Insurance	1.520	3.2	1.520	2.7
Specialty Contractors	0.448	0.9	0.448	0.8
Environmental Surveillance	0.246	0.5	0.246	0.4
Security and Surveillance System	0.138	0.3	0.138	0.2
Entombment Barrier Installation	0.496	1.0	0.496	0.9
License Fees	0.086	0.2	0.086	0.2
Cost Adders(d)				
Additional Staff Needed to Reduce Average Annual Dose to 5 rem/year	2.480	5.2	3.120	5.5
Use of External Decommissioning Contractor	8.400	17.5	9.120	16.2
Predecommissioning Engineering by an External Contractor	5.920	12.3	6.000	10.7
Supplies for Extra Staff	0.480	1.0	0.560	1.0
Post-TMI-2 Impacts by an External Contractor	0.240	0.5	0.240	0.4
Subtotals	48.080	100.0	56.300	100.0
25% Contingencies	12.020		14.075	
Total, Entombment Costs	60.100		70.375	
Annual Continuing Care Costs and NRC Licensing Costs	0.074		0.074	

(a) Costs adjusted to January 1986.
(b) Number of figures shown is for computational accuracy and does not imply precision to the nearest thousand dollars.
(c) For this entombment scenario, dismantlement will eventually be required.
(d) See text for details concerning this category.

3.3 REFERENCES

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

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

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

4.0 ESTIMATED IMPACTS OF POST-TMI-2 REQUIREMENTS AND OTHER SELECTED REGULATORY CHANGES ON DECOMMISSIONING OF THE REFERENCE PRESSURIZED WATER REACTOR

Since the original PWR decommissioning reports[1,2] were prepared, a number of post-TMI-2 backfit requirements have been imposed on operating nuclear power stations. These requirements were actions judged necessary by the NRC to correct or improve the safety of operation of nuclear power plants based on the experience from the accident at TMI-2. Other plant changes, such as reracking of spent fuel pools, have also occurred, resulting in more contaminated material for disposal.

Examined and assessed in quantitative terms in this chapter are all NRC-initiated post-TMI-2 plant modifications imposed on the previously studied reference PWR, whether mandated (as in a rule, regulation, or order) or committed to by the licensees (originating in a generic letter or IE Bulletin, for example), for their impact on estimated decommissioning costs and occupational radiation doses. The purpose of this examination was to provide the NRC decision-makers with pertinent information concerning the effects of those backfit requirements and associated regulatory changes on decommissioning. The results of these analyses also make a useful addition to the already existing decommissioning data base and increases its general applicability.

The study results are summarized in Section 4.1. The study approach is presented in Section 4.2. The analyses are based on the reference PWR nuclear power plant reported in NUREG/CR-0130[1] and Addendum.[2] The sources of information used in the analyses are discussed in Section 4.3, and the detailed results of the analyses are given in Section 4.4.

4.1 SUMMARY OF STUDY RESULTS

The results of this study to assess the impacts on decommissioning of post-TMI-2 requirements and other selected changes in the regulatory climate are summarized in this section. The principal results are given, in brief, in the following paragraphs, with more details presented in subsequent sections.

4.1.1 Study Bases

For consistency, the major study bases are the same as those used in the original PWR decommissioning studies with one exception--costs are in January 1986 dollars. The results obtained in this study are specific to these major bases and to the specific assumptions that are derived from them. Applying these results to situations with conditions different from those in this study could produce erroneous conclusions. However, without additional evidence/information, more refined analyses are not expected to significantly change the results of this study.

4.1.2 Additional Decommissioning Costs Associated with Backfit Assessment

All additional costs associated with this backfit assessment are given in January 1986 dollars, with 25% contingencies included.

In addition to the backfit requirements, since the time of the reference PWR study (1978), the plant owner has installed high-density racks in the fuel storage pool, resulting in a greater mass of spent fuel storage racks to be removed during decommissioning than was originally estimated. About 86% of the total additional decommissioning cost is related to the shipment and disposal of contaminated materials. The disposal of the spent fuel pool storage racks comprises about 60% of those costs.

Immediate dismantlement of the reference PWR is estimated to cost an additional $788,500 based on this assessment of the backfit requirements and other plant modifications.

Entombment of the reference PWR is estimated to cost an additional $259,500, whether or not the reactor vessel internals are removed. The principal cost item is disposal of contaminated materials, contributing almost 58% of the total additional cost. The staff labor requirement for onsite handling/emplacement within the containment building of the contaminated materials from the fuel and auxiliary buildings is estimated to be similar to that required to remove just the additional materials from the containment building itself during immediate dismantlement. Therefore, no significant change in additional labor cost is anticipated for entombment from that previously given for immediate dismantlement. No increase in costs associated with continuing care activities is anticipated to result based on this backfit assessment.

Preparing the reference PWR for safe storage is estimated to cost an additional $10,300. Little, if any, additional effort is anticipated to be required in the reactor building during the preparations for safe storage based on this backfit assessment. Deactivation and tagging of the additional valves and equipment in the auxiliary building that were identified in this study are likewise estimated to require little effort. However, preparations for safe storage of the fuel building will require additional effort for decontamination and immobilization of the greater mass of spent fuel storage racks in the spent fuel pool. For this study, one additional week has been allocated for this task. Thus, the principal cost item is staff labor. No increase in costs associated with continuing care activities is anticipated to result based on this backfit assessment.

The additional costs of deferred dismantlement following safe storage of the reference PWR for intervals of 10, 30, 50, and 100 years after final shutdown are estimated in January 1986 dollars to be $677,500, $677,500, $13,000, and $13,000, respectively. The lesser costs after the longer intervals are the result of having less of the contaminated materials identified in this study for packaging, shipment, and burial [illegible] to decay of the radionuclides.

The total estimated additional co[illegible] 1986 dollars for each of the decommissioning alternatives are s[illegible]ble 4.1.

TABLE 4.1. Summary of Estimated Additional Costs for Possible Decommissioning Alternatives for the Reference PWR

Decommissioning Alternative	Additional Decommissioning Costs ($ thousands)[a] Number of Years After Shutdown Dismantlement is Deferred				
	0	10	30	50	100
Immediate Dismantlement	789	--	--	--	--
Preparations for:					
Safe Storage	10	10	10	10	10
Continuing Care	--	--	--	--	--
Deferred Dismantlement	--	678	678	13[b]	13[b]
Total Additional Cost	--	688	688	23	23
Entombment	260	260	260	260	260
Continuing Care	--	--	--	--	--
Deferred Dismantlement	--	--	--	--	--
Total Additional Cost	--	260	260	260	260[c]

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) These reduced values result from lesser amounts of contaminated materials for burial in a licensed disposal site.
(c) It is assumed that the entombed radioactive material decays to the unrestricted release level in 100 years.

4.1.3 Additional Decommissioning Radiation Doses Associated with Backfit Assessment

Estimates of additional accumulated occupational radiation doses associated with this backfit assessment are briefly described in the following paragraphs. Included are the additional occupational doses and the additional radiation doses received by transport workers and by the general public as a result of transporting the increased amount of radioactive materials identified in this study to disposal sites.

The individual estimates of additional occupational, transport worker and public radiation doses for the various decommissioning alternatives are summarized in Table 4.2. Additional accumulated occupational radiation doses are estimated to be 31.5 man-rem for immediate dismantlement and for entombment, and about 3.3 man-rem for placing the facility in safe storage, with essentially no increase in occupational radiation dose for surveillance and maintenance staff during continuing care. Deferring the dismantlement sequence beyond 30 years for those items identified in this backfit assessment results in relatively little reduction in accumulated occupational radiation dose,

TABLE 4.2. Summary of Estimated Additional External Occupational, Transport, and Public Radiation Doses for Decommissioning the Reference PWR

Decommissioning Mode	Time After Reactor Shutdown (years)	Estimated Additional Dose (man-rem)		
		Occupational	Transport Workers[a]	Public[a]
Immediate Dismantlement[b]	0	31.5	0.73	0.15
Safe Storage:[c]				
Preparations for Safe Storage[b]	0	3.4	0	0
Continuing Care	10	0	0	0
	30	0	0	0
	50	0	0	0
	100	0	0	0
Deferred Dismantlement	10	8.5	0	0
	30	0.6	0	0
	50	<0.05	0	0
	100	<0.0001	0	0
Total for Safe Storage[c] with Deferred Dismantlement in year:	10	11.9	0	0
	30	4.0	0	0
	50	3.4	0	0
	100	3.4	0	0

(a) Based on the radiation doses per shipment delineated in Table 11.4-2 in NUREG/CR-0130.
(b) Total additional shipments: 10 for immediate dismantlement; zero for preparations for safe storage.
(c) Safe Storage consists of three phases: preparations for safe storage, continuing care, and deferred dismantlement.

and virtually no reduction results from deferment beyond 50 years. The estimated additional external radiation dose from transport operations for immediate dismantlement is 0.73 man-rem to transport workers and 0.15 man-rem to the general public.

Since no additional truck shipments are contemplated, there are no additional radiation doses to workers or to the public resulting from the post-TMI-2 backfits during the preparations for safe storage.

4.1.4 Conclusions and Recommendations

Based upon the results of this study, it appears that the changes that have already resulted, as well as those changes anticipated to result from full implementation of post-TMI-2 regulatory requirements at the reference PWR, will have only a minor impact on decommissioning costs and occupational radiation doses. Site-specific issues will have to be addressed in every case where precise assessments of the exact extent of the impact on decommissioning are desired. For example, the license conditions for plants licensed before January 1, 1979, vary in both scope and content. After January 1, 1979, inclusion of a fire protection program (including a fire hazards analysis) in the Final Safety Analysis Report became a prerequisite for licensing. Plant modifications resulting from such analyses apparently varied widely. At some plants such modifications have been extensive, including rerouting of cable, affixing fire retardant materials, installing new conduits, improving barriers, and adding pumps and other equipment. To identify all the practical aspects involved in such assessments would require an in-depth study of each plant, since each reactor and its respective site are unique. Thus, cost and occupational dose estimates for post-TMI-2 requirements (and other regulatory adjustments) for the single PWR examined in this study may not represent the circumstances at all PWR stations.

One unexpected result of this assessment is the identification of the positive effect that the technical support centers (TSCs) required in the aftermath of TMI-2 will eventually have on decommissioning activities. TSCs are required to provide up-to-date, as-built drawings for the purpose of emergency preparedness. The availability of those drawings will facilitate planning and preparation of decommissioning activities and subsequently will support implementation of those activities.

It should be noted that a number of plant modifications have been made for which no specifics could be obtained (and thus no quantification of potential impacts on decommissioning could be made). These modifications pertain to safeguards and/or plant security areas or equipment, and this type of information is not available without appropriate need-to-know. However, it is unlikely that these modifications would have any significant effect on the safety or cost of decommissioning.

An emerging area of change that was identified concerns the steadily increasing costs associated with the burial of radwastes and the concomitant efforts at volume reduction by nuclear power plant operators. Whether such efforts are done by a contractor or by the addition of new equipment at the plant itself, an increase in the inventory of contaminated materials, in the form of outdated original equipment, could result. In many cases, this equipment may lie unused at the plant for years until the plant is decommissioned. Then, it must be accounted for. A case in point is the extension to the fuel building at the reference PWR (see Section 4.4 for details). One of the reasons it was built was to provide more space and equipment for sorting and packaging radwastes than was provided for in the original design of the plant. For older plants, it is suggested that this area be examined closely during periodic updates of their decommissioning plans.

4.2 STUDY OBJECTIVE, APPROACH, ALTERNATIVES, BASES AND ASSUMPTIONS

This section contains brief descriptions of the study objective, approach, decommissioning alternatives, and bases and assumptions.

4.2.1 Study Objective

The primary objective of this study is to examine post-TMI-2 backfits and assess their potential impacts on decommissioning cost and dose estimates previously developed for the reference PWR.[1] Development of this information is necessary in order to provide NRC decision-makers with all the pertinent information they need concerning those impacts on decommissioning.

4.2.2 Technical Approach

A methodology was developed to guide the acquisition and assessment of the data concerning post TMI-2 backfit impacts on the decommissioning estimates previously developed for the reference PWR.[1,2]

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 4.1. The first step in the process was to acquire background material on the reference PWR by consulting the literature. Coinciding with that task were contacts (initially arranged by the respective NRC project manager) with the utility that operates the reference reactor involved in the study. The final step was a visit to the utility headquarters where information was collected and meetings were conducted with staff familiar with licensing and decommissioning matters.

4.2.3 Decommissioning Alternatives

The three decommissioning alternatives evaluated in the reference PWR study are examined again in this study to estimate the additional costs and

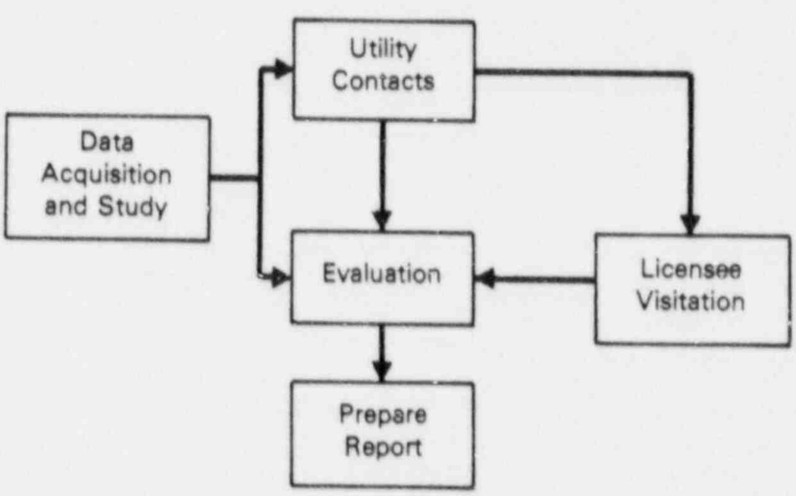

FIGURE 4.1. Post-TMI-2 Backfit Impacts Study Methodology

radiation doses that may result from implementation of post-TMI-2 backfits. These alternatives are defined briefly below.

- Immediate Dismantlement (DECON) - The station is decontaminated and the radioactive materials are removed shortly after final reactor shutdown. Upon completion, the nuclear license is terminated and the property is released for unrestricted use.

- Safe Storage with Deferred Dismantlement (SAFSTOR) - The radioactively contaminated materials and contaminated areas are decontaminated or secured and the structures and equipment are maintained as necessary to ensure the protection of the public from the residual radioactivity. During the period of safe storage, use of the property remains limited by the nuclear license. Eventual dismantlement is necessary for unrestricted release and license termination.

- Entombment (ENTOMB) - The radioactively contaminated materials and contaminated areas are decontaminated and the nonreleasable materials are confined within a monolithic structure that provides integrity to ensure the protection of the public from the entombed radioactivity for a period of sufficient length to permit the decay of the radioactivity to unrestricted release levels. During the period of entombment, the property is maintained as necessary and remains restricted in use by the nuclear license.

4.2.4 Study Bases and Assumptions

The study is intended to provide decommissioning information useful to NRC decision-makers. In addition, the information will provide the basis for developing current cost and occupational dose estimates for decommissioning the reference plant. The study bases are:

- Costs are in January 1986 dollars.
- All other applicable bases and assumptions necessary to the conduct of this study are the same as those used in the original NUREG reports (see References 1 and 2 for details).

4.3 SOURCES OF INFORMATION

A manual literature search was conducted to obtain information about post-TMI-2 backfits. Government reports, technical journals, conference proceedings, etc. were examined for information relative to the reference PWR. A computer-based licensee event report (LER) search was conducted for the licensee's plant. Although the LERs were not viewed in the same context as other more clearly defined post-TMI-2 backfits, they were nonetheless examined and assessed for their potential impact on decommissioning costs, since they often reveal modifications to the plant. Where those modifications involved equipment, components, and/or materials that would eventually become radioactive and/or contaminated, they were assessed for their impact on decommissioning as well.

The utility visitation was a very significant part of the study, though limited in scope in terms of actual time spent with utility representatives. The NRC is cognizant of the criticism focusing on the regulatory burden on licensees. Therefore, initial discussions were conducted between the licensee and their respective NRC project manager. Subsequently, PNL staff contacted the cognizant utility staff identified by the NRC project manager, meetings were conducted, and the information gathering process was carried out.

4.3.1 Licensee Visitation

The visitation itself involved an introductory conference with utility representatives for licensing, and/or decommissioning planning. Topics covered included: 1) the purpose and objectives of this study; 2) a brief review of their decommissioning plans; 3) a discussion focusing on understanding differences between various decommissioning cost estimates by others; and 4) arrangements for responsible utility staff to provide backfit information to PNL.

The discussions were kept informal to facilitate development of backfit information specific to the study. This effort was quite productive as meaningful, pertinent backfit information was obtained. Some of the information secured on the utility visit was not available from other sources.

4.3.2 Discussion Concerning Information Sources Used in this Study

As previously mentioned, the primary objective of this study is to examine post-TMI-2 backfits for their potential impact on decommissioning. If a plant modification is needed for a facility to comply with a license, an NRC rule or order, or to conform with a written commitment by the licensee, it will probably show up in the utility's record system (either as a backfit or possibly as a design change).

Backfitting is defined as a modification of or addition to systems, structures, components, or design of a facility; or the design approval or manufacturing license for a facility; or to the procedures or organization required to design, construct, or operate a facility; any of which may result from a new or amended provision in the NRC rules or the imposition of a regulatory staff position interpreting the Commission rules that is either new or different from a previously applicable staff position after: (i) The date of issuance of the construction permit for the facility for facilities having construction permits issued after October 21, 1985; or, (ii) Six months before the date of docketing of the operating license application for the facility for facilities having construction permits issued before October 21, 1985; or (iii) The date of issuance of the operating license for the facility for facilities having operating licenses; or, (iv) The date of issuance of the design approval under 10 CFR Part 50, Appendices M, N, or O.[3]

Generic backfitting is governed by the Committee to Review Generic Requirements process. On the other hand, plant-specific backfitting is governed by NRC staff manual chapter 0514, which encompasses power reactors. Plant-specific backfitting is different from generic backfitting in that the former involves the imposition on a licensee of positions unique to a particular plant, whereas generic backfitting involves the imposition of the same or similar positions on two or more plants. In the case of generic backfitting, additional guidance on the subject to the licensee is provided via generic letters,[a] since a systematic and documented analysis is required to be done by the NRC for any generic backfit it seeks to impose.

The examination and assessment of information contained in generic letters concerning backfits led into other records-keeping systems that revealed areas with the potential for additional information on various kinds of changes to the reference plant. For example, the LERs include a detailed narrative description of potentially significant safety events. These reports are initiated by the licensee. By describing in detail the event and the planned corrective action, the LER system provides the basis for the careful study of events or conditions that might lead to serious accidents. For the purpose of this study, the "planned corrective action" feature of the LERs (and the followup correspondence associated with that action) was examined for the reference plant to assess any potential impacts on decommissioning. About 400 LERs were examined for the Trojan plant (the reference PWR), which corresponds roughly to most of the LERs produced for the plant since commercial operation began.

In all cases, the subsequent identification of any change that might impact on decommissioning was investigated further, including examination of plant annual reports[b] and discussions with plant engineering and/or licensing staff. In some cases, as-built drawings were obtained from which estimates of volumes of contaminated and/or radioactive wastes were subsequently made. For the most part, best estimates concerning material quantities were based upon discussions with utility staff and upon engineering judgment. Records associated with most material quantities and with all occupational

---

(a) Generic letters are issued by the NRC Office of Nuclear Reactor Regulation, Division of Licensing. They are used to transmit information to, and obtain information from reactor licensee, applicants, and/or equipment suppliers regarding matters of safety, safeguards, or environmental significance. Generic letters usually either 1) provide information thought to be important in assuring continued safe operation of facilities, or 2) request information on a specific schedule that would enable regulatory decisions to be made regarding the continued safe operation of facilities. They have been a significant means of communicating with licensees on a number of important issues, the resolutions of which have contributed to improved quality of design and operation.

(b) The annual reports contain, together with other licensee information, a section devoted to plant modifications and design changes. Equipment, components, and/or other materials that had been or were scheduled to be installed in radiation zones were carefully examined for their potential impact later during decommissioning.

exposures associated with installation activities were generally unavailable. Therefore, estimates concerning occupational exposures presented in this study rely on the composite values developed for the reference plant contained in the parent documents.[1,2]

4.4 RESULTS OF THE BACKFIT IMPACT ASSESSMENT FOR THE REFERENCE PWR

This section contains the results of the backfit impact assessment for the reference nuclear power plant, including estimates of the additional decommissioning costs and occupational doses resulting from the post-TMI-2 requirements imposed on the licensee to date by the NRC as well as other selected changes resulting from adjustments in the regulatory climate. The results are based upon the information sources previously discussed in Section 4.3.

Information found in the Trojan reactor's Annual Reports, generic letters, LERs, and selected Portland General Electric Company (PGE) reports, together with discussions with Trojan licensing staff, were carefully assessed to identify those plant modifications and design changes subsequent to the TMI-2 accident that could potentially have an impact on decommissioning. Included in this category are equipment, components, and/or materials that have been or are scheduled to be installed in the near-term in radiation zones (i.e., in those plant areas whereby such entities will probably become contaminated or radioactive during the plant's remaining lifetime and thus become candidates for removal during decommissioning). Table 4.3 lists the equipment, piping, valves, and other items that are estimated to eventually have an impact on decommissioning of the reference plant.

The major changes identified at the Trojan plant that could impact decommissioning are primarily associated with the fuel building. A single-story, 30-foot extension was added to the building itself (see Figure 4.2) to provide a larger area for sorting and compacting dry radwastes than was provided in the original design of the plant. In addition, a new compactor was installed.

Reracking in the spent fuel storage pool has resulted in racks of greater mass being present in the pool than were considered in the original decommissioning study undertaken by PNL. The Trojan spent fuel storage pool was originally designed to hold 280 assemblies. Since the reactor began operating, a succession of plans for disposing of spent fuel (reprocessing, storage in a repository under the National Waste Terminal Storage Program, Federal away-from-reactor storage, and storage in a repository under the National Waste Policy Act of 1982) have been considered but not yet realized. To deal with its accumulating inventory of spent fuel, PGE applied for and received licenses from the NRC to increase the at-reactor storage capacity at Trojan to 651 assemblies in 1978 and to 1408 assemblies in 1983.[4] The storage racks used to hold the accumulated fuel will become contaminated during the reactor's lifetime and will subsequently have to be removed during decommissioning.

4.4.1 Estimated Additional Costs for Decommissioning the Reference PWR

The estimated additional costs for decommissioning the reference PWR via the three decommissioning alternatives described previously in Section 4.2.3

TABLE 4.3. Summary of Information Regarding Additional Potentially Contaminated Materials at the Reference PWR

Location	Description of Material[a]	Number of Units[b]	Length, m	Mass, kg	Estimated Number of Disposable Containers (rounded up)[c]
Reactor Containment Building	Piping, 1/2 in.	18	31	39	--[d]
	Piping, 3/4 in.	7	12	20	--
	Valves, 1 in.	3	NA[e]	42	--
	Valves, 3/4 in.	4	NA	56	--
	Tank, 300 gal capacity	2	NA	1,806	--
	Radiation Monitors	4	NA	90	--
	Panel	2	NA	45	--
Fuel Building	Piping, 2 in.	9	15	84	--
	Valves, 2 in.	4	NA	56	--
	Compactor, Dry Waste	1	NA	910	--
	Concrete Rubble	NA	NA	13,094	3
	Spent Fuel Storage Racks	NA	NA	173,447	115[f]
Auxiliary Building	Piping, 1/2 in.	35	61	78	--
	Valves, 1/2 in.	4	NA	56	--
	Skid-Mounted Unit[f]	1	NA	228	--
	Shielded Box[g]	1	NA	68	--
Totals		95	119	190,119	118 + 3[d]

(a) Obtained or estimated from information supplied by Portland General Electric Company.
(b) A piping unit consists of a piece 1.75 meters in length.
(c) Assumed to be 1.2-m by 1.2-m by 2.4-m metal boxes, unless otherwise indicated.
(d) A dash indicates that only a fraction of a disposable container is utilized for that particular item; in total, it is estimated that three additional containers are required to dispose of all the materials represented by a dash in the above table.
(e) NA means not applicable.
(f) This estimate represents the difference between an adjusted case and a base case and is based on a calculated mass of 1500 kg per container (see text for discussion and see Table 4.5 for additional details).
(g) These materials represent post-TMI-2 additions to an existing post-accident sampling system.

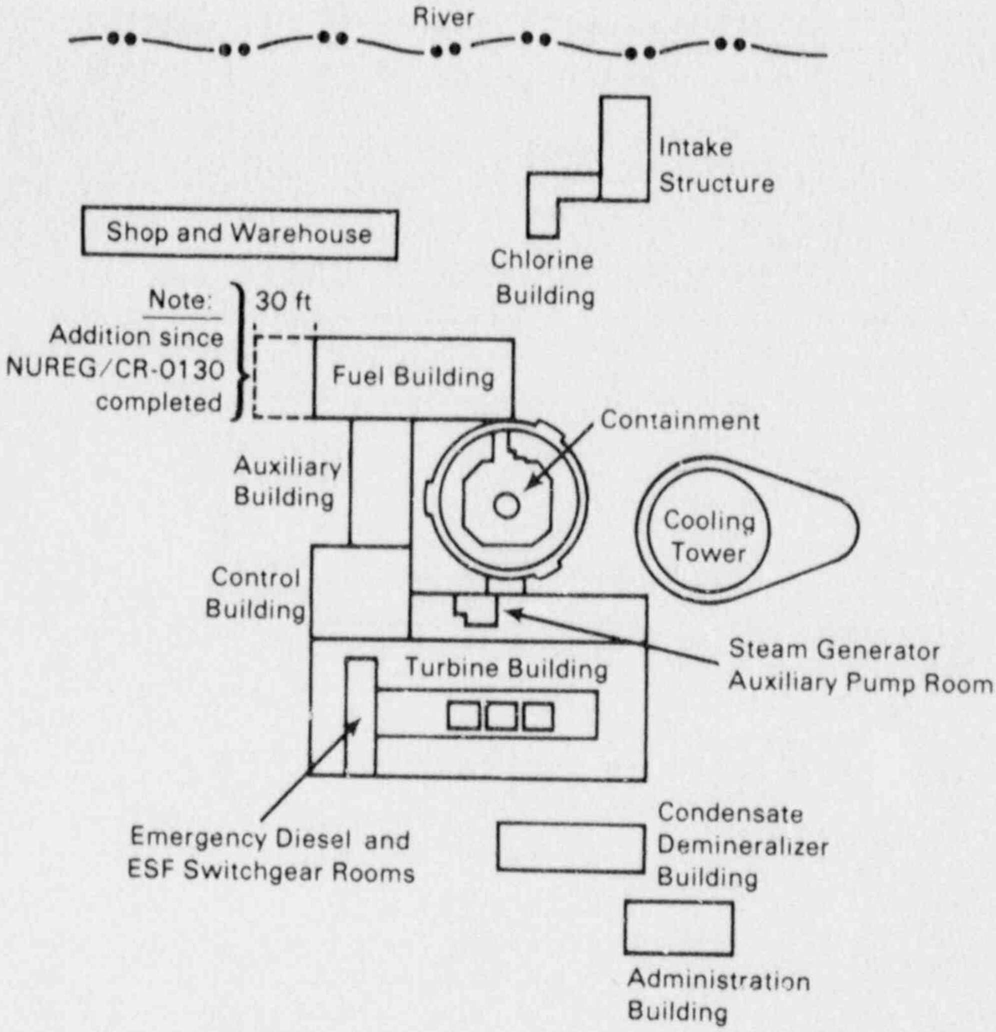

FIGURE 4.2. Reference PWR Plant Layout Showing the Extension to the Fuel Building

are presented in the following subsections. The costs include a 25% contingency and are adjusted to January 1986 dollars in all cases.

4.4.1.1 Estimated Additional Costs for Immediate Dismantlement

The estimated additional costs for immediate dismantlement are summarized and totaled in Table 4.4. It can be seen from the table that the total additional cost associated with this backfit assessment for immediate dismantlement is about $788,500, including a 25% contingency.

Detailed cost data for the individual cost categories shown in Table 4.4 are presented and discussed in the following subsections.

Costs for Disposal of Contaminated Materials. As previously discussed, a greater mass of spent fuel pool storage racks is now anticipated to be removed during decommissioning than was originally estimated. The total estimated

TABLE 4.4. Summary of Estimated Additional Costs for Immediate Dismantlement of the Reference PWR

Cost Category	Estimated Costs,$(a,b)
Disposal of Contaminated Materials	677,507
Staff Labor	83,817
Special Tools and Equipment	11,480
Miscellaneous Supplies	15,738
Total, Immediate Dismantlement Costs	788,542

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) The number of significant figures shown is for computational accuracy and does not imply precision to the nearest dollar.

disposal cost for the original racks (base case) and for the current racks (adjusted case) are presented in Table 4.5. The base case costs and adjusted case costs shown in the table are escalated to January 1986 dollars and include a 25% contingency. Thus, the adjusted case cost minus the base case cost (about $409,000) represents the estimated total differential cost attributable to the plant modifications previously discussed in this section.

For the purpose of this study, it is assumed that about 65% of the concrete floor surface area of the new extension to the fuel building (see Figure 4.2) will require decontamination to acceptable levels. This will be done by removing the surface either with a concrete spaller or with other physical-removal means. Based on a contamination thickness of 0.051 meters and a contaminated surface area of approximately 111 square meters, it is estimated that about 5.7 cubic meters of contaminated concrete rubble will require disposal during decommissioning.

A summary of the estimated costs for the disposal of all of the additional potentially contaminated materials listed previously in Table 4.3 is presented in Table 4.6. The materials listed in Table 4.3 are anticipated to be removed from various locations (and at various radiation dose rates) within the reactor containment building, the fuel building, and the auxiliary building. Ten additional overweight truck shipments are estimated to be required to transport the contaminated materials to a shallow land-burial facility, where they will occupy an estimated 440 cubic meters of space. The total disposal cost (see Table 4.6) for these materials from the immediate dismantlement of the reference PWR is estimated at $677,500, including a 25% contingency.

Costs for Staff Labor. The additional costs for staff labor attributable to removal of backfits and other plant modifications during immediate dismantlement are shown in Table 4.7. The estimated staff labor requirements

TABLE 4.5. Two Cases of Estimated Costs for Disposal of Spent Fuel Pool Storage Racks from the Reference PWR

Description	Base Case[(a)] SFP Racks	Adjusted Case[(b)] SFP Racks
Estimated Mass, kg	48,182	221,629
Number of Disposable Containers[(c)]	88	168
Container Costs, $[(d)]	132,000	210,000
Number of Shipments[(e)]	11	14
Transport Costs, $[(f)]	46,035	58,590
Handling Costs, $	0	0
Burial Volume, m^3	406.7	608.5
Burial Cost, $[(g)]	350,599	669,244
Total Disposal Cost, $[(h)]	528,634	937,834
Estimated Difference in Cost, $	+ 409,200	

(a) Based on Table G.4-5, Reference 1; costs are escalated to January 1986 dollars and include a 25% contingency.
(b) Values include a 25% contingency and are in January 1986 dollars.
(c) Assumed to be 1.2-m by 1.2-m by 2.4-m metal boxes, unless otherwise indicated.
(d) Based on information in Section I.2 of Appendix I, Reference 1, and escalated to January 1986 dollars.
(e) Assumed to be overweight shipments.
(f) Based on Section I.4 of Appendix I, Reference 1, and escalated to January 1986 dollars.
(g) Based on Table I.5-1, Reference 1, and escalated to January 1986 dollars; based on an assumed container surface dose rate of <0.20 R/hr.
(h) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.

shown in the table are based on a task-by-task analysis to determine the man-years of effort required to remove and package all of the materials previously given in Table 4.3. The same basic assumptions made in developing the staff labor estimates given in the original study (see Section 9.1.3, Reference 1) are used here. It is assumed that the laborers and craftsmen shown in Table 4.7 are hired from the local union hall and that they are adequately trained on-site for the decommissioning work.

Costs for Special Tools and Equipment for Immediate Dismantlement. The inventory of special tools and equipment given in Table 10.1-7, Reference 1, was reviewed for adequacy. It is estimated that an additional $11,480, including 25% contingency, is required for supplemental concrete removal tools and

TABLE 4.6. Summary of Estimated Costs for the Disposal of Additional Contaminated Materials from the Reference PWR[a]

Description:	All materials shown in Table 4.3.
Estimated Mass, kg[b]:	190,119
Number of Disposable Containers [c]:	121
Container Costs, $[d]:	151,250
Number of Shipments[e]:	10
Transport Costs, $[f]:	41,850
Handling Costs, $:	0
Burial Volume, m^3:	440.5
Burial Cost, $[g]:	484,407
Total Disposal Cost, $[h]:	677,507

(a) Values include 25% contingency and are in January 1986 dollars.
(b) Based on Table 4.3.
(c) Assumed to be 1.2-m by 1.2-m by 2.4-m metal boxes, unless otherwise indicated.
(d) Based on information in Section I.2 of Appendix I, Reference 1, and escalated to January 1986 dollars.
(e) Assumed to be overweight shipments.
(f) Based on Table I.4-4, Reference 1, and escalated to January 1986 dollars.
(g) Based on Table I.5-1, Reference 1, and escalated to January 1986 dollars; based on an assumed container surface dose rate of <0.20 R/hr.
(h) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.

equipment to be used in removing concrete from the extension that has been added to the fuel building at the reference plant.

for Additional Miscellaneous Supplies. The additional miscellaneous supplies needed to accomplish the decommissioning tasks attributable to this backfit assessment include anticontamination clothing, cleaning and contamination control supplies (chemical agents, sweeping compounds, rags, mops, and plastic bags and sheeting), expendable hand tools, and cutting and welding supplies (saw blades, torch gas, and welding rod). The total estimated cost for these additional miscellaneous supplies during immediate dismantlement of the reference PWR is about $16,000 (see Table 4.8). Individual costs shown in the table are estimated by determining the average cost of the respective items per man-year for the original decommissioning worker staff, then multiplying that cost by the additional number of man-years estimated to accomplish the decommissioning tasks identified in this backfit assessment, and then escalating the costs to January 1986 dollars.

TABLE 4.7. Estimated Costs for Staff Labor During Immediate Dismantlement of the Reference PWR

Position	Total Staff Labor Required (man-years)	Total Staff Labor Costs, $(a,b,c)
Decommissioning Workers		
Crew Leader(d)	0.2144	14,641
Utility Operator(d)	0.2128	11,564
Laborer	0.4628	24,031
Craftsman	0.2355	20,787
H.P. Technician(d)	0.3839	12,794
Totals	1.5094	83,817

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) Calculated as the product of the estimated staff labor requirements shown above (based on a task-by-task analysis) and the corresponding data given in Table I.1-1 of Reference 1, and escalated to January 1986 dollars.
(c) The number of significant figures shown is for computational accuracy and does not imply precision to the nearest dollar.
(d) One additional trained person is maintained for the time period shown above to meet the additional requirements associated with these tasks.

TABLE 4.8. Estimated Costs for Additional Miscellaneous Supplies During Immediate Dismantlement of the Reference PWR

Item	Estimated Costs, $(a,b)
Anticontamination Clothing(c)	9,435
Cleaning and Contamination Control Supplies	4,687
Hand Tools and Cutting and Welding Supplies	1,616
Total	15,738

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) The number of significant figures shown is for computational accuracy and does not imply precision to the nearest dollar.
(c) Estimated at four changes per day per decommissioning worker.

4.4.1.2 Estimated Additional Costs for Entombment

PNL considered two approaches to entombment in an addendum[2] to its earlier PWR study.[1] In both approaches, as much solid radioactive material from the entire facility as can be accommodated is sealed in the containment building beneath the operating floor by means of a continuous concrete slab. For the purpose of this study, it is postulated that all of the radioactive materials from the fuel building and the auxiliary building attributable to this backfit assessment are moved to the containment building and entombed there, rather than shipping them offsite. This is postulated for both of the approaches to entombment previously considered by PNL. Thus, cost savings are estimated to result from a lesser volume of radioactive equipment and material having to be dismantled, packaged, and transported concerning the containment building (see Table 4.3 for details).

The estimated additional costs for entombment, for either approach considered previously by PNL, are summarized in Table 4.9. It can be seen from the table that the total additional cost associated with this backfit assessment for entombment is about $259,500, including a 25% contingency.

The staff labor (and time) required for onsite handling/emplacement within the containment building of the radwastes from the fuel and auxiliary buildings is estimated to be similar to that required to remove just the additional materials from the containment building itself during immediate dismantlement (see Table 4.3). Therefore, no significant change in additional labor cost from that previously given in Table 4.4 for immediate dismantlement is anticipated for entombment.

The costs for special tools and equipment for entombment are anticipated to be similar to those estimated previously for immediate dismantlement. The

TABLE 4.9. Summary of Estimated Additional Costs for Entombment of the Reference PWR

Cost Category	Estimated Costs, $[a,b]
Disposal of Contaminated Materials	150,000
Staff Labor	83,817
Special Tools and Equipment	11,480
Miscellaneous Supplies	4,164
Total, Entombment Costs	259,461

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) The number of significant figures shown is for computational accuracy and does not imply precision to the nearest dollar.

reason for this is that the same tasks are scheduled to be accomplished in the fuel building for which the additional special tools and equipment are required.

The costs for additional miscellaneous supplies during entombment are estimated to be reduced only slightly from those given in Table 4.8 for immediate dismantlement--on the order of 10% overall--because the additional materials in the containment building are not required to be removed for entombment.

No increase in costs associated with continuing care activities is anticipated based on this backfit assessment.

4.4.1.3 Estimated Additional Costs for Preparations for Safe Storage

Little, if any, additional effort is anticipated to be required in the reactor building during the preparations for safe storage based on this backfit assessment. Deactivation and tagging of valves and equipment in the auxiliary building (see Table 4.3 for details) are likewise estimated to require little effort. However, preparations for safe storage of the fuel building will require additional effort for decontamination and immobilization of a greater mass of spent fuel storage racks in the spent fuel pool. For purposes of this study, one additional week has been allocated for this task.

The estimated additional costs for preparations for safe storage are summarized in Table 4.10. It can be seen from the table that the total additional cost associated with this backfit assessment for preparations for safe storage is about $10,300, including a 25% contingency.

TABLE 4.10. Summary of Estimated Additional Costs for Preparations for Safe Storage of the Reference PWR

Cost Category	Estimated Costs, $[(a,b)]
Disposal of Contaminated Materials	Negligible
Staff Labor	8,750
Special Tools and Equipment	Negligible
Miscellaneous Supplies	1,560
Total, Preparations for Safe Storage Costs	10,310

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) The number of significant figures shown is for computational accuracy and does not imply precision to the nearest dollar.

No increase in the costs associated with continuing care activities is anticipated based on this backfit assessment.

4.4.1.4 Estimated Additional Costs for Deferred Dismantlement

The cost of deferred dismantlement of the reference PWR has previously been estimated assuming that dismantlement takes place starting at intervals of 10, 30, 50, and 100 years after reactor shutdown. These estimates are developed in Appendix H.5 of Reference 1, together with the costs for continuing care. Continuing care costs of the reference PWR are not anticipated to be affected based on this backfit assessment.

The total costs of deferred dismantlement are affected only slightly because of the increased quantity of contaminated materials (see Table 4.3 for details) that must be removed. However, the additional costs due to this increase in the contaminated materials inventory could be expected to decrease for dismantlement at 50 years or later just as they were judged to do so in the parent document.[1] This lower disposal cost is because of the lesser quantities of contaminated materials for burial, due to decay of the radionuclides.

It is assumed that the radioactive contamination of the piping systems, tanks, pools, etc. is primarily ^{60}Co. Thus, for safe storage periods of less than fifty years (~10 half-lives of ^{60}Co), the material remains radioactively contaminated to levels greater than those that would permit unrestricted use of the material. After 50 years of decay, it is assumed that the radioactive contamination on the bulk of the formerly contaminated material has decayed to levels that are indistinguishable from the natural radioactivity in the environment, and can be either salvaged for scrap value, buried in a landfill, or left in the structures.

The same basic activities that are performed during immediate dismantlement are also performed during deferred dismantlement. It is assumed that a work force of essentially the same size as was used in immediate dismantlement is needed for deferred dismantlement, and for approximately the same duration.

A convenient way to estimate the additional costs incurred for deferred dismantlement, based on this backfit assessment, after periods of safe storage of various lengths is to examine only those cost parameters that are different from immediate dismantlement. The manpower costs are assumed to be the same as for immediate dismantlement. The major difference in cost identified in this study concerns the cost of disposal of contaminated material.

The estimates of the additional volumes of contaminated material that must be packaged and shipped for burial when dismantlement is performed starting immediately and starting at 10, 30, 50 and 100 years after reactor shutdown are given in Table 4.11, together with their respective estimated disposal costs. The estimated additional volumes given in the table are summarized from information discussed previously in this section. The total additional volume of contaminated material, as previously presented in Table 4.3, is

TABLE 4.11. Estimated Additional Volumes and Costs of Contaminated Material Disposed of During the Various Decommissioning Options for the Reference PWR

Decommissioning Option	Option Starts (Years after Shutdown)	Estimated Burial Volume, m^3 Contaminated Material	Estimated Disposal Costs, $[a]
Immediate Dismantlement	0	440.5	677,507[b]
Preparations for Safe Storage	0	--	--
Deferred Dismantlement	10	440.5	677,507
	30	440.5	677,507
	50	3	12,983[c]
	100	3	12,983

(a) Values include a 25% contingency and are in January 1986 dollars.
(b) Based on Table 4.6.
(c) Based on: 1) one legal-weight truck shipment of two disposable containers (1.2-m by 1.2-m by 2.4-m metal boxes) to a low-level waste burial ground; 2) information in Appendix I, Reference 1, escalated to January 1986 dollars; and 3) Table I.5-1, Reference 1, for assumed container surface dose rates of <0.20 R/hr.

assumed to remain constant through 30 years but to have decreased to about 3 cubic meters by 50 years and thereafter based on engineering judgment.

Essentially no additional volume of contaminated material is attributable to the preparations for safe storage as determined by this study; thus no disposal cost is assigned to it in Table 4.11.

Using the additional volumes of contaminated materials and their respective estimated disposal costs listed in Table 4.11 for the different time periods, it can be seen that after about 50 years, additional deferred dismantlement costs associated with those additional contaminated materials are reduced by a significant amount--about $665,000.

In summary, the total cost of deferred dismantlement could be expected to increase by about $678,000 when dismantlement starts at either 10 or 30 years after reactor shutdown. Deferred dismantlement at 50 years or more after reactor shutdown is estimated to result in an increase of about $13,000. In any case, the increase in the total cost of deferred dismantlement is attributable to the increase in the volume of contaminated materials as determined by this backfit assessment.

4.4.2 Estimated Additional External Occupational Radiation Doses for Decommissioning the Reference PWR

Detailed estimates are made of the additional external occupational radiation doses that are accumulated by the workers used to accomplish the decommissioning tasks attributable to this backfit assessment. The estimates are based on a task-by-task analysis to determine the man-hours of effort required in radiation-zone work and the anticipated dose rates associated with each task for all labor categories. The same basic assumptions made in developing the occupational radiation dose estimates given in the original study (see Section G.3, Reference 1) are used here.

Estimates of the additional occupational radiation doses for decommissioning the reference PWR via three decommissioning alternatives are presented in the following subsections.

4.4.2.1 Estimated Additional External Occupational Radiation Doses for Immediate Dismantlement

The estimated total dose for each task (within each building) is corrected for radioactive decay with a decay factor calculated using the half-life of ^{60}Co and the midpoint of the timeline for the given task as it is accomplished within the reactor building/primary containment, fuel building, and the auxiliary building. For the purpose of this study, the approximate timeline selected to accomplish the decommissioning tasks attributable to this backfit assessment falls between the sixteenth and the twenty-fourth months (after shutdown) of the original immediate dismantlement schedule. The reason for this selection is that this period roughly corresponds to the piping and equipment removal activities scheduled to take place in all three of the buildings (see Figure 9.1-2, Reference 1, for details).

The results of these analyses, including decay corrections, are presented in Table 4.12. The total corrected additional external occupational radiation dose is about 31.5 man-rem. It can be seen from the table that the removal and packaging of the additional spent fuel pool storage racks account for about 94% of this total.

4.4.2.2 Estimated External Occupational Radiation Doses for Entombment

Based on the scenarios postulated for entombment,[2] the radiation doses associated with the containment building are the only ones significantly affected by performing an entombment rather than a dismantlement. The same holds true for this study. As a result, the estimated additional occupational radiation dose shown in Table 4.12 for the containment building is reduced from 0.21 man-rem to zero. However, it is assumed that this reduction is completely offset by the fact that the materials from the fuel building and the auxiliary building must now be transferred into the lower levels of the containment building by the decommissioning workers instead of being shipped to a low-level waste burial ground. Thus, the total corrected additional external occupational radiation dose is anticipated to remain essentially constant at about 31.5 man-rem for entombment.

TABLE 4.12. Estimated Additional Occupational Radiation Doses for Immediate Dismantlement of the Reference PWR

Position	Estimated Occupational Exposure (man-hr)/Corrected Dose (man-rem)[a]			Totals	
	Reactor/ Primary Containment	Fuel Building	Auxiliary Building	Exposure (man-hr)	Corrected Dose[b] (man-rem)
Decommissioning Workers					
Supervisors[c]					
Task 1[d]		276/ 4.6368		276	4.6368
Task 2[e]		13/ 0.0108		13	0.0108
Task 3[f]	6/0.0312	4/ 0.1220	5/0.1078	15	0.2610
Utility Operators and Laborers					
Task 1		716/12.0288		716	12.0288
Task 2		126/ 0.1046		126	0.1046
Task 3	15/0.0768	11/ 0.3354	13/0.3757	39	0.7879
Craftsmen					
Task 1		533/7.5665		533	7.5665
Task 2		Not Involved		0	0
Task 3	11/0.0616	8/ 0.2292	10/0.2718	29	0.5626
H.P. Technicians					
Task 1		312/ 5.2416		312	5.2416
Task 2		15/ 0.0125		15	0.0125
Task 3	7/0.0381	5/ 0.1529	6/0.1220	18	0.3130
Totals	39/0.2077	2,019/30.4411	34/0.8773	2,092	31.5261

(a) The task decay factors utilized in these analyses are as follows:
Task 1--0.84
Task 2--0.83
Task 3--0.80, 0.84, and 0.77 for the reactor/containment building, the fuel building, and the auxiliary building, respectively.

(b) The number of significant figures shown is for computational accuracy and does not imply precision to the nearest millirem.

(c) Includes shift engineers, crew leaders, craft supervisors, and senior health physics technicians.

(d) Task 1 activities concern the removal and packaging of the additional spent fuel pool storage racks.

(e) Task 2 activities concern the removal and packaging of contaminated concrete from the fuel building extension.

(f) Task 3 activities concern the removal and packaging of all materials listed in Table 4.3 except the spent fuel storage fool storage racks and the concrete from the fuel building extension.

4.4.2.3 Estimated Additional External Occupational Radiation Doses for Preparations for Safe Storage and Continuing Care

As previously mentioned in Section 4.4.1, one additional week of effort was allocated for the decontamination and immobilization of the greater quantity of spent fuel storage racks located in the spent fuel pool. For the crew size envisioned, it is estimated that this equates to an additional 208 hours of radiation zone work, which results in a total corrected additional occupational dose of about 3.3 man-rem. Deactivation and tagging of valves and equipment in the reactor and auxiliary buildings are anticipated to add less than one-tenth of a man-rem to this total.

During the continuing care period, the external occupational radiation dose of the surveillance and maintenance staff is not anticipated to be significantly affected by the additional equipment and materials identified in this study.

4.4.2.4 Estimated Additional External Occupational Radiation Doses for Deferred Dismantlement

The same basic activities that are performed during immediate dismantlement (see Table 4.12 for details) are also performed during deferred dismantlement. It is assumed that a work force of essentially the same size as wasused in immediate dismantlement (see Section 4.4.1 for details) is needed for deferred dismantlement, and for approximately the same time duration.

For this study, it is assumed that the additional amounts of occupational radiation dose accumulated by the decommissioning workers is controlled largely by the radiation levels of ^{60}Co throughout the plant. Thus, if a given task performed immediately after shutdown caused a radiation dose of N_0, that same task performed t years later during deferred dismantlement would cause a dose of $N(t) = N_0 e^{-\lambda t}$, where λ is the decay constant for ^{60}Co in years.

Since one of the key assumptions for deferred dismantlement is that essentially all of the same jobs would be performed in approximately the same way as for immediate dismantlement, using the same techniques and equipment, the occupational radiation dose accumulated during deferred dismantlement, including those jobs concerning this backfit assessment, would be proportional to that accumulated during immediate dismantlement (see Table 4.12), reduced by the relative reduction of the radioactivity levels of ^{60}Co over the safe storage period. Therefore, to estimate the additional external occupational dose for deferred dismantlement, a simple reduction of the immediate dismantlement dose in proportion to the decay of ^{60}Co over the safe storage period is a reasonable and conservative approach. These estimates are given in Table 4.13 for dismantlement starting 10, 30, 50 and 100 years after reactor shutdown. After 100 years, essentially all of the remaining radioactivity is contained only in the activated reactor vessel components, and the occupational radiation dose associated with this backfit assessment is extremely small.

TABLE 4.13. Estimated Additional External Occupational Radiation Doses for Deferred Dismantlement of the Reference PWR[a]

Decommissioning Mode	Years After Final Reactor Shutdown	Estimated Additional Dose, man-rem
Immediate Dismantlement	0	31.5
Deferred Dismantlement	10	8.5
	30	0.6
	50	<0.05
	100	<0.0001

(a) Man-rem estimates derived from Table 4.12.

4.4.3 Estimated Additional Radiation Doses from Routine Transportation Tasks

The same basic assumptions made in developing the estimated accumulated radiation dose from truck transport of radioactive wastes in NUREG/CR-0130, Section 11, are used in this study. The estimated routine doses from truck transport of the additional contaminated materials identified in this backfit assessment from immediate dismantlement and from preparations for safe storage are listed in Table 4.14. These radiation dose rates are based on the maximum allowable dose rates for each shipment in exclusive-use trucks, as analyzed in the parent study, and are thus conservatively high. The estimated additional external radiation dose for routine transportation operations for immediate dismantlement is 0.73 man-rem to transport workers and 0.13 man-rem to the general public.

Based on this study, there are no additional radiation doses to workers or to the public during the preparations for safe storage, since no additional truck shipments are contemplated.

TABLE 4.14. Estimated Additional Accumulated Radiation Doses from Truck Transport of Radioactive Wastes from the Reference PWR

Mode	Group	Radiation Dose per Shipment,[a] (man-rem)	Estimated Additional Total Dose (man-rem)
Immediate Dismantlement[b]	Truck Drivers	0.07	0.7
	Garagemen	0.003	0.03
	Total		0.73
	Onlookers	0.005	0.05
	General Public	0.01	0.1
	Total		0.15
Preparations for Safe Storage[b]	Truck Drivers	0	0
	Garagemen	0	0
	Total		0
	Onlookers	0	0
	General Public	0	0
	Total		0

(a) Based on Table 11.4-2 in NUREG/CR-0130.
(b) Total additional shipments: 10 for immediate dismantlement; zero for preparations for safe storage.

4.5 REFERENCES

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

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

3. U. S. Code of Federal Regulations. 1985. Title 10, Part 50.109, "Backfitting," Superintendent of Documents, Government Printing Office, Washington, D.C.

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

5. U.S. Code of Federal Regulations. 1982. Title 10, Part 50.48, "Fire Protection," Superintendent of Documents, Government Printing Office, Washington, D.C.

5.0 REASSESSMENT OF COST AND DOSE ESTIMATES FOR REMOVAL OF STEAM GENERATORS DURING DECOMMISSIONING OF THE REFERENCE PRESSURIZED WATER REACTOR

In connection with the decommissioning rulemaking activities, the accuracy of selected aspects of the data base developed by PNL for the NRC has been questioned. Specifically, it has been suggested that the occupational radiation doses for the removal of steam generators from a PWR during immediate dismantlement may be underestimated, based on recent experience with major nuclear removal/replacement work on these failed components at PWR stations. A quantitative examination has been performed to fully document the resolution of this concern. Recently developed information on the removal and replacement operations associated with failed steam generators at operating PWR plants, which was not available at the time of the original 1978 report (NUREG/CR-0130),[1] has been examined and assessed for the purpose of refining those earlier estimates on the cost and occupational doses for this major decommissioning activity.

In this chapter, the costs and occupational radiation doses associated with steam generator removal during immediate dismantlement of the reference PWR plant described in NUREG/CR-0130 are reassessed in quantitative terms, based on examination and appropriate adjustment of data from recent steam generator removal/replacement projects in the U.S. The purpose of this reassessment is to provide NRC decision-makers with a current evaluation of information concerning those impacts on decommissioning. It should be recognized, however, that, like the original analysis, this analysis is not intended to result in an "exact" solution concerning occupational doses for steam generator removal during decommissioning because of the many variables involved. The resultant dose and cost values are intended as reliable updated estimates (based on key assumptions) for the removal of PWR steam generators during decommissioning. Consequently, the results of this analysis make a useful addition to the already existing decommissioning data base and increase its general applicability.

The study results are summarized in Section 5.1. The study approach is presented in Section 5.2. The sources of information used in the analyses are discussed in Section 5.3. A review of past estimates and recent PWR nuclear experience concerning repair/replacement of failed steam generators is presented in Section 5.4. A comparative analysis is conducted on a selected steam generator changeout program and the results are compared to the estimate made earlier for the reference PWR reported in NUREG/CR-0130. Appropriate adjustments are applied, where necessary, to the earlier cost and dose estimates to reflect the results of recent cost updates and the knowledge gained from the recent experiences. The detailed results of the analyses are given in Section 5.5. Conclusions, observations, and comments concerning this reassessment are presented in Section 5.6.

5.1 SUMMARY OF STUDY RESULTS

The results of this study to evaluate and compare the costs and occupational radiation doses of recent PWR steam generator changeout programs with cost and dose estimates previously developed for immediate dismantlement of the reference PWR described in NUREG/CR-0130 are summarized in this section. The principal results are given, in brief, in the following paragraphs, with more complete discussions presented in subsequent sections.

5.1.1 Additional Decommissioning Cost Estimates

For the reference PWR, the original immediate dismantlement decommissioning cost estimate[1] could be expected to increase about $8.7 million (in January 1986 dollars), due to the incremental cost adjustments associated with two of the cost adders developed in the 1984 EPRI cost update (EPRI NP-4012).[2] These cost adders result from the additional staff ($7.5 million) utilized to assure meeting the 5 rem/year dose limit for personnel associated with all immediate dismantlement tasks, and from the extra supplies ($1.2 million) used by the additional staff. These adders have been escalated from 1984 to January 1986 for this study and include a 25% contingency. The fraction of that additional $8.7 million that is attributable only to the removal of the reference PWR's four steam generators is conservatively estimated to be about $1.4 million.

5.1.2 Radiation Dose Estimates

The comparison of the reported radiation doses for the steam generator removal project at the Point Beach Nuclear Power Plant No. 1 (PBNP-1), which was selected for examination in this study, with the earlier estimates made in NUREG/CR-0130 considers in detail the tasks involved to determine their applicability to decommissioning under the immediate dismantlement alternative. Data on the occupational radiation exposure for this removal/replacement project were obtained from the literature as well as from personal communication with utility personnel. Analysis of these data involved assessing the reported radiation doses concerning all specified tasks and then eliminating those doses associated with tasks determined to be unrelated to decommissioning. In addition, dose adjustments were made where it was determined that the task was performed in a different sequence or manner than envisaged during decommissioning. These adjusted doses are then compared to those previously estimated in NUREG/CR-0130.[1]

Based on the results of this assessment of the recent steam generator replacements at PBNP-1, the total radiation dose to decommissioning workers for the removal of steam generators during immediate dismantlement of the reference PWR appears to have been conservatively estimated initially in NUREG/CR-0130.[1]

5.1.3 Observations

For perspective, it should be emphasized that the considerations for any decommissioning alternative in which the steam generators are to be physically removed are quite different from the operational considerations involved in in the replacement of steam generators during reactor outages. This is because the consequences associated with continued operation, including preservation of building structures, concern for capital equipment, materials, continuing use of air, water, etc., dictate the performance of many activities associated with restoration of the system to service. Large component removal (such as steam generators removal) during decommissioning, on the other hand, contains no requirements for subsequent operational considerations, thereby necessitating a much smaller commitment of resources than does removal and replacement of the steam generators.

Specific information pertaining to steam generator repair/replacement costs was generally not available, due to the inherently proprietary nature of this highly competitive type of reactor outage work in the U.S. Therefore, no direct comparisons of costs could be made in this study.

5.2 STUDY OBJECTIVE, APPROACH, BASES AND ASSUMPTIONS

This section contains brief descriptions of the study objective, approach, bases and assumptions.

The primary objective of this study is to compare and evaluate the occupational radiation doses of selected recent PWR steam generator removal projects and assess that information relative to decommissioning dose estimates previously developed for the reference PWR analyzed in NUREG/CR-0130 and subsequent updates,[1-5] to arrive at supportable dose estimates for steam generator removal during immediate dismantlement.

A methodology is developed to guide the assessment of recent steam generator removal data relative to decommissioning estimates previously developed for the reference PWR. The study methodology is shown in Figure 5.1. The

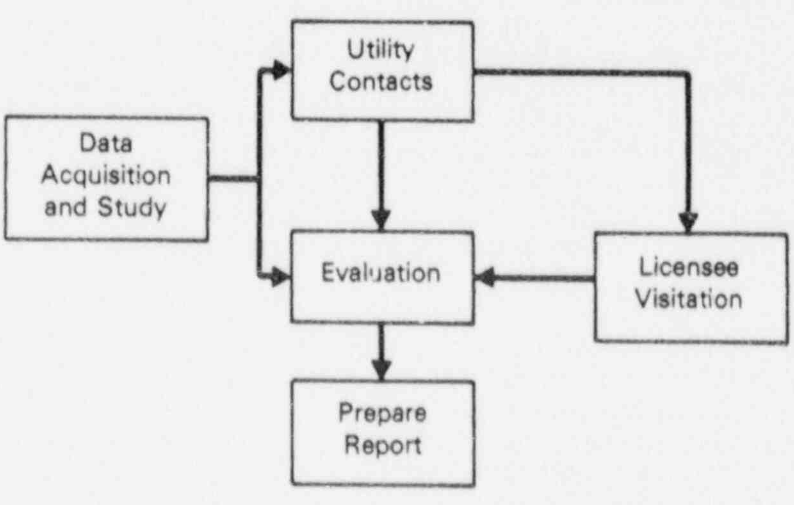

FIGURE 5.1. Steam Generator Removal Reassessment Study Methodology

first step in the process was to acquire background material on previous relevant steam generator removal projects by consulting the literature. Coinciding with that task were contacts with selected utilities that had recently completed PWR steam generator removal/replacement projects (initially arranged by the respective NRC project manager). The final step was a visit to the site of one of the most recent steam generator removal/replacement projects (Point Beach).

This study is intended to provide reliable decommissioning information useful to NRC decision-makers. In addition, the information provides the basis for developing current cost and occupational dose updates associated with the reference PWR analyzed in NUREG/CR-0130 and subsequent updates. The study bases are:

- Costs are in January 1986 dollars, unless indicated otherwise.
- Occupational radiation doses to decommissioning workers will not exceed 5 rem per person per year. It should be recognized that revisions to 10 CFR 20.101 since NUREG/CR-0130 was published in 1978 have tended to reduce annual cumulative radiation dose allowable to persons working in the nuclear industry. Under normal circumstances, the allowable quarterly radiation dose is now 1 - 1/4 rem (rather than 3 rem per quarter postulated in NUREG/CR-0130 for decommissioning workers), with an annual cumulative dose of 5 rem.
- For consistency, all other applicable bases and assumptions necessary to the conduct of this study, except for the two described above, are the same as those utilized in the original NUREG report and subsequent updates (see References 1 through 5 for details).

5.3 SOURCES OF INFORMATION

A literature search was conducted to obtain information on recent experience with major removal/replacement work on failed steam generators. Government reports, technical journals, and conference proceedings, etc., were examined for information relative to such projects. A source of particular usefulness to this study were the plant-specific draft and final environmental statements prepared by the NRC staff. These statements contain an environmental evaluation of the proposed steam generator repair program for a given plant, and reasonable alternatives thereto.

The utility visitation was a very significant part of the study, though limited in scope in terms of actual time spent with utility representatives. The NRC is cognizant of criticism focusing on the regulatory burden on licensees. Therefore, in an effort to reduce that burden on the utility selected for visitation--Wisconsin Electric Power Company (WEPCO)--initial discussions were conducted between the licensee and their respective NRC project manager.

Subsequently, PNL staff contacted the cognizant utility staff identified by the NRC project manager, meetings were conducted, and the information gathering process was carried out.

The site visit to PBNP-1 involved an introductory conference with utility representatives representing licensing and/or decommissioning planning. Topics covered included: 1) the purpose and objectives of this study; 2) a brief review of their decommissioning plans; 3) a discussion focusing on understanding differences between various decommissioning cost estimates by others; and 4) making arrangements for responsible utility staff to provide the necessary steam generator project information to PNL.

The discussions were kept informal in order to facilitate development of steam generator information specific to the study. This effort was quite productive, as meaningful, pertinent information was obtained. Some of the information secured on the visit to the PBNP-1 site was not available from any other sources (e.g., videocassette tapes of the steam generator removal operations).

The discussions with the PBNP-1 supervisory personnel in charge of the steam generator replacement project proved invaluable in conducting this reassessment, as did the videocassette tapes they provided concerning all phases of the work.

5.4 REVIEW OF PAST ESTIMATES AND RECENT PWR NUCLEAR EXPERIENCE

This section contains a brief review of previous reference estimates on steam generator removal during decommissioning as well as a review of recent experience concerning the removal/replacement and repair of steam generators in reactor outage environments. Selected portions of the latter information base are subsequently utilized in this study to develop a meaningful comparison between the PBNP-1 steam generator removal project and the estimated results for similar work that were previously reported in NUREG/CR-0130.[1]

A listing of some of the generic assessment factors considered in the course of this review is presented in Table 5.1. The list is not intended to be all inclusive, but it is considered to be representative of the multiplicity of assessment factors necessary for the subsequent comparative analysis.

5.4.1 Review of Pertinent Past Estimates

The first published evaluation of occupational radiation doses associated with the removal of steam generators during decommissioning appeared in a 1976 AIF/NESP decommissioning report prepared by Manion and LaGuardia.[6] Two years later, Pacific Northwest Laboratory, under contract to the NRC, produced a comprehensive generic study (NUREG/CR-0130) on decommissioning a reference PWR, which included estimates of the occupational doses for all decommissioning tasks, including the removal of steam generators. In 1986,

TABLE 5.1. Generic Assessment Factors Considered in this Study

Factor	Selected Earlier Estimates			Selected Recent Experiences in the U.S.			
	AIF/NESP-009(a)	NUREG/CR-0130(b)	AIF/NESP-036(c)	Surry 1 and 2	Turkey Point 3 and 4	Point Beach 1	H. B. Robinson 2
Removal Under Outage Conditions	No	No	No	Yes	Yes	Yes	Yes
Internal Decontamination Conditions:							
- Chemical Decontamination of Reactor Coolant System	No	Yes(e)	No	No	No	No	No
- Steam Generators	Partial(d)	Yes(e)	Yes	No	Partial(f)	No	Partial(g)
Start Time of Removal Operations After Shutdown (months)	43	16	Unknown	Immediately following defueling	Immediately	Immediately following defueling	Immediately following defueling
General Description of Activities Accomplished	4 steam generator units and pressurizer removed	4 steam generator units removed	3 steam generator units removed	3 steam generator lower assemblies removed and replaced	3 steam generator lower assemblies removed and replaced	2 steam generator lower assemblies removed and replaced	3 steam generator lower assemblies removed and replaced
General Description of Removal Process	Units segmented at the steam drum	Units segmented into multiple components	Units removed intact; no segmentation performed	Units segmented at upper assemblies for removal of lower assemblies	Tube section of lower assembly removed with channel head left in place	Units segmented at upper assemblies for removal of lower assemblies	Tube section of lower assembly removed with channel head left in place
Subsequent Pre-Startup Testing Required	No	No	No	Yes	Yes	Yes	Yes
Total Dose (man -rem)	23	144	Not specified for the postulated project	1,759 and 2,141(h)	2,151 and 1,305(i)	590	1,207

(a) The information in this column is extracted from Reference 6.
(b) The information in this column is extracted from Reference 1.
(c) The information in this column is extracted from Reference 7.
(d) Steam generator tube decontamination is postulated to be performed using remotely operated, high-pressure water jet.
(e) A chemical decontamination and water flush are postulated to be performed.
(f) Channel heads were decontaminated using an alumina grit decontamination process (see Reference 8).
(g) Channel heads were decontaminated using an alumina grit decontamination process (see Reference 9).
(h) The personnel exposure for just the steam generator removal phases of the steam generator repair progress were 592 and 946 man-rem, respectively (see Reference 10).
(i) Includes all dose for outage, some of which may not have been related to steam generator activities (See Reference 8).

another AIF/NESP report[7] again considered the removal of steam generators during decommissioning, using a different set of assumptions and based on the experiences from recent selected steam generator changeout programs. For purposes of this study, only the steam generator removal projects that would occur during immediate dismantlement are considered.

According to Table 3.10 of AIF/NESP-009, five months are allowed for decontamination of steam generator tubes via remotely operated, high-pressure water jets. Another five months are allowed for removing the four steam generators and the pressurizer. It was envisioned that the steam generators were cut into two segments by cutting the shell just above the tube bundle. It was then assumed that these segments were shipped by rail to a burial site. These decontamination and removal activities were estimated to result in a total exposure to the work force of 23 man-rem, which was reported to represent 4% of the total exposure for the removal/dismantling option. The activity-dependent cost for component removal was estimated at $15,470 (1975 dollars) per steam generator. The total cost of decontamination of the steam generator tubes, seal welding the steam generators and the pressurizer openings, and removing, shipping, and burying the steam generators and the pressurizer was estimated to be about $337,000 in 1975 dollars.

According to NUREG/CR-0130, following the chemical decontamination of the reactor coolant system (RCS) and the steam generators, an estimated 144 man-rem (14,400 man-hours in an average radiation field of 10 mR/hr) would be required to remove four steam generators during immediate dismantlement. This amount represents 10% of the total exposure for immediate dismantlement. According to Figure G.2-2 of NUREG/CR-0130, three months are allowed for removing the four steam generators, starting in the sixteenth month following final reactor shutdown. The estimated total cost of decontamination, labor, and disposal is about $800,000 in 1978 dollars.

A different set of assumptions is used in the 1986 AIF/NESP report, based on the recent Surry, Turkey Point, Point Beach, and H. B. Robinson experiences, to develop a steam generator removal scenario for decommissioning. This analysis focuses only on steam generator removal and does not combine it with the pressurizer removal as in the 1976 AIF/NESP report, since the authors acknowledge that there has not been a need to replace a PWR pressurizer in an operating plant of major size. This report goes into great detail in discussing topics such as generic decommissioning activities (e.g., decontamination, packaging and shipping radioactive waste, and special equipment requirements) and decommissioning-specific activities (e.g., manpower requirements by labor category, schedules, and disassembly procedures). However, unlike the 1976 AIF/NESP report, the following key assumptions have been added:

- The generators will have been chemically decontaminated and flushed to reduce exposure doses to the crews.

- Furthermore, the decontamination flush will permit the use of the generator's outer shell as its own shipping and burial container.

- The steam dome and transition section would not be removed. The entire steam generator would be removed intact with the dome left in place and all openings would be welded closed.

- Each steam generator would be shipped as an intact unit on a Schnabel railcar.

The decommissioning work force is postulated to consist of three crews of 30 men each. At this rate, with one crew assigned per steam generator, it is estimated that three steam generators can be removed from a PWR similar to one of the Surry plants (the reference plant used in this example) in approximately four to five months, using about 70,700 labor hours. Unfortunately, no removal costs or occupational radiation doses are given in this hypothetical example.

5.4.2 Review of Recent PWR Nuclear Experience

A summary of pertinent information for recent PWR steam generator replacement projects is presented in Table 5.2. It can be seen from the table that, for U.S. reactors, the radiation exposures decreased markedly with experience. This is an obvious reflection on the industry's learning curve for this kind of complex project.

Brief descriptions of all of the recent significant steam generator removal/replacement projects as well as other major repair work concerning U.S. steam generators follow.

5.4.2.1 Surry 1 and 2, Gravel Neck, Virginia

The Surry nuclear power plant replaced the six steam generators from Units 1 and 2, with Unit 2 being the first to undergo steam generator removal and replacement in the U.S. In all cases, the steam generator upper assemblies and the reactor coolant pipes were cut for removal of the lower assemblies. As can be seen from Table 5.2, the total dose for Surry 1 was significantly lower than for the Surry 2 replacement project because of the experience gained from Surry 2, even though Surry 1 had slightly higher radiation fields. The implementation of many improvements in personnel exposure control, shielding design, use of containment envelopes, and waste handling helped to keep the total exposure down on the second removal/replacement project at the Surry Plant.[10]

5.4.2.2 Turkey Point 3 and 4, Florida City, Florida

The Turkey Point nuclear power plant replaced the six steam generators from Units 3 and 4. The supports for these generators were located beneath the channel heads, and it would have been difficult to remove the entire lower assembly from its normal position. Consequently, Florida Power and Light Company (FP&L) chose to remove the tube section of the lower assembly and leave the channel head in place. To reduce the dose to welders and other personnel working in and around the channel head, an alumina grit decontamination process was used that reduced the average radiation fields inside the channel heads. In addition to the experience factor gained from unit 3, some

TABLE 5.2. Recently Completed Steam Generator Replacement Projects

Plant	NRC Docket Number	Commercial Operation	Capacity MW Net[(a)]	Replacement Date	Project Duration (months)	Activity	Total Dose (man-rem)
Surry 2	50-281	5/73	781	1979	10[(b)]	Removal and replacement of 3 steam generator lower assemblies	946[(c)]
Surry 1	50-280	12/72	781	1980-1981	9[(b)]	Removal and replacement of 3 steam generator lower assemblies	592[(d)]
Turkey Point 3	50-250	12/72	666	1981-1982	9	Removal and replacement of 3 steam generator lower assemblies	2,151[(e)]
Turkey Point 4	50-251	9/73	666	1982-1983	7	Removal and replacement of 3 steam generator lower assemblies	1,365[(e)]
Point Beach 1	50-266	12/70	485	1983	4	Removal and replacement of 2 steam generator lower assemblies	590
Obrigheim (German)	Not Applicable	3/69	340	1983	Unknown	Removal and replacement of 2 steam generator lower assemblies	690
H. B. Robinson 2	50-261	3/71	665	1984	9	Removal and replacement of 3 steam generator lower assemblies	1,207

(a) Extracted from Reference 11.
(b) Includes reinstallation of the new steam generators (see Reference 8).
(c) The personnel exposure for the total repair program was 2,070 man-rem (see Reference 10).
(d) The personnel exposure for the total repair program was 1,750 man-rem (see Reference 10).
(e) Includes all dose for the outage, some of which may not have been related to steam generator activities (see Reference 8).

of the lower dose reduction from Unit 3 to unit 4 (see Table 5.2) was due to slightly lower radiation fields for unit 4. The aforementioned decontamination of the channel heads accounted for 155 man-rem and 91 man-rem, respectively, of the total occupational dose for units 3 and 4.[(8)]

NOTE: For purposes of subsequent comparison, about 27 man-rem were estimated to be sufficient in NUREG/CR-0130 for chemical decontamination of the entire reactor coolant system (RCS), which includes the four steam generators. This preparatory ALARA activity included filling and draining the RCS and related systems and evaporation and solidification of the waste solutions as well as a liberal allowance for the repair and maintenance of the evaporators at the reference plant. In addition, it should be recognized that practical and proven RCS chemical decontamination technology is a major dose reduction procedure being used by U.S. nuclear utilities. Based on nine plants, the average cost of RCS chemical decontamination and waste handling is $1 million in 1985 dollars.[(12)]

5.4.2.3 Point Beach 1, Two Creeks, Wisconsin

Westinghouse Electric Corporation had full turnkey responsibility for the steam generator replacement program at the Point Beach nuclear power plant, a two-loop 485 MW_e Westinghouse PWR. Their major responsibilities included project management, steam generator removal and installation, construction of the steam generator storage facility, and temporary facilities, engineering, quality assurance and quality control, health physics implementation, and preparation of licensing documents. Westinghouse also provided all craft labor required for the project. They established an independent project organization within Westinghouse for the purposes of planning engineering, construction, contract administration, and quality assurance activities.[13]

The repair report submitted to the NRC for the Point Beach 1 reactor contained an estimate of 1,390 man-rem for the removal and replacement of two steam generator lower assemblies. However, by capitalizing on innovative ideas, combined with extensive planning and thorough training, the final exposure figure was actually 590 man-rem, corresponding to less than 300 man-rem per steam generator. This latter figure is less than half the U.S. industry average of about 635 man-rem per steam generator.[13]

5.4.2.4 H. B. Robinson 2, Hartsville, South Carolina

In 1984, the Carolina Power and Light Company's (CP&L) 665 MW_e H. B. Robinson 2 nuclear power plant became the seventh PWR to undergo steam generator replacements. Like FP&L before them, CP&L chose to remove the tube section of the lower assembly and leave the channel head in place. Since the channel head removal method was used, no reactor primary system cuts were required to be made. The steam dome was removed from each of three steam generators and refurbished. Then, the tube section of the lower assembly was removed, painted, and plates were welded on the top and bottom of the section. These units were then stored in a specially constructed mausoleum, located on the site.

An existing rail spur to the plant was inspected and subsequently repaired for use in shipment of the new, replacement steam generators to the plant.

The dose estimated by CP&L for the removal and replacement of the three steam generator lower assemblies was 2,120 man-rem. This estimate was derived by the licensee from anticipated man-hours in known radiation fields for all tasks planned.[9,14] The actual personnel exposure accumulated was significantly lower than the original estimated exposure (i.e., 1207 man-rem versus 2120 man-rem). In CP&L's Final Radiological Progress Report,[9] it is concluded that "the exposure accumulated indicates that the planning for the project served to provide a higher level of productivity with reduced personnel exposure. In addition, the use of temporary shielding has proven more effective than originally estimated."

5.4.3 Discussion of Previous Estimates and of Recent Changeout Programs

A partial explanation of differences between the NUREG/CR-0130 dose estimate and that cited by other nuclear industry reports (e.g., AIF/NESP-009) rests with differing assumptions regarding decommissioning techniques, processes, and/or the labor necessary to complete the steam generator removal tasks and differing assumptions regarding area dose rates to which the workers would be exposed. These different assumptions came about based partially on the uncertainty inherent in making the estimates at that time. For example, the NUREG/CR-0130 (1978) estimate assumed that the reactor primary coolant system was chemically decontaminated before the steam generators were removed, whereas the AIF/NESP-009 (1976) analysis assumed only a drain and flush of the reactor coolant system would be used.

Chemical decontamination of major reactor systems and components to reduce radiation exposure associated with special maintenance operations is now routinely used at U.S. nuclear power stations.(12) Additional evidence that this also has been accepted as recommended protocol during decommissioning as well is found in the following assumption, which is excerpted from a recent AIF report (AIF/NESP-036 1986):

> "The NSSS (reactor vessel and recirculation piping and valves) will be chemically decontaminated using one chemical flush and two water rinses prior to component segmentation for removal. Typically, a decontamination factor (DF) of 10 is expected."

Extreme care was taken during all of the steam generator removal projects examined in this study because these activities occurred during very tightly scheduled and costly reactor outages. Many precautionary activities were performed that would neither be done nor necessary for steam generator removal during decommissioning. On the other hand, some feasible preparatory activities were never attempted. For example, internal chemical decontaminations of either the reactor primary coolant system or the individual steam generators were not done.

Overall, examination of information on steam generator removal projects reveals that it is difficult to segregate information on the detailed occupational doses associated with specific removal tasks because of the use of all-inclusive special work permits (SWPs) during reactor outages. Such records seldom differentiate steam generator tasks from other tasks associated with the outage. For example, a health physicist might, in the course of a day's work, cover two, three, or more tasks involving numerous workers, only one of which might be associated with the steam generator removal project. Unfortunately, only the <u>total</u> occupational doses for the workers are reported on a daily basis, regardless of where they spent their time. Thus, accurate reconstruction of those occupational doses associated with just the steam generator tasks is difficult, if not impossible.

5.4.4 Additional Major Work Involving Steam Generators

Additional major work involving steam generators in the U.S. is presented in Table 5.3. The information presented in the table represents the work

TABLE 5.3. Recent Steam Generator Tube Sleeving Repairs[a]

Plant	MWe	Primary Loops	Outage Dates	Duration (months)	Number of tubes sleeved	Occupational Dose Total (man-rem)[b]	Occupational Dose Decontamination Task (man-rem)
San Onofre 1	456	3	9/1980 to 6/1981	10[c]	6,900	3,493	173
Point Beach 2	524	2	4/1983 to 6/1983	2	3,600	525	44[d]
R. E. Ginna	496	2	4/1983 to 6/1983	2	79	471	136
Indian Point 3	965	4	early 1985	Unknown	Unknown	125[e]	27[e]

(a) Information is extracted from Reference 8.
(b) Includes all dose for outage, some of which may not have been related to steam generator activities, unless noted otherwise.
(c) Outage began in April 1980 for maintenance and refueling. The discovery of tube damage led to initiation of pre-sleeving activities in September 1980.
(d) The number shown is based on vendor's task accounting and is slightly different than the utility's accounting.
(e) Information is extracted from Reference 15. Each of the four steam generators was decontaminated separately.

involved in tube sleeving repairs on intact steam generators during reactor outages, not on steam generator removal/replacement work during reactor outages. It was not within the scope of this study to compare and assess the applicability of such indirectly related steam generator repair work to postulated steam generator removal projects during decommissioning scenarios. The information is included here for historical completeness concerning recent major steam generator work in the U.S.

It is interesting to note, however, that the utility that owns the Indian Point 3 plant estimates that without decontamination, the total dose for the tube sleeving repairs would have been 620 man-rem. Thus, the decontamination provided a net saving of over 460 man-rem.[15]

5.5 STUDY RESULTS

The results of the reassessment of costs and occupational radiation doses for the removal of the steam generators from the reference PWR, described in NUREG/CR-0130, are presented in detail in the following subsections.

5.5.1 Estimated Additional Costs for Steam Generator Removal During Immediate Dismantlement of the Reference PWR

A number of circumstances have changed since the original PWR decommissioning report was prepared that influence the development of the estimated decommissioning costs. For example, revisions to 10 CFR 20 since publication of NUREG/CR-0130 in 1978 have tended to reduce the annual cumulative radiation dose allowable to persons working in the nuclear industry. Under normal circumstances, the allowable quarterly radiation dose is 1-1/4 rem, rather than 3 rem as utilized in NUREG/CR-0130, with an annual cumulative dose of

5 rem. Exceptions to these limits are allowed under carefully controlled conditions, with appropriately detailed exposure history records, within the constraint that the total cumulative dose to an individual shall not exceed (N-18), where N is the age of the individual. The allowable annual individual radiation dose from the original study bases ranged from 6 to 11 rem/year. For purposes of this evaluation, it is assumed that the individual annual radiation doses could not exceed 5 rem. Therefore, additional staff are employed in selected radiation worker categories to assure that no one exceeds the 5 rem per year limit. These additional staff represent a significant increase in staff labor costs for the reference PWR in general, and for the postulated removal of the steam generators in particular.

For the reference PWR, the original immediate dismantlement decommissioning cost estimate[1] could be expected to increase about $8.7 million (in January 1986 dollars), due to the incremental cost adjustments associated with two of the cost adders developed in the 1984 EPRI cost update.[2] These cost adders are 1) the additional staff ($7.5 million) to assure meeting the 5 rem/year dose limit for personnel associated with <u>all</u> immediate dismantlement tasks, and 2) the extra supplies ($1.2 million) for the additional staff. These adders have been escalated from 1984 to January 1986 for this study and include a 25% contingency. The fraction of the additional $8.7 million that is attributable to the removal of the reference PWR's four steam generators is conservatively estimated to be about $1.4 million. This additional cost is based on an average salary per worker of about $210 per day and includes a proportional share of the costs for the extra supplies over the entire task duration.

5.5.2 Results of the Reassessment of the Radiation Dose Estimate

The PBNP-1 steam generator replacement project was chosen for examination because: 1) it was recently completed; 2) they had obviously taken full advantage of previous U.S. experiences, as evidenced by the resultant lowest total occupational dose per unit incurred; 3) they had made RCS piping cuts, whereas Turkey Point and H. B. Robinson had not; such cuts were of a nature similar to those postulated originally in NUREG/CR-0130 for the reference PWR and therefore the data were expected to be more suitable for the purpose of subsequent comparisons; 4) its two Westinghouse steam generators are similar in size and mass to the steam generators at the reference PWR; 5) videocassettes of the major replacement activities were made available for review by PNL staff; and 6) most importantly, the supervisory staff for the changeout program were still onsite and available for consultation.

The original dose estimate of 1,390 man-rem for the PBNP-1 steam generator replacement project was derived from the anticipated man-hours (623,937) in known radiation fields for all tasks planned in five distinct phases of work, as shown in Table 5.4. Only Phases I and II are directly applicable to steam generator removal during immediate dismantlement, and the overall average dose rate for these two phases of work is about 3.3 mR/hr. The actual project total man-hours and radiation dose are also shown in Table 5.4 for comparison.

The actual occupational radiation doses associated with the changeout program for PBNP-1 (a two-loop PWR) are summarized in Table 5.5. The data shown

TABLE 5.4. Estimated and Actual Personnel Radiation Doses from the Steam Generator Replacement Operations at PBNP-1[(a)]

Phase	Description	Estimated Labor (man-hours)	Estimated Exposure (man-rem)	Average Dose Rate (mR/hr)
I	Shutdown and Preparatory Activities	58,887	237.3	4
II	Removal Activities	141,680	421.7	3
III	Installation Activities	334,138	605.8	1.8
IV	Post-Installation and Startup Activities	87,700	118.3	1.3
V	Steam Generator Storage Activities	1,532	6.6	4.3
	Estimated Project Totals	623,937	1,389.7	2.2
	Actual Project Totals	320,000	590	1.8

(a) The information in this table is extracted from Reference 18, Table 6-2.

in the table were extracted from References 16 and 17. In total, 590 man-rem were incurred over a total of 320,000 hours of craft labor expended during the entire project.[(16)] This equates to an overall average dose rate of about 1.8 mR/hr.

It should be recognized that the shutdown dose rates postulated in NUREG/CR-0130 represented a composite of operating exposures from one 2-loop and five 3-loop PWRs. All the plants had operating histories of from 3 to 6 years. Specific area radiation levels did not vary greatly from plant to plant. The overall average dose rate used in NUREG/CR-0130 for steam generators removal, after the chemical decontamination of the RCS, was estimated to be 10 mR/hr. On the other hand, PBNP-1, which had been operating for 13 years at the time they initiated their changeout program, had average dose rates that ranged from a high of about 10.6 mR/hr for cutting reactor coolant piping to a low of less than 2 mR/hr for numerous other tasks, which included cutting of mainstream and feedwater piping, installation and removal of temporary lighting and power, material handling, equipment maintenance, and miscellaneous construction activities.[(18)] Therefore, PBNP-1 data suggest that more realistic average dose rates for the steam generators removal task during decommissioning would be at least a factor of three less than those used in NUREG/CR-0130.

Furthermore, the PBNP-1 program was conducted shortly after shutdown and defueling of the reactor, whereas in NUREG/CR-0130, the steam generator removal was scheduled to start in the sixteenth month after final reactor shutdown. The potential beneficial effects of this difference in schedules on the occupational dose postulated in NUREG/CR-0130 are twofold: 1) sixteen months of radioactive decay would have taken place, and 2) an extensive containment vessel cleanup campaign would have been completed.

TABLE 5.5. Summary of Occupational Radiation Doses from the Point Beach Steam Generator Replacement Project[a]

Task	Dose (rem)
Containment access building preparation	0.09
Equipment move-in/set-up in containment	7.09
Containment access modification	2.27
Temporary shielding - install/remove	44.52
Biological shield - install/remove	0.13
S/G supports - remove/refurbish[b]	6.83
S/G temporary supports and restraints - install/remove	7.26
Temporary power installation	5.98
Temporary power removal--restoration of permanent power	0.18
Protection of containment components	4.29
Interference removal	0.92
Foundation shoring of containment access	0.83
Communication system - install/remove	0.58
Tenting	14.42
Breathing air system install/remove	0.15
Polar crane modification	11.97
Load test	0.52
Equipment decontamination	6.63
Cleanup and decontamination of containment	62.97
Insulation removal	15.1[illegible]
S/G girth cuts	3.82
Steam drum handling	0.45
S/G main steam and feedwater pipe cuts	1.62
S/G small bore piping and instrument line cuts	2.10
S/G reactor coolant pipe cuts	35.13
S/G lower assembly removal	22.19
S/G laydown stands	0.37
Steam drum modification	16.22
S/G lower assembly installation	12.45
Reactor coolant pipe weld	135.70
S/G girth weld	6.18
S/G main steam and feedwater pipe weld	4.27
S/G blowdown pipe and instrument line weld	12.18
Post weld heat treatment	0.18
Insulation installation	39.36
Containment restoration	17.49
System integrity	3.76
Primary side search and retrieval	5.62
Secondary side search and retrieval	0.83
General containment entry and miscellaneous work	75.60
Total Occupational Dose	589.65

(a) The information in this table is extracted from References 16 and 17.
(b) S/G = steam generator.

Upon examination and discussion (with PBNP-1 staff) of the elemental constituents of each activity given in Table 5.5, the occupational radiation dose is adjusted by PNL for the "removal only" tasks concerning both PBNP-1 steam generators. The results are presented in Table 5.6, together with the rationale for the adjustments used to derive the estimated occupational radiation doses for steam generator removal during immediate dismantlement. The estimated dose resulting from the postulated removal of the four steam generators similar to the PBNP-1 units during immediate dismantlement, but without the benefit of a chemical decontamination of the RCS, and the estimated dose resulting from the removal of the same four steam generators during immediate dismantlement following a RCS chemical decontamination, are presented. Events likely to be affected by the chemical decontamination are identified in the table with an asterisk. Only those activities that would be performed during decommissioning, or would fall under the task description of steam generator removal in NUREG/CR-0130 are included. The adjusted total dose shown in the table (77.1 man-rem) is conservatively based on the assumption that the chemical decontamination of the RCS results in a decontamination factor (DF) of 5. If a DF of 2 is assumed, the total occupational radiation dose is calculated to be about 136.2 man-rem. Thus, the total radiation dose to decommissioning workers for the removal of steam generators during immediate dismantlement of the reference PWR appears to have been conservatively estimated in NUREG/CR-0130.

Rotation of the decommissioning work force envisioned for the steam generator removal project conducted at the reference PWR is made necessary by the presence of non-uniform dose rates within the steam generator cubicle work areas. Therefore, during the estimated 3-month removal period, two dedicated 30-man crews and another 55 support workers, who rotate throughout the nuclear plant as needed to maintain occupational doses within the limits of 10 CFR Part 20, are anticipated to work at any given time on removing the steam generators. It is further anticipated that approximately 46,000 hours will be expended by all of the workers, in radiation zones that average about 3.2 mR/hr. Compared to the original estimates given in NUREG/CR-0130, these latter estimates represent a trebling of the work force for this task (to stay within the quarterly radiation dose limit for workers of 1 - 1/4 rem). In addition, the average dose rate conditions are anticipated to be less than the NUREG/CR-0130 estimates by about a factor of three.

5.6 CONCLUSIONS, OBSERVATIONS AND COMMENTS

The cost and conditions for removal of a steam generator during decommissioning can be much more sharply defined now than they could be in the earlier decommissioning studies. The activities associated with the removal process are no longer first-of-a-kind, but rather reflect direct applications of developed techniques and equipment. Recent learning experiences can be used to guide the industry in planning for future steam generator removal operations.

However, while relevant information on steam generator removal during reactor outages is now available, similar information from actual decommissioning experience is still largely unavailable. From the experience base

TABLE 5.6. Estimated Occupational Dose for the Postulated Removal of Four Steam Generators Similar to PBNP-1 Units During Immediate Dismantlement With and Without Chemical Decontamination of the Reactor Coolant System[a]

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem): Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)[d]: Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Containment access building (CAB) preparation	0.09	--[e]	0.09	Although a CAB is considered an optional structure at the reference PWR, it is included in this study for conservatism.	Negligible, no change in estimate.	0.090	0.090
Equipment move-in/set-up in containment	7.09	--	7.09	Includes the movement and set-up of numerous items and materials not related to decommissioning, including refurbishment/repair tasks as well as SG installation, post-installation and startup activities.	Examination of PBNP-1 data suggests that approximately 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	2.363	2.363
Temporary shielding install/remove[f]	44.52	44.52	89.04	This activity is somewhat mislabeled since it also includes installing and removing scaffolding (which was done twice). The majority of these activities are required only once during immediate dismantlement.[g]	Therefore, the total dose for 4 SG's is estimated to be 44.52 rem without chemical decontamination.	44.520	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		8.904

Note: Footnotes are defined at the end of this table.

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem): Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)(d): Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
S/G supports remove/ refurbishe	6.83	6.83	13.66	Refurbishment is not necessary for decommissioning--simply remove and box for disposal.	Dose reduced by a factor of 10 due to severely reduced time and staff labor requirements.	1.366	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		0.273
Temporary power installation	5.98	--	5.98	Cable runs for 15 or more TV cameras and sound equipment, welding machines, etc. Much of the needed cutting equipment will already be inside the containment vessel (see schedule delineated in Figure G.2-2 of Reference 1). In addition, only 3 to 4 TV cameras are anticipated to be used during decommissioning. Power needs associated with SG installation, post-installation, and startup activities are not required.	It is estimated that approximately 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	1.993	1.993
Temporary power removal--restoration of permanent power	0.18	--	0.18	Restoration of permanent power is an unnecessary step for decommissioning.	It is estimated that approximately 1/2 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	0.090	0.090

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem): Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)[d]: Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Protection of containment components	4.29	--	4.29	An inventory is taken from prints and drawings to identify those components that must be protected for use during subsequent startup of the reactor. It is not known precisely how many of these components will be needed for decommissioning but according to the schedule presented in Figure G.2-2 of Reference 1, the reactor pressure vessel has already been removed and the RCS is empty.	It is estimated that approximately 1/2 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 2.	2.145	2.145
Interference removals	0.92	0.92	1.84	Conduits and minor piping which might interfere with the removal of the lower assemblies are identified, locations are precisely marked (for subsequent reinstallation), removed, and stored.	It is estimated that approximately 1/4 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 25%.	1.380	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		0.276
Foundation shoring of containment access	0.83	--	0.83	This task is included in this study for conservatism, because such shoring may be necessary at the reference PWR.	Negligible, no change in estimate.	0.830	0.830
Communication system install/remove	0.58	--	0.58	No dose reduction for this task is anticipated.	No change in estimate.	0.580	0.580

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem)			Rationale for Dose Reduction		Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)(d)	
	Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Cause	Effect	Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
Tenting•	14.42	14.42	28.84	Tenting requirements inside the SG cubicles for removal and installation activities; tenting requirements for cutting and welding RCS piping; and staging associated with these tasks.		28.840	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		5.768
Breathing air system install/remove	0.15	--	0.15	Backup system to existing containment vessel system; includes laying down hoses from a compressor located outside of the containment vessel.	No change in estimate.	0.150	0.15
Polar crane modification	11.97	--	11.97	It should be recognized that many aspects of this task are unique to PBNP-1. This task includes erection of a reinforced steel structure over the reactor cavity that was used to support a center beam that extended from the structure to the polar crane bridge. This upgrade increased the lifting capacity of the polar crane from 100 to 230 tons. Additional, but smaller modifications were made during the upgrade as well.	Upgrading the polar crane for SG removal at the Trojan plant (the reference PWR) is a far less complex operation than the upgrade at the PBNP-1. It consists of the installation of a blocking arrangement located at the same height in the containment vessel as the polar crane itself. It is estimated that approximately 1/2 of the staff labor requirements are not	5.985	5.985

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem)			Rationale for Dose Reduction		Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)[d]	
	Initial Dose for Two SGs[b,c]	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Cause	Effect	Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
					necessary for decommissioning; therefore, the dose is reduced by a factor of 2.		
Load test	0.52	--	0.52	During load testing, the crane load block bearings and a motor starter on the hoist failed and had to be replaced.	It is estimated that approximately 1/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 33%.	0.347	0.347
Equipment decontamination[e]	6.63	6.63	13.26	This task includes SG hosedown and waxing as well as attempts to decontaminate RCS pipe cuts in preparation for subsequent welding.	For the most part, the decontamination of RCS pipe cuts proved futile, but somewhat costly in terms of man-rem. It is estimated that approximately 1/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by 33%.	8.884	
				Chemical decontamination of the RCS.[h]	Dose reduced by a factor of 5.		1.777
Cleanup and decontamination of containment	62.97	--	62.97	An ongoing (but not continuous) effort throughout the project at PBNP-1.	No change in cleanup procedure is anticipated at the reference PWR, except that the project starts in the 18th	20.990	20.990

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem): Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Rationale for Dose Reduction: Cause	Effect	Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)(d): Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
					month after final reactor shutdown and after other major decommissioning tasks have been completed (e.g., reactor pressure vessel segmentation and removal). It is estimated that approximately 2/3 of these staff labor requirements are not necessary at this stage in the schedule; therefore, the dose is reduced by a factor of 3.		
Insulation removal*	15.16	15.16	30.32	At PBNP-1, this task involved the removal of an older type of insulation; subsequently, it was replaced with the stainless steel strap-on type of insulation.	A reduction in staff labor of about 25% is anticipated at the reference plant because it uses the newer type of insulation.	22.740	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		4.548
S/G girth cuts*	3.82	3.82	7.64	Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.	7.640	1.528
Steam drum handling	0.45	0.45	0.90	This task included lifting the steam drums, placing them in storage stands inside the containment vessel and includes all refurbishment work that was subsequently done.	It is estimated that fully 2/3 of these staff labor requirements are not necessary for decommissioning; therefore, the dose is reduced by a factor of 3.	0.300	0.300

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem)			Rationale for Dose Reduction		Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)(d)	
	Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Cause	Effect	Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
S/G main steam and feedwater pipe cuts	1.62	1.62	3.24	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	1.620	1.620
S/G small-bore piping and instrument line cuts*	2.10	2.10	4.20	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	2.100	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		0.420
S/G reactor coolant pipe cuts*	35.13	35.13	70.26	This task was done with precision because of subsequent reinstallation requirements.	Such precision is not necessary for decommissioning; therefore, the task time/dose is reduced by a factor of 2.	35.130	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		7.026
S/G lower assembly removal*	22.19	22.19	44.38	A large number of preparations are required for this task.		44.380	
				Chemical decontamination of the RCS.(h)	Dose reduced by a factor of 5.		8.876
S/G laydown stands	0.37	--	0.37	This task included building the stands, inside containment, for holding the steam drums in upright positions. These were special stands for a special purpose.	Much simpler devices can be used for decommissioning; therefore, the task time/dose is reduced by at least a factor of 2.	0.185	0.185

TABLE 5.6. (contd)

Immediate Dismantlement Task	Removal of Four SGs of PBNP-1 Type (Base Data from PBNP-1 Project) Estimated Dose (man-rem)			Rationale for Dose Reduction		Removal of Four Steam Generators During Immediate Dismantlement Estimated Dose (man-rem)(d)	
	Initial Dose for Two SGs(b,c)	Estimated Dose for Two Additional SGs	Estimated Total Dose for Four SGs	Cause	Effect	Without Chemical Decontamination of the RCS	With Chemical Decontamination of the RCS
General containment entry and miscellaneous work*(i)	75.60	--	75.60	This general category of activities is encompassed by the 170 man-rem originally estimated in Table G.3-1 of NUREG/CR-0130 for "miscellaneous activities" for the entire immediate dismantlement effort, including removal of the reference PWR's steam generators. Therefore, the category "General containment entry and miscellaneous work" is not included in the total for steam generator removal only.		0	0
Total dose	324.41	153.79	478.20			234.646	77.064

(a) The information in this table is extracted from Table 5.5 and modified for this study (see text for details).
(b) SG = steam generator.
(c) The information in this column is taken directly from Table 5.5.
(d) The number of figures shown is for computational accuracy and does not imply precision to that many significant figures.
(e) Dash indicates that the task is required to be done only once per plant.
(f) Events likely to be affected by chemical decontamination of the RCS are designated by an asterisk.
(g) Private communication with Douglas F. Johnson of Wisconsin Electric Power Company on September 24, 1987.
(h) Chemical decontamination of the RCS is the largest dose reduction factor of commonality used in this table. For the purpose of this study, it is conservatively estimated to reduce doses by a factor of five.
(i) Table G.3-1 of NUREG/CR-0130 allows a total of 170 man-rem for miscellaneous work during the entire immediate dismantlement effort.

reviewed in this study, it is clear that 1) estimates of occupational doses for this type of large-component removal during decommissioning will probably remain imprecise because of the uncertainties in the exact procedures which could be utilized (e.g., harsher decontamination methods and more extensive dismantling operations could be used in decommissioning than would be allowed during a replacement project); and 2) the feasibility and practicality of reactor-specific procedures for steam generator removal will remain primary considerations for decommissioning planners, since the estimated occupational dose is highly dependent on the degree and manner of decommissioning envisioned.

In general, it is concluded that dose reduction during decommissioning, relative to recent steam generator repair/replacement projects at the U.S. operating power plants examined in this study, would be attributable to:

- Essentially no channel head or manway entries required for decommissioning.

- Chemical decontamination of the RCS, including the steam generators, which is anticipated to significantly reduce both contact and background radiation dose rates for decommissioning workers. If a significant reduction in worker dose is to be achieved, the value of chemical decontamination of the RCS cannot be overemphasized in the steam generator removal process during immediate dismantlement.

- Partially filling the steam generators with water for shielding after the chemical decontamination task, thus providing further reductions in background radiation during the initial cutting operations. This preparatory ALARA step also was done at Surry, Turkey Point, and H. B. Robinson.

- Removal and replacement of each steam generator in one piece (or in as few pieces as possible), thus minimizing the cutting and welding operations inside containment.

Historically, it appears that a combination of poorly-defined data, controversial assumptions, and modeling difficulties for large-component removal projects have often resulted in significantly different occupational radiation doses than were originally estimated. It seems reasonable, therefore, that the actual occupational radiation doses for steam generator changeout projects at operating PWRs in the future can probably be expected to continue to vary for a variety of reasons. It is anticipated that the occupational radiation dose during decommissioning will also vary considerably from plant to plant. In all cases, the total dose for this large component removal operation is sensitive to 1) the amount of preparations required; 2) the quality and thoroughness of the preparations; 3) the degree of success of the chemical decontamination campaign; 4) the duration and working conditions; 5) the steam generator design and other plant-specific conditions; 6) the technology applied, involving to a large extent the need for and the successful use of purpose-built tools and equipment; 7) the removal methodology employed; 8) the skills of properly trained and qualified workers; and 9) the degree of success of the management commitment to maintain the occupational doses within the 10 CFR Part 20 limits and as low as reasonably achievable (ALARA).

Chemical decontamination processes for the RCS will be dictated by cost, decontamination effectiveness, and radioactive waste management considerations during decommissioning, as compared with operating plants where outage time and corrosion concerns are of primary importance. In general, more aggressive decontamination processes can be used for decommissioning-related applications, particularly since damage due to excessive corrosion associated with such processes would not be of concern.

One potential change identified in this study is that fewer segmentation cuts per steam generator may be required for removal during decommissioning than were envisioned in NUREG/CR-0130. For decommissioning planners, additional emphasis is recommended on the initial general cleanup and decontamination of containment as well as on the periodic housekeeping and decontamination of walkways, platforms, tools, and equipment. All of these activities will be beneficial in reducing worker skin contamination, airborne radioactivity, and the need for respiratory-protection devices during steam generator removal projects.

5.7 REFERENCES

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

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

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

4. G. M. Holter and E. S. Murphy. 1983. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130, Addendum 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

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

6. W. J. Manion and T. S. LaGuardia. "An Engineering Evaluation of Nuclear Power Reactor Decommissioning Alternatives." AIF/NESP-009, November 1976.

7. T. S. LaGuardia, et al. "Guidelines for Producing Commercial Nuclear Power Plant Decommissioning Cost Estimates." AIF/NESP-036, May 1986.

8. M. A. Parkhurst. Nuclear Plant Safety. "Occupational Exposure Reduction in Major Steam Generator Repairs." pp. 4-6, May-June 1984.

9. Carolina Power & Light Company. "Steam Generator Repair Program for H. B. Robinson Unit 2. Final Radiological Progress Report 3 for the Period February 1, 1984, Through October 31, 1984." Docket 50-261, License No. DPR-23.

10. H. S. McKay. Steam Generator Replacement at Surrey Power Station, "Techniques Applicable to Power Station Decommissioning." Changeout of Large Components/Systems Experience Applicable to Decommissioning, Proceedings of the 1987 International Decommissioning Symposium in Pittsburgh, Pennsylvania, October 4-9, 1987.

11. Nuclear News. "World List of Nuclear Power Plants." August 1987.

12. R. A. Shaw and C. J. Wood. Nuclear News, "Chemical Decontamination: An Overview," pp. 107-111, June 1985.

13. Nuclear Engineering International. "New Point Beach SGs go to Full Power." pp. 10-11, June 1984.

14. U.S. Nuclear Regulatory Commission. 1983. Safety Evaluation Report Related to Steam Generator Repair at H. B. Robinson Steam Electric Plant Unit No. 2. NUREG-1004, Prepared by the Office of Nuclear Reactor Regulation of the U.S. Nuclear Regulatory Commission, Washington, D.C.

15. Nuclear Engineering International. "Lomi Proves Successful in Recent Applications at American Plants." pp. 49-50, March 1986.

16. Nuclear Engineering International. "Point Beach 1 Steam Generators Replaced Ahead of Schedule." pp. 38-42, January 1985.

17. D. F. Johnson. "Health Physics and Exposure Management Aspects of the Point Beach Nuclear Plant Steam Generator Replacement Project," Paper presented at the Westinghouse Radiation Exposure Management Seminar, October 2, 1984, Pittsburgh, Pennsylvania.

18. WEPCO Steam Generator Repair Report, March 1983.

6.0 DEVELOPMENT OF SCALING AND ESCALATION FORMULAE FOR THE DECOMMISSIONING RULE

A necessary part of the Decommissioning Rule developed by the NRC, related to commercial power reactors, is the section dealing with assurance that funds will be available for decommissioning when the time comes to accomplish that effort. To provide reasonable assurance of adequate funding, the NRC has placed into the Rule a formula for estimating the amount of funds required as a function of the power rating of the reactor. Since the actual date of decommissioning for most plants is as yet undefined, an additional formula has been developed for adjusting the cost estimate to include escalation from the time the Rule was issued to the time of actual decommissioning. The bases and methodology used in developing these formulae are presented in this chapter.

6.1 DEVELOPMENT OF SCALING FORMULAE FOR ESTIMATING DECOMMISSIONING COSTS OF PWRs DIFFERENT IN SIZE FROM THE REFERENCE PWR

In the original analysis of decommissioning a reference PWR,[1] a methodology was developed for estimating the costs of decommissioning plants with smaller power output than the reference plant. This methodology was based on the assumption that essentially all of the decommissioning costs were proportional to the size of the principal components of the plant (e.g., the reactor vessel, number of steam generators, etc.). Subsequent analyses have suggested that only the waste disposal costs should be proportional to the size of the major components, and that the other costs (principally labor and materials) should be nearly independent of the plant size. These revised assumptions and formulae for estimating costs for plants smaller than the reference plant were initially documented in a letter (R. I. Smith to C. Feldman, 11/12/86), which is presented in Appendix B. Since that letter was written, small adjustments to the cost estimates have been made to include the effects of post-TMI-2 backfits, as documented in Chapter 4 of this report. The development of these revised scaling formulae is presented here for completeness.

The smallest conventional PWR examined in the original scaling analysis for PWRs was the R. E. Ginna station, with a thermal rating of 1300 MW_t, and a derived scaling factor of 0.518. The reference reactor (Trojan) had a thermal rating of 3500 MW_t and a scaling factor of 1.0. To develop a new scaling relationship, it was necessary to recalculate the cost estimate for the R. E. Ginna reactor, as shown in Table 6.1.

TABLE 6.1. Revised Estimated Decommissioning Costs for Trojan and R. E. Ginna Reactors (millions of January 1986 dollars)

Reactor Site	Waste Disposal	Scaling Factor	Other Costs	External Contractor	Utility Only	Utility Plus Contractor
Trojan	40.233	1.00	48.559	14.740	88.782	103.522
R. E. Ginna	40.223	0.518	48.559	14.740	69.395	84.135

To develop the revised scaling formulae, the cost estimates given in Table 6.1 were inserted into two linear equations having two unknown coefficients and the equations were solved for the unknown coefficients.

$$A + B(3500\ MW_t) = \$103.522, \quad A = B(1300\ MW_t) = \$84.135$$

$$B = 8.81 \times 10^{-3}\ \text{Million}\ \$/MW_t, \quad A = \$72.687\ \text{million (Utility + Contractor)}$$

$$A = \$57.947\ \text{million (Utility-only)}$$

Thus, the PWR scaling equation for decommissioning costs becomes:

$$\text{Total Cost (millions 1986\$)} = (72.687 + 0.0088\ \{\text{Plant}\ MW_t\})$$

when the utility employs an external decommissioning contractor, and

$$\text{Total Cost (millions 1986\$)} = (57.947 + 0.0088\ \{\text{Plant}\ MW_t\})$$

when the utility acts as its own decommissioning contractor.

These equations were developed using data from plants ranging from about 1200 MW_t to 3500 MW_t, and are only assumed to be applicable within that range. For plants smaller than 1200 MW_t, the value calculated at 1200 MW_t should be used, a conservative assumption. For plants greater than 3500 MW_t, the value calculated at 3500 MW_t should be used.

Subsequently, in the development of the Decommissioning Rule, some additional conservatism has been added to the constant terms in the above equations. As a result, the equation appearing in the Rule is:

$$\text{Estimated PWR Decommissioning Cost} = 75 + 0.0088\ MW_t\ \text{(millions January 1986\$)}$$

Where the cost for plants smaller than 1200 MW_t is set equal to the cost for a 1200-MW_t plant, and the cost for plants larger than 3400 MW_t is set equal to the cost for a 3400-MW_t plant.

This equation is believed to represent an adequate approach to estimating the amount of funds that should be available to provide reasonable assurance that decommissioning of a PWR station can be performed at the appropriate time. This equation is applicable to cost estimates for immediate dismantlement for reactor plants that are smaller than the reference plant examined in Addendum 1(1) to the original PWR decommissioning analysis (NUREG/CR-0130). Since immediate dismantlement (DECON) is generally the more expensive of the acceptable decommissioning possibilities, if funds for DECON are available, the other possibilities are also covered.

6.2 DEVELOPMENT OF A COST ESCALATION FORMULA FOR DECOMMISSIONING COSTS

The cost estimate for decommissioning the reference PWR was developed in 1978 dollars initially. Because of the significant amount of escalation that has occurred since that time, it has been necessary to periodically update the estimated cost to reflect increases in the various components of that cost, with the results of the most recent update given in Chapter 3 of this report. As a result of performing several cost updates over the years since 1978, it became apparent that the total cost could be divided into three principal components, as regards to cost escalation. These components are:

- Labor and other components that escalate at the same rate as labor
- Energy: electricity, fuel, and other components that escalate at the same rate as energy
- Waste Disposal: handling and burial charges at a low-level waste disposal site.

Assuming that the escalation factors for each of these components can be derived for any point in the future, relative to the 1986 data provided in this report, then the escalated decommissioning cost is given by:

$$\text{Estimated Cost (Year X)} = [\text{January 1986 Cost}]\ [A\ L_X + B\ E_X + C\ B_X]$$

where A, B, and C are fractions of the total cost in January 1986 dollars that are attributable to labor, energy, and burial, respectively, and sum to 1.0. The factors L_X, E_X, and B_X are defined below.

L_X = [labor cost escalation from 1986 to Year X]

E_X = [energy cost escalation from 1986 to Year X]

B_X = [disposal cost escalation from 1986 to Year X]
or
[disposal cost in Year X / disposal cost in 1986]

Evaluation of L_X and E_X for years subsequent to 1986 are left to the licensees, based on the national consumer price indices and on local conditions at a given site. Evaluation of B_X is to be provided to the licensees via NUREG-1307, a report to be issued periodically by the U.S. NRC, which will contain the disposal rate schedules for each radioactive waste disposal site operating in the U.S. at the time of report issuance, and values of B_x applicable to each operating site. Evaluation of the coefficients A, B, and C is illustrated in the following tables and paragraphs.

The distribution of total disposal costs between container cost, transportation cost, and burial cost is illustrated in Table 6.2, with the costs given in January 1986 dollars, based on the original estimates given in NUREG/CR-0130.[1]

TABLE 6.2. Distribution of Radioactive Waste Disposal Costs into Components that Escalate Proportional to Labor, Energy, and Burial Costs

NUREG/CR-0130 Reference Table	Type of Waste	Costs in Millions of January 1986 Dollars: Container Costs	Transportation Costs	Burial Costs
G.4-3	Activated Materials	2.96	1.00	2.60
G.4-4	Contaminated Reactor Bldg.	0.84	0.56	2.63
G.4-5	Contaminated Other Bldgs.	4.47	2.65	11.89
G.4-6	Radwaste	0.45	0.76	0.86
Subtotals		8.71	4.86	17.98
Contingency (25%)		2.18	1.22	4.50
Totals		10.89	6.08	22.48

Evaluation of the coefficients A, B, and C in the decommissioning cost escalation formula is presented here for the reference PWR. This evaluation is based on information presented in Chapter 3 of this report and on Table 6.2, above. The cost components that escalate similarly are grouped together in Table 6.3. The sum of those grouped costs is divided by the total cost of decommissioning to obtain the fraction of the total cost attributable to that group of components.

The analysis presented in Table 6.3 has shown the values of A, B, and C to be 0.64, 0.14, and 0.22, respectively. A similar analysis for the reference BWR has yielded values of 0.66, 0.12, and 0.22, respectively. In view of the uncertainties and contingencies on these values, and considering that the values of the coefficients for both the PWR and the BWR are so similar, it has been concluded that the best estimates for the coefficients are the averages of the PWR and BWR values:

$$\bar{A} = 0.65 \qquad \bar{B} = 0.13 \qquad \bar{C} = 0.22$$

TABLE 6.3. Derivation of the Coefficients A, B, and C in the Decommissioning Cost Escalation Formula

Cost Category	Millions of January 1986 Dollars	Coefficient Derivation	Data Source
Labor	17.98		Table 3.1
Equipment	1.64		"
Supplies	3.12		"
Decommissioning Contractor	12.9		"
Insurance	1.9		"
Added Staff	7.5		"
Added Supplies	1.2		"
Specialty Contractor	0.78		"
Pre-engineering	7.4		"
Post-TMI Backfits	0.9		"
Surveillance	0.31		"
Fees	0.14	A = 66.67/103.5	"
Containers	10.9		Table 6.2
Subtotal	66.67	A = 0.64	
Energy	8.31	B = 14.39/103.5	Table 3.1
Transportation	6.08		Table 6.2
Subtotal	14.39	B = 0.14	
Burial	22.48	C = 22.48/103.5	Table 6.2
Total	103.5	C = 0.22	

Note: All costs include a 25% contingency.

6.3 REFERENCES

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

APPENDIX A

COST UPDATING BASES AND METHODOLOGY

APPENDIX A

COST UPDATING BASES AND METHODOLOGY

Cost adjustment factors used to update decommissioning costs to a January 1986 cost base for the Final Generic Environmental Impact Statement (FGEIS) on Decommissioning are contained in the following letter to Dr. Carl Feldman (NRC) from Richard I. Smith (PNL).

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)

Telex 15-2874

June 25, 1986

Dr. Carl Feldman
Chemical Engineering Branch
Division of Engineering Technology
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Dr. Feldman:

Enclosed are the marked-up draft of Chapter 14, NON-FUEL-CYCLE NUCLEAR FACILITIES, for the Generic EIS on Decommissioning, and a brief summary of the bases and methodology used in updating the cost estimates contained in Chapter 14. This same bases and methodology is being applied to updating the remaining chapters of the GEIS, and these chapters will be forwarded to you as they are completed.

In addition, we reviewed the text of Chapter 14 and offer a few minor suggestions for revisions where we thought a revision might clarify a point. These suggestions are also marked on the enclosed draft text.

If you have any questions about any of this material, please call me.

Sincerely,

Richard I. Smith, PE
Staff Engineer

Enclosures

RIS:sb

COST UPDATING BASES AND METHODOLOGY

E. S. Murphy and G. J. Konzek

Cost adjustment factors used to update decommissioning costs to a January 1986 cost base are shown in Table 1. The rationale for these cost adjustment factors is given in the following paragraphs.

TABLE 1. Adjustment Factors for Updating Costs to a January 1986 Cost Base

Cost Category	Cost Adjustment Factor Applied to	
	1978 Costs	1981 Costs
Staff Labor	1.6	1.3
Equipment	1.6	1.2
Miscellaneous Supplies	1.6	1.2
Energy		
Electricity	1.9	1.4
Fuel Oil	2.1	0.9
Specialty Contractors	1.6	1.3
Regulatory Fees	See rationale	See rationale
Insurance	1.9	1.5
Waste Management		
Containers	See rationale	See rationale
Transportation	1.8	1.3
Burial	See rationale	See rationale

Staff Labor. Cost adjustment factors for staff labor were determined by using the January 1986 Handy Whitman Index of Public Utility Construction Costs. Average values, determined by averaging cost escalation factors for building trades labor for the six regions of the United States defined by the Handy-Whitman index, were used in making comparisons between 1978 or 1981 and 1986.

Equipment. Equipment costs were escalated based on national average cost escalation values for capital equipment obtained from the U.S. Department of Labor publication, "Producer Prices and Price Indexes."

Miscellaneous Supplies. Cost adjustment factors used for miscellaneous supplies are the same as those used for equipment.

Electricity. Costs of electricity were escalated based on national average values of the electric power index in the U.S. Department of Labor publication, "Producer Prices and Price Indexes."

Fuel Oil. Costs of fuel oil were escalated based on national average values of the index for No. 2 fuel oil in the U.S. Department of Labor publication, "Producer Prices and Price Indexes." The price index shows a decline in the price of fuel oil between January 1981 and January 1986.

Specialty Contractors. Specialty contractor costs are primarily costs associated with labor and equipment. The same cost escalation factors were used for specialty contractor labor and equipment as were used for facility licensee labor and equipment.

Regulatory Fees. Fees charged for licensing services performed by the NRC are on a cost recovery basis as defined in 10 CFR Part 170. For these cost updates it is assumed that licensee submittals are of a quality such that one NRC staff-year is required to accomplish the appropriate reviews, operational surveillance, and termination inspections, with an estimated cost in 1986 dollars of about $120,000.

Insurance. Based on telephone discussions with American National Insurers (ANI) representatives and with Oregon State University personnel who operate a research reactor, 1978 insurance premiums were escalated by a factor 1.9 and 1981 premiums were escalated by a factor of 1.5.

Containers. Insofar as possible, container costs were updated using actual 1986 costs determined by telephone contact with a supplier. For cases where this was not practicable, 1978 container costs were escalated by a factor of

1.6 and 1981 container costs were escalated by a factor of 1.2. (These are the same escalation factors used to update equipment costs.)

Transportation. Per a telephone call to Tri-State Motor Transit Company on May 27, 1986, it was determined that the 1986 cost of a legal-weight, exclusive-use truck shipment employing a single driver is $1.89/mile for a shipment from Raleigh, North Carolina to Hanford. The 1978 cost of a similar shipment was $1.03/mile, and the 1981 cost was $1.42/mile. These values were used to establish transportation cost adjustment factors.

Low-Level Waste Burial. Current rate schedules for disposal of radioactive waste were obtained from both U.S. Ecology and Chem-Nuclear Systems, Inc. The two companies use different bases for determining surcharges, and, therefore, their rate schedules are not directly comparable. Chem Nuclear's charges appear to be slightly higher than those of U.S. Ecology. Waste disposal costs in the original decommissioning studies were based on U.S. Ecology rate schedules. Cost adjustment factors were therefore obtained by comparisons of 1978 and 1981 U.S. Ecology rate schedules with the current U.S. Ecology rate schedule.

Waste disposal cost escalation factors are larger than escalation factors for any other cost category. For example, for the disposal of steel drums or wood boxes with surface dose rates <0.2 R/hr, the escalation factor is 9.4 for adjustment of disposal costs from the early-1978 base to the January 1986 base, and 2.9 for the adjustment of disposal costs from the early-1981 base to the January 1986 base. Waste disposal cost escalation factors for different categories of waste depend on several parameters including type of waste container, quantity of radioactive material in the container, and package weight. Waste disposal cost escalation factors were therefore determined on a case-by-case basis.

APPENDIX B

REVISED ASSUMPTIONS AND FORMULAE FOR ESTIMATING COSTS AS A FUNCTION OF PLANT SIZE

APPENDIX B

REVISED ASSUMPTIONS AND FORMULAE FOR ESTIMATING COSTS AS A FUNCTION OF PLANT SIZE

For purposes of developing upper-bound estimates of costs for immediate dismantlement of reactor plants different in size from the reference PWR, scaling analyses were performed and overall scaling formulae were developed. The initial results of these analyses are contained in the following letter to Dr. Carl Feldman (NRC) from Richard I. Smith (PNL). In addition, the letter presents the cost escalation factors from 1984 to 1986 that were developed in PNL's cost update for the Electric Power Research Institute[a] and subsequently utilized as an integral part of the cost base for the NRC's Final Generic Environmental Impact Statement (FGEIS) on Decommissioning. It should be recognized that since the letter was written, small adjustments to the cost estimates have been made to include the effects of post-TMI-2 backfits as documented in Chapter 4 of this report. Development of the revised scaling formulae is presented in Chapter 6 of this report.

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

November 12, 1986

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)
Telex 15-2874

Dr. Carl Feldman
Materials Branch
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Carl:

In response to your request, we have examined the updated costs for decommissioning the reference PWR and BWR as developed for the GEIS, and have made further adjustments which include the cost adders developed in our EPRI cost update (EPRI NP-4012) for pre-decommissioning engineering, additional staff to assure meeting the 5 Rem/year dose limit for personnel, extra supplies for the additional staff, and the additional costs associated with utilizing an external contractor to conduct the decommissioning effort. These adders have been escalated from 1984 to 1986. Engineering and staff labor was escalated by a factor of 1.02 from the 1984 values, while the extra supplies were escalated by a factor of 1.04. Since the external contractor costs are essentially all staff labor, these costs were escalated by a factor of 1.02. All values include a 25% contingency. The results are presented in Table 1.

Table 1. Immediate Dismantlement Costs in Millions of 1986 Dollars

Reactor Type	GEIS Value	Pre-D&D Engrng.	Extra Staff	Extra Supplies	External[(a)] Contrtr.	Utility Only	Utility+ Contrtr.
PWR	73.608	5.610	7.527	1.248	14.740	87.993	102.733
BWR	98.564	5.610	4.412	0.208	22.972	108.794	131.766

(a) Includes incremental cost (1.836) of utilizing an external contractor for pre-decommissioning analyses.

SCALING ANALYSIS

For purposes of developing an upper-bound estimate of costs for immediate dismantlement of reactor plants smaller than the reference plants, assume that all costs (staff labor, equipment, supplies, etc.) except waste disposa[illegible] e independent of plant size, and that the scaling factors developed in the NUREG/CR-0130 Addendum and in the NUREG/CR-0672 Appendix O are applicable to just the disposal costs. This analysis will be limited to plants with thermal power ratings greater than 1200 MW_t. Using the 1986 GEIS cost updates for the reference plants, as given in the table above, the portion of those costs that are due to waste disposal, the overall scaling factors from the previous scaling analyses, and the escalated cost adders from Table 1, above, the results shown in Table 2 are obtained:

Table 2. Immediate Dismantlement Costs For Plants Smaller Than The Reference PWR and BWR, Based On Previously-Derived Overall Scaling Factors

Reactor	Waste Disposal	Scaling Factor	Remaining Costs	Escalated Adders	Utility Only	Utility + Contractor
R E Ginna	39.434	0.518	34.174	14.385	68.986	83.726
Trojan	39.434	1.000	34.174	14.385	87.993	102.733
Ver. Yankee	44.100	0.648	54.464	10.230	93.271	116.243
WNP-2	44.100	1.000	54.464	10.230	108.794	131.766

Using the results from Table 2, a set of linear equations can be derived for the scaling of the immediate dismantlement costs for plants in the 1200 to 3500 MW_t range.

PWR: $\text{Cost} = 57.756 + 8.640 \times 10^{-3} [MW_t]$ Utility Only
$\text{Cost} = 72.495 + 8.640 \times 10^{-3} [MW_t]$ Utility + Contractor

BWR: $\text{Cost} = 78.948 + 8.986 \times 10^{-3} [MW_t]$ Utility Only
$\text{Cost} = 101.924 + 8.986 \times 10^{-3} [MW_t]$ Utility + Contractor

For the reference plants, the thermal power ratings used in developing these equations are PWR (3500 MW_t), BWR (3320 MW_t). The thermal power ratings of the other plants used in developing the overall scaling factors are given in the respective NUREG/CR reports.

I trust this information will be adequate and appropriate for your use in developing the final decommissioning rule. If you have any questions about any of the material presented in this letter, please call me.

Sincerely,

Dick

Richard I Smith, P.E.
Staff Engineer
Waste Systems and Transportation

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202 — U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-0130
Addendum 4

2 TITLE AND SUBTITLE
Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station: Technical Support for Decommissioning Matters Related to Preparation of the Final Decommissioning Rule

3 LEAVE BLANK

4 DATE REPORT COMPLETED
MONTH: May — YEAR: 1988

5 AUTHOR(S)
G. J. Konzek and R. I. Smith

6 DATE REPORT ISSUED
MONTH: July — YEAR: 1988

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Pacific Northwest Laboratory
Richland, Washington 99352

8 PROJECT/TASK/WORK UNIT NUMBER

9 FIN OR GRANT NUMBER
B2902

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a TYPE OF REPORT

b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)
Preparation of the final Decommissioning Rule by the Nuclear Regulatory Commission (NRC) staff has been assisted by Pacific Northwest Laboratory (PNL) staff familiar with decommissioning matters. These efforts have included updating previous cost estimates developed during the series of studies of conceptually decommissioning reference licensed nuclear facilities for inclusion in the Final Generic Environmental Impact Statement (FGEIS) on Decommissioning; documenting the cost updates; evaluating the cost and dose impacts of post-TMI-2 backfits on decommissioning; performing revised scaling factor analyses concerning reactor plants different in size from the reference PWR described in the earlier studies; determining the formula for adjusting current cost estimates to reflect escalation in labor, materials, and waste disposal costs; and completing a study of recent PWR steam generator replacements to determine realistic estimates for time, cost, and radiation doses associated with steam generator removal during decommissioning. This report presents supporting information in four of the aforementioned areas concerning decommissioning the reference PWR: 1) updating the previous cost estimates to January 1986 dollars, 2) assessing the cost and dose impacts of post-TMI-2 backfits, 3) developing scaling and escalation formulae, and 4) assessing the impact of recent steam generator replacements.

14 DOCUMENT ANALYSIS – a KEYWORDS/DESCRIPTORS
pressurized water reactor (PWR)
decommissionin
rules

b IDENTIFIERS/OPEN-ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

16 SECURITY CLASSIFICATION
(This page) Unclassified
(This report) Unclassified

17 NUMBER OF PAGES

18 PRICE

*U.S. GOVERNMENT PRINTING OFFICE:1988-202-292:80136

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

SPECIAL FOURTH-CLASS RATE
POSTAGE & FEES PAID
USNRC
PERMIT No. G-67

NUREG/CR-0130, ADD. 4

TECHNOLOGY, SAFETY AND COSTS OF DECOMMISSIONING A
REFERENCE PRESSURIZED WATER REACTOR POWER STATION

JULY 1988