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**Assessment of Foreign
Decommissioning Technology
with Potential Application to U.S.
Decommissioning Needs**

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**Pacific Northwest Laboratory
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ASSESSMENT OF FOREIGN DECOMMISSIONING
TECHNOLOGY WITH POTENTIAL APPLICATION
TO U.S. DECOMMISSIONING NEEDS

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SUMMARY

This study was conducted by the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE) to identify and technically assess foreign decommissioning technology developments that may represent significant improvements over decommissioning technology currently available or under development in the United States. Technology need areas for nuclear power reactor decommissioning operations were identified and prioritized using the results of past light water reactor (LWR) decommissioning studies to quantitatively evaluate the potential for reducing cost and decommissioning worker radiation dose for each major decommissioning activity.

Based on these identified needs, current foreign decommissioning technologies of potential interest to the U.S. were identified through personal contacts and the collection and review of an extensive body of decommissioning literature. These technologies were then assessed qualitatively to evaluate their uniqueness, potential for a significant reduction in decommissioning costs and/or worker radiation dose, development status, and other factors affecting their value and applicability to U.S. needs.

The results of the study show that the major cost elements in LWR decommissioning, and thus the activities with the greatest potential for cost savings through improved technology, are 1) management of radioactive decommissioning wastes, 2) the demolition of heavily reinforced nonradioactive structures, and 3) the detachment, removal and segmentation of fluid systems and components. Similarly, decommissioning worker radiation dose data show clearly that improved technology for the last category represents the major opportunity for worker dose reduction.

The technology assessment in this study indicates that there are no presently identified, fully developed foreign technologies directly applicable to major U.S. decommissioning needs that are not currently available in the U.S. There are, however, several promising technologies in the conceptual or R&D/demonstration stage that should be monitored and periodically reassessed as further development and demonstration studies are conducted. These include:

- Decontamination of metallic waste to levels permitting release as nonradioactive material using aggressive acid mixtures or decontamination agents incorporated in pastes and gels.
- Development of easily processed electrolytes, or purification processes for minimizing secondary decontamination waste volumes.
- New methods for the removal of contaminated concrete using microwave spalling or a milling cutter with accurate depth control.
- Decontamination of major reactor components and systems to reduce worker radiation dose using abrasive particles suspended in the decontamination solution, or a one-step process based on Ce(IV).

There also are several technologies that, although known or used in the U.S., are the subjects of extensive foreign R&D, demonstration or application programs. This foreign work represents a valuable source of information on costs, waste volumes, adaptations, etc., that could be very beneficial for U.S. application of these technologies. These include:

- Melting and melt-refining of metallic waste for volume reduction and decontamination, and to facilitate assay for release and recycle.
- Use of abrasive water jet cutting, mechanical cutting and controlled blasting to demolish heavily reinforced and prestressed concrete structures.
- Use of remote operations technology and improved cutting methods to reduce worker radiation dose associated with decontamination, detachment, removal and segmentation operations.

The majority of the foreign decommissioning work reviewed for this study was directed toward one or more of the major technology need areas identified for power reactor decommissioning, thus confirming the general validity of the need identification process and the specific areas selected. No specific decommissioning technology needs were identified that are not addressed to some degree either by the foreign technology development work or by existing U.S. technology or development programs. Based on the outcome of the ongoing R&D work, the technology need areas that potentially could benefit most from

additional R&D emphasis would include improved monitoring methods for metallic waste to assure compliance with release criteria, better survey/sampling methods for contaminated concrete surfaces to guide operations on the extent of concrete removal, and cost-effective treatment processes for secondary decontamination wastes.

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INTRODUCTION

BACKGROUND

At present, a total of seven commercial nuclear power reactors in the United States are shut down and are undergoing or awaiting decommissioning. In addition, a total of 14 major U.S. civilian experimental reactors are shut down. By the year 2010, an estimated 40 large nuclear power reactors in the U.S. will have reached the end of their current licensing periods and will be potential candidates for decommissioning. The Department of Energy (DOE) is assisting the U.S. commercial nuclear power industry in assuring the availability of demonstrated technology for safe and effective decommissioning of these retired nuclear power stations when it is needed. The DOE has, since 1981, sponsored a major decommissioning program to develop and demonstrate key elements of the decontamination and decommissioning of nuclear fuel cycle facilities.

The DOE program has demonstrated that technology is available to carry out all aspects of decommissioning of these facilities. However, decommissioning is still in the demonstration phase, and some aspects of power reactor decommissioning have room for major improvement. A number of other countries with significant nuclear electric power programs are similarly facing the near-term decommissioning of older nuclear power stations, and are developing and demonstrating their related technologies. It may be of significant value to the U.S. DOE decommissioning program to have access to improved decommissioning technologies under development in other countries.

OBJECTIVE AND SCOPE

The objective of this study is to identify and technically assess foreign decommissioning technology and developments that may represent significant improvements over decommissioning technology currently available or under development in the U.S. The scope of this study includes reviewing all potentially useful foreign decommissioning technology developments, with an overview evaluation of areas reflecting major U.S. decommissioning technology

needs for nuclear power stations (i.e., improved equipment and methods that could significantly reduce decommissioning costs and radiation dose to decommissioning workers).

The results of this study are expected to be useful to the DOE in planning future research and development work and in identifying potentially beneficial areas for international decommissioning technology exchange activities. Acquisition and application of selected foreign technologies should improve the cost-effectiveness and enhance the safety of U.S. decommissioning activities, for both the DOE and the U.S. nuclear industry.

APPROACH

As illustrated schematically in Figure 1, the study was started by first developing a list of major nuclear fuel cycle facility decommissioning activities. Next, general areas with incentives for improvements were identified based on expert opinion and decommissioning experience. These incentives, or need areas, were further focused and prioritized for power reactor decommissioning operations by using the results of past LWR decommissioning studies (Smith et al. 1978; Oak et al. 1980; Smith et al. 1985) to quantitatively evaluate the potential for reducing cost and decommissioning worker dose for each decommissioning activity.

Concurrently with the identification of U.S. needs, foreign decommissioning technologies of potential interest to the U.S. were identified through personal contacts and the collection and review of an extensive body of decommissioning literature. Initial selections were made based on apparent technical uniqueness and potential value as a source of otherwise unavailable decommissioning information. The foreign technologies in the major need areas identified for power reactor decommissioning were further assessed qualitatively to evaluate uniqueness, potential for cost and/or dose reduction, development status, and other factors affecting their value and applicability to U.S. needs.

FIGURE 1. Approach Used to Identify Needs and Select/Assess Technologies

IDENTIFICATION OF DECOMMISSIONING TECHNOLOGY NEEDS

Nuclear fuel cycle facilities can be safely decommissioned using existing technology. The technology areas with the highest priority for improvement in this study are those decommissioning activities that result in the highest costs and/or worker radiation dose. The specific areas where technology improvements would be most beneficial were qualitatively identified by:

- Developing a list of major decommissioning activities to serve as a framework for organizing and assessing the foreign technology information. This list was based on a review of recent decommissioning studies and projects.
- Holding two workshop sessions involving PNL staff with extensive experience and expertise in decommissioning technology and cost-benefit studies to evaluate technology needs for each of the decommissioning activity categories. This evaluation included consideration of the technology needs and development directions identified in recent OECD/NEA and IAEA reports (NEA 1986, IAEA 1985).
- Personal contacts with knowledgeable individuals representing DOE and commercial decommissioning activities to identify specific technology needs related to their interests and experience.
- Evaluating decommissioning technology needs as reflected by past and current technology development programs both in the U.S. and in other countries.

NUCLEAR FUEL CYCLE FACILITY DECOMMISSIONING ACTIVITIES

The results of the preliminary evaluation of decommissioning technology needs for generic nuclear fuel cycle facilities are summarized in Table 1. The table shows the major activities required for decommissioning, and the authors' collective qualitative judgment of where improved technology would be beneficial. The designations "low, moderate and high" are used to reflect the relative need for improved technology with respect to potential reductions in cost and/or worker dose.

TABLE 1. Major Decommissioning Activities for Nuclear Fuel Cycle Facilities and Estimated Technology Needs

<u>Decommissioning Activity</u>	<u>Technology Need</u>
1. Planning/Engineering/Management	
1.1 Pre-Decommissioning	Low
1.2 Decommissioning	Low
2. Preparatory Operations	
2.1 Physical Inventory of Property	Moderate
2.2 Radiological Characterization	
2.2.1 Site Survey/Sampling	Moderate
2.2.2 Facility Survey/Sampling	Moderate
2.2.3 Inventory Calculation	Low
2.3 Hazardous Materials Characterization	Low
2.4 Site Modifications	Low
2.5 Long-Lead Time Activities	
2.5.1 Obtain Licenses and Permits	Low
2.5.2 Procurements/Subcontracting	Low
2.6 Worker Training	Low
3. Direct Decommissioning Operations	
3.1 Decontamination	
3.1.1 Fluid Systems	Moderate
3.1.2 Hardware/Components	Moderate
3.1.3 Facility Surfaces	High
3.1.4 Soil	High
3.2 Hazardous Material Removal/Handling	Moderate
3.3 Disassembly/Removal	
3.3.1 Electrical Equipment/HVAC	Low
3.3.2 Fluid Systems/Components	
3.3.2.1 Detachment/Removal	High
3.3.2.2 Segmentation	High
3.3.3 Concrete	High

TABLE 1. (contd)

Decommissioning Activity	Technology Need
3.4 Interim Radiological Surveys	Moderate
3.5 Demolition of Nonradioactive Structures	
3.5.1 Conventional Structures	Low
3.5.2 Heavily Reinforced Structures	High
3.6 Equipment/Facility Maintenance	Low
4. Waste Management	
4.1 Radworker Practices/Contamination Control	Low
4.2 Treatment of Liquid Waste	High
4.3 Volume Reduction of Solid Waste	Moderate
4.4 Waste Categorization/Segregation	High
4.5 Packaging of Dry Solid Waste	Low
4.6 Waste Containers	Low
4.7 Waste Transport	Moderate
4.8 Waste Disposal	Moderate
4.9 Treatment for Recycle/Reuse	Moderate
5. Release Characterization	
5.1 Site Final Survey/Sampling	Low
5.2 Facility Final Survey/Sampling	Low
6. Site Restoration	Low

Based on the qualitative and preliminary evaluation presented in Table 1, generic nuclear fuel cycle facility decommissioning activities that could benefit the most from new or improved technology include:

- Radiological characterization of sites and facilities: improved equipment, techniques and/or automated methods to reduce time, costs and worker radiation dose and/or to improve characterization associated with initial, interim and release surveys of sites and facilities.
- Decontamination: new techniques and equipment for decontaminating systems and components and for decontaminating or removing facility surfaces and coatings; development of a true soil decontamination process and/or additional methods to stabilize contamination in place.
- Disassembly, removal and demolition: better technology to reduce cost and dose and improve contamination control for detaching, removing and segmenting metallic components, and for cutting concrete and heavily reinforced structures.
- Waste management: better methods for handling, treating and minimizing the volume of decommissioning and secondary radioactive and mixed wastes; improved assay equipment to facilitate classification and segregation of wastes and release of components and materials for recycle/reuse.

LIGHT WATER REACTOR DECOMMISSIONING ACTIVITIES

It should be noted that the incentive areas for improved technologies identified in Table 1 are generic and will differ in number and priority for specific types of fuel cycle facilities and decommissioning operations. Since the primary focus of this study was on nuclear power reactors, the second phase of the need identification work was to quantitatively identify and prioritize the major technology needs for LWR decommissioning operations. Cost and decommissioning worker radiation dose information for each of the major decommissioning activity areas listed in Table 1 was extracted from the comprehensive

studies on the technology, safety and costs of decommissioning commercial nuclear power plants that were conducted for the U.S. Nuclear Regulatory Commission by PNL (Smith et al. 1978; Oak et al. 1980) and from a PNL study performed for the Electric Power Research Institute to develop estimates for several alternatives with potential for increasing decommissioning costs (Smith et al. 1985).

The results of this quantitative evaluation are summarized in Table 2, using the same decommissioning activities listed in Table 1. The cost and worker radiation dose data represent an average of the estimates for the immediate dismantlement of reference BWR and PWR reactors, with detailed values given in Appendix A. The values shown for each decommissioning activity are the percentage of the estimated total cost and worker radiation dose for the entire decommissioning operation, including the demolition of uncontaminated structures and site restoration.

The data presented in Table 2 indicate that the major cost elements in power reactor decommissioning, and thus the greatest potential for cost savings through improved technology, are 1) management of the radioactive wastes from decommissioning, 2) the demolition of heavily reinforced nonradioactive structures, and 3) the detachment, removal and segmentation of fluid systems and components. The decommissioning worker radiation dose estimates show clearly that improved technology for the detachment, removal and segmentation of fluid systems and components represents the major opportunity for dose reduction.

Waste management costs represent approximately 35% of the estimated total decommissioning cost when transportation and cask and container costs are added. The packaging of waste as it is generated by the removal and segmenting operations also is part of waste management, but these costs are included in the disassembly/removal category because they are difficult to identify separately. Table 3 contains detailed estimate data on radioactive waste types, volumes and waste management costs, to permit identification of the specific waste sources and waste management activities with the greatest potential for cost savings. The data are extracted from Oak et al. 1980; Smith et al. 1978; Smith et al. 1985) and, as in Table 2, represent average

TABLE 2. Estimated Cost and Dose Percentages for Commercial Nuclear Power Reactor Decommissioning Activities^(a)

Decommissioning Activity	Cost %	Dose %
1. Planning/Engineering/Management		
1.1 Pre-Decommissioning	7	0
1.2 Decommissioning	8	0
2. Preparatory Operations		
2.1 Physical Inventory of Property	(b)	(c)
2.2 Radiological Characterization		
2.2.1 Site Survey/Sampling	(c)	(c)
2.2.2 Facility Survey/Sampling	<1	<1
2.2.3 Inventory Calculation	(b)	0
2.3 Hazardous Materials Characterization	(b)	(c)
2.4 Site Modifications ^(c)	<1	1
2.5 Long-Lead Time Activities		
2.5.1 Obtain Licenses and Permits	<1	0
2.5.2 Procurements/Subcontracting	(b)	0
2.6 Worker Training	(c)	(c)
3. Direct Decommissioning Operations		
3.1 Decontamination		
3.1.1 Fluid Systems	<1	2
3.1.2 Hardware/Components		
3.1.3 Facility Surfaces		
3.1.4 Soil	(c)	(c)
3.2 Hazardous Materials Removal/Handling	(c)	(c)
3.3 Disassembly/Removal		
3.3.1 Electrical Equipment/HVAC	<1	1
3.3.2 Fluid Systems/Components		
3.3.2.1 Detachment/Removal	8	69
3.3.2.2 Segmentation		
3.3.3 Concrete	2	4
3.4 Interim Radiological Surveys	<1 ^(e)	<1
3.5 Demolition of Nonradioactive Structures ^(f)		
3.5.1 Conventional Structures	2	0
3.5.2 Heavily Reinforced Structures	15	0
3.6 Equipment/Facility Maintenance	<1	1

TABLE 2. (contd)

Decommissioning Activity	Cost %	Dose %
4. Waste Management		
4.1 Radworker Practices/Contamination Control	(c)	(c)
4.2 Treatment of Liquid Waste	<1	<1
4.3 Volume Reduction of Solid Waste	(c)	(c)
4.4 Waste Categorization/Segregation	(c)	(c)
4.5 Packaging of Dry Solid Waste	<1	2
4.6 Waste Containers	8	(c)
4.7 Waste Transport	6	7
4.8 Waste Disposal	21	(c)
4.9 Treatment for Recycle/Reuse	(c)	(c)
5. Release Characterization		
5.1 Site Final Survey/Sampling	<1	<1
5.2 Facility Survey/Sampling	<1	<1
6. Site Restoration	<1	0
7. Miscellaneous	22(g)	12(h)
TOTALS	100	100
	\$95M	1500 (man-rem)

(a) Taken from Oak et al. 1980; Smith et al. 1978; and Smith et al. 1985.

(b) Cost included as part of activity 1.1.

(c) Not estimated directly or treated analytically in the reference studies.

(d) Includes activities such as installing new HEPA filters, enlarging the suppression chamber access (BWR), and installing a temporary radwaste system.

(e) Although actual interim radiological survey/sampling costs are low, delays in dependent activities may impact operational costs.

(f) Includes disposal of nonradioactive waste on site or in local landfills.

(g) Includes specialty contractors (<1%), nuclear insurance (2%), special tools and equipment (2%), energy (7%), and miscellaneous supplies (4%).

(h) Includes an allowance of up to 1 rem per year for selected management and support staff whose radiation doses are not specifically estimated. Also includes miscellaneous post-defueling activities preparatory to decommissioning such as the replacement of the reactor vessel head in preparation for chemical decontamination of the reactor coolant system.

TABLE 3. Estimates of Radioactive Waste Types, Volumes, and Management/Disposal Costs

Waste Type	% of Total Waste Volume ^(a)	Percent of Total D&D Cost						TOTALS ^(b)
		Transportation			Burial Ground Costs			
		Container	Cask Lease	Freight	Handling	Burial	Surcharge	
Activated Concrete	2	-- ^(c)	--	--	--	--	--	--
Activated Metals	2	2	--	--	--	--	3	6
Contaminated Concrete	33	2	--	2	--	6	--	10
Contaminated Metals	57	3	--	2	--	10	--	15
Dry Radwaste ^(d)	3	--	--	--	--	--	--	1
Wet Radwaste ^(e)	<u>3</u>	<u>1</u>	<u>--</u>	<u>--</u>	<u>--</u>	<u>--</u>	<u>--</u>	<u>2</u>
TOTALS ^(b)	100	8	1	5	1	17	3	35
	(18,000 m ³)							(\$33M)

(a) Volume percent of radioactive waste as packaged.

(b) Values less than 1% (after rounding) are not shown; totals are rounded up to the nearest whole number.

(c) A dash indicates values less than 1%.

(d) Dry solid radioactive waste includes discarded contaminated materials used in the decommissioning operations such as plastic sheeting, rags, and anti-contamination protective clothing. The volumes reflect a five-fold mechanical compaction in standard 55-gallon steel drums.

(e) Wet solid radioactive waste results from the processing of chemical decontamination solutions and contaminated water volumes. These wastes include concentrator bottoms, filter sludges, and spent demineralizer resins. The wastes are solidified and encapsulated in steel cask liners for disposal.

values of estimates for the immediate dismantlement of the reference BWRs and PWRs. The percentages shown are the percentages of the estimated total cost for the entire LWR decommissioning operation, including the demolition of uncontaminated structures and site restoration.

The estimates in Table 3 show that the majority of the waste management costs from LWR decommissioning are associated with disposal of the contaminated metals and concrete. Although unit charges for containers, transportation and burial are externally controlled, major cost savings could be realized by substantially reducing the disposal volumes of the contaminated metals and concrete.

Combining the waste management information with the other cost and dose information from Table 2 leads to the following prioritized list of technology needs with the greatest potential for significant reductions in cost and/or radiation dose during the decommissioning of commercial LWRs:

1. New or improved technology to minimize the volume of contaminated metals requiring packaging, handling and disposal as radioactive waste; improved methods to treat or otherwise minimize secondary decontamination wastes; and better assay technology to facilitate the release of material for recycle and reuse.
2. New or improved technology to further reduce the volume of contaminated concrete requiring packaging, handling and disposal as radioactive waste.
3. New or improved technology for demolishing heavily reinforced concrete structures.
4. Adaptation and application of remote operations (robotics, automation) and system decontamination technology to reduce the high worker radiation doses associated with the detachment, removal, and segmentation of major reactor systems and components.

ASSESSMENT OF FOREIGN DECOMMISSIONING TECHNOLOGY

The decommissioning activity list and associated generic technology needs developed in the preceding section (Table 1) were used to identify potentially applicable foreign decommissioning technology. (The screened and reduced list of potentially applicable foreign technologies is given in Appendix B.) Specific technologies that represent the prioritized major need areas identified for decommissioning of light water power reactors were selected from this compilation and further assessed to evaluate their uniqueness, potential for cost and exposure reduction, development status, and other factors related to their value and applicability to the identified U.S. needs. The following sections describe the technology identification and assessment methodology and present the results of the technology assessments.

TECHNOLOGY IDENTIFICATION

Identification of foreign decommissioning technology of potential interest to the U.S. was accomplished through personal contact with foreign technical experts; by reviewing recent IAEA and OECD/NEA reports, bulletins and research abstracts; and by reviewing foreign trip reports, industry briefs, trade journal articles, D&D-related bibliographies, and several hundred foreign D&D literature references (including information from the IAEA data base) obtained through the Remedial Action Program Information Center.

The preliminary selection of foreign decommissioning technologies identified in this report was based on apparent technical uniqueness and/or possible value as sources of otherwise unavailable decommissioning information. In some cases, the technology may have been conceived or developed originally in the U.S., but subsequent foreign R&D or application studies have resulted in technical improvements, specialized adaptations, or application experience that provide data on costs, waste volumes, or other information of potential benefit to the U.S. in applying this technology.

The identified foreign technologies are organized and listed in Appendix B under the general headings for the decommissioning activities outline presented in Table 1. Technologies related to remote/automated operations are grouped with the appropriate decommissioning activity. It should be noted that there is a substantial amount of potentially useful information available from foreign sources. The 68 items appearing in Appendix B represent just a small part of the information base that was reviewed. Approximately 50 of these technologies appeared relevant to the power reactor technology needs and were selected for further assessment.

ASSESSMENT METHODOLOGY

The decommissioning technologies identified through the review of foreign R&D activities were assessed technically with respect to available U.S. technology and applicability to U.S. needs. The specific evaluation factors included:

- Potential for a substantial reduction in decommissioning costs compared with currently available U.S. technology
- Potential for a substantial reduction in decommissioning worker radiation dose compared with currently available U.S. technology
- Availability or development status of comparable U.S. technology
- Development status of the foreign technology; i.e., concept, R&D program or applied process.

Other factors considered in the assessment included technical feasibility and application experience with similar processes. Accessibility of the developed/demonstrated technology, and an estimate of the effort required to implement the approach also would have to be considered before actively pursuing a given technology.

The assessment was conducted by PNL staff with expertise in the identified technologies, supplemented as required by contacts with experts in industry and at other DOE facilities.

RESULTS OF THE TECHNOLOGY ASSESSMENT

Application of the previously described assessment methodology to the most recent foreign decommissioning technology did not disclose any unique, developed foreign technologies that are ready for direct application to U.S. needs. There are, however, several potentially applicable technologies in the conceptual or R&D/demonstration stage that should be monitored and periodically reassessed as further development and demonstration studies are conducted. In addition, there are some technologies that, although known or used in the U.S., are the subjects of extensive foreign development or application efforts that could result in technology improvements. This latter work category represents a potentially valuable source of foreign information on costs, waste volumes, specialized adaptations, etc., that could be very helpful for U.S. applications of these base technologies.

Presented below are the results of the technology assessment for each major need category. For each potentially applicable foreign technology, the organization and country are given, comments regarding the technology are presented, and recommendations on possible follow-up activities are provided. Foreign technologies that do not appear applicable and thus do not merit information exchange actions are not included here, but are retained in the list generated by the initial technology screening (Appendix B).

1. Minimization of Contaminated Metal Volumes

The objective for this category is to reduce decommissioning costs through new or improved technology to minimize the volume of contaminated metals requiring packaging, handling, and disposal as radioactive waste.

Potentially Applicable Technologies

- Technology. Use of hydrochloric acid and mixtures of hydrofluoric and nitric acids enhanced by ultrasonic agitation to decontaminate metallic decommissioning wastes to free-release levels.

- Organization: Ente Nazionale per l'Energia Elettrica/Italy
 - Comments: This is not a unique approach, but represents a current CEC research effort that will generate valuable data on effectiveness, costs and waste volumes for this type of decontamination process as adapted for decommissioning operations. Studies to date indicate good results for accessible surfaces, but difficulties in decontaminating crevice regions. Secondary waste volumes also can be relatively high.
 - Recommendation: Monitor the progress and results of the ongoing research program.
- Technology. Use of strippable pastes containing acids and other decontamination agents to remove and contain surface contamination. This technique was developed to avoid aerosol formation and the generation of large volumes of decontamination and rinse solutions.
 - Organizations: NUKEM; Max Morant Chemische Fabrik/FRG.
 - Comments: Decontamination pastes based on metal cleaning formulations have been used in the FRG for many years. Studies to develop improved, strippable formulations were initiated by NUKEM, and have been continued by the CEC through research currently in progress at Max Morant Chemische Fabrik. Pastes can be very effective as a single stage decontamination process.
 - Recommendation: Monitor the progress of the ongoing research program for process effectiveness (ability to decontaminate to free-release levels) and cost/benefit information.
 - Technology. Incorporation of decontamination agents in gel-based media to minimize secondary waste volumes.
 - Organizations: CEA, CEN Saclay/France

- Comments: Gel-based media have been under development in France for several years. High decontamination factors were obtained in recent tests with sprayed gels containing hydrofluoric and nitric acids; however, aerosol generation is a problem.
- Recommendation: Periodically monitor progress in this technology area for additional developments and application data.
- Technology. Decontamination of stainless steel by the vapor phase transport separation of the metallic constituents using iodine as the carrier gas.
 - Organization: CEA, DMG Grenoble/France.
 - Comments: Thermodynamic modeling of this novel approach indicates that cobalt can be readily separated from iron and nickel, although successive treatments are required. However, it may be very difficult to separate cobalt from chromium.
 - Recommendation: Monitor the progress of the modeling and subsequent experimental work to evaluate process feasibility and cost.
- Technology. Electrolyte development and processing
 - Sub-Technology: Development of an easy-to-process electrolyte for decontamination by electropolishing.
 - Organization: Kraftanlagen Heidelberg/FRG
 - Sub-Technology: Purification of decontamination electrolytes by diffusion dialysis; purification of decontamination electrolytes by electrodeposition.
 - Organization: Shinko-Pfautler Co. Ltd./Japan
 - Sub-Technology: Purification of decontamination electrolytes using anionic exchange resins; purification of decontamination electrolytes by diffusion osmosis and diaphragm electrolysis; enhancement of electrolyte purification processes by phosphorous acid reduction.

- Organization: Mitsubishi Heavy Industries Ltd./Japan
- Comments: Electropolishing using phosphoric acid electrolytes is a very effective technique for decontaminating uncoated metallic waste to levels permitting release as nonradioactive material. However, the contaminated electrolyte is not readily amenable to treatment to produce a stable solid or to reduce disposal volumes. Moreover, chromium introduced from the electropolishing of stainless steel results in a mixed waste that may require special disposal considerations. Development of alternative electrolytes, or an effective and economical process for purifying decontamination electrolytes, including the removal of chromium, is highly desirable if electropolishing is to be used extensively to reduce contaminated metal volumes. The listed FRG and Japanese technologies represent new research programs or concepts addressing this need. The FRG work, in particular, has shown encouraging results using formic or oxalic acid with potassium bromide added (to increase electrical conductivity) as a substitute for the conventional phosphoric-acid based decontamination electrolytes. Organic acids can be purified and/or destroyed using simple processes such as filtration and thermal decomposition to produce a minimum-volume waste form that is readily incorporated in cement.
- Recommendation: Monitor progress in this technology area. It may be desirable to initiate U.S. work, particularly to resolve the chromium/hazardous waste issue, if the foreign efforts are not successful.

Supporting Technologies and Information

- Technology. Melting and melt-refining of metallic waste for volume reduction and decontamination, and to facilitate assay for release and recycle.

- Organizations: British Steel Corporation/United Kingdom; Kernforschungsanlage Juelich GmbH; Nuclear Ingenieur-Service GmbH; Siempelkamp Giesserei GmbH and Company/FRG; and Seridnault Ingenierie/France
- Comments: This work is being conducted as a major cooperative CEC research program that will establish the feasibility and cost/benefits of this approach for minimizing contaminated metal volumes. Large quantities of contaminated metal have been melted in special facilities to demonstrate volume reduction and the processing of material for recycle and reuse. Recent studies also confirm the possibility of removing cesium contamination through incorporation in an acidic slag. Similar efforts to remove cobalt have not been successful.
- Recommendation: Periodically monitor the progress of the research and demonstration activities, particularly as U.S. residual radioactivity criteria are established for recycled materials.

2. Minimization of Contaminated Concrete Volumes

The objective for this category is to reduce decommissioning costs through new or improved technology to minimize the volume of contaminated concrete requiring packaging, handling and disposal as radioactive waste.

Potentially Applicable Technologies

- Technology. Use of microwave heating to vaporize occluded water and spall concrete surface layers from contaminated structures and activated biological shields.
 - Organizations: Japan Atomic Energy Research Institute/Japan; Building Research Establishment/United Kingdom
 - Comments: Microwave spalling may prove to be an effective alternative technique for removing contaminated or activated surface concrete. Up to 3 cm of concrete can be removed per pass, and the equipment can be used for walls and ceilings as

well as floors. The technology will be field-tested and compared with conventional concrete surface removal equipment as part of the JPDR dismantlement operations in 1989-90.

- Recommendation: Monitor the progress of the ongoing research and demonstration programs with particular emphasis on the ability to control the removal depth to minimize disposal volumes.
- Technology. Removal of contaminated concrete surface layers using a hydraulically operated milling cutter with accurate control of the cutting depth.
 - Organization: Sato Kogyo Co. Ltd./Japan
 - Comments: The major advantage of this type of concrete decontamination technology is that the single pass cutting depth can be adjusted to remove only the required amount of material, thus minimizing the waste volumes. The equipment has been demonstrated in field operations, and can be scaled for use on large surface areas or in constricted spaces.
 - Recommendation: Obtain additional operating data to permit detailed cost/benefit comparisons with available U.S. concrete decontamination techniques.

3. Demolition of Reinforced Concrete Structures

The objective for this category is to reduce decommissioning costs through new or improved technology for demolishing heavily reinforced concrete structures.

Supporting Technologies and Information

- Technology. Use of explosive demolition techniques to demolish heavily reinforced and prestressed concrete structures.
 - Organizations: Taylor Woodrow Construction Ltd./United Kingdom; Battelle-Institut e.V.; Noell (G.G.) GmbH; Kernforschungszentrum Karlsruhe/FRG

- Comments: The CEC is conducting an integrated R&D program to provide a scientific basis for the use of explosive demolition techniques for heavily reinforced and prestressed concrete structures. This includes the controlled removal of multiple layers to maintain contamination confinement, the use of shaped charges to drill charge holes, immobilization of dust, and consideration of safety, environmental impact and licensing requirements. Although the base technology is available in the U.S., the detailed information developed in this foreign program may facilitate greater use of cost-effective explosive demolition techniques, particularly where there are application constraints such as an adjacent operating nuclear station.
- Recommendation: Maintain awareness of the information developed by the ongoing research program.
- Technology. Evaluation and demonstration of mechanical, chemical, and thermal methods for the controlled removal of reinforced concrete.
 - Organizations: Taylor Woodrow Construction Ltd.; UK Central Electricity Generating Board/United Kingdom; Japan Atomic Energy Research Institute/Japan.
 - Comments: The CEC has sponsored the testing and/or evaluation of a variety of concrete demolition techniques in addition to controlled blasting. These include large-diameter, diamond-tipped abrasive saws; stitch drill and burst methods; expanding slurries; aggressive acids; and oxygen lance/power-assisted flame cutting. The JAERI also is developing and evaluating alternative mechanical and thermal demolition techniques including sawing, abrasive water-jet cutting, and thermal lance methods. Although these are not unique techniques, their adaptation and testing, particularly in conjunction with the Japan Power Demonstration Reactor (JPDR) dismantlement demonstration,

will provide valuable technical and cost/benefit information on the selective removal of activated concrete and the demolition of heavily reinforced structures.

- Recommendation: Maintain awareness of the information developed by the ongoing research programs.

4. Reduction of Worker Radiation Dose

The objective for this category is to reduce the high worker radiation dose associated with the detachment, removal and segmentation of major reactor systems and components.

Potentially Applicable Technologies

- Technology. Use of suspended abrasive particles to enhance or replace the chemical decontamination of reactor primary coolant systems and other contaminated piping.
 - Organization: Japan Atomic Energy Research Institute/Japan
 - Comments: Chemical cleaning of reactor systems is an established decontamination technology capable of significantly reducing decommissioning worker dose. The alternative use of abrasives could reduce the volume of secondary waste containing chelating agents and chromium, but this advantage could be negated if large quantities of contaminated abrasive waste are generated.
 - Recommendation: Monitor progress as this technology is further developed and demonstrated.
- Technology. Development of a one-step decontamination process for primary coolant system piping based on the use of Ce(IV) in sulfuric acid to dissolve chromium-rich corrosion films.
 - Organization: Japan Atomic Energy Research Institute/Japan
 - Comments: Ce(IV) decontamination technology is under development in the U.S. for specialized applications. The JAERI studies should establish the feasibility and possible benefits

of this technique for larger-scale decontamination applications, particularly if secondary waste concerns are addressed.

- Recommendation: Monitor progress as this technology is developed and demonstrated.
- Technology. Development of a combined gouging and gas-cutting torch for the underwater dismantling of reactor pressure vessels.
 - Organization: Government Industrial Research Institute/Japan.
 - Use of air arc gouging followed by gas cutting to section stainless steel-clad pressure vessel steel was originally developed and demonstrated in the U.S. A single light-weight torch that combines both functions and can cut thick sections of clad pressure vessel steel underwater has been developed and tested by the Government Industrial Research Institute and will be demonstrated by Babcock Hitachi KK in late 1987 using an underwater mockup.
 - Recommendation: Review the results of the demonstration work including the amenability to remote operation.
- Technology. Development of a rotary disc knife for the remote cutting of large-diameter pipe from the inside.
 - Organization: Kawasaki Heavy Industries Ltd./Japan
 - Comments: This technique could reduce dose for selected pipe sectioning operations where access or other constraints prevent the use of conventional external methods. The technology will be tested as part of the JPDR decommissioning demonstration.
 - Recommendation: Evaluate the technology based on the results of the JPDR tests, and compare with test results for similar U.S. techniques.
- Technology. Use of an electrochemical dissolution technique employing a sodium nitrate electrolyte to segment metallic components.

- Organization: Kernkraftwerk RWE-Bayernwerk GmbH/FRG
- Comments: This technology represents a novel application of standard electrochemical machining techniques. Possible worker radiation dose-reduction advantages could be negated by the large volumes of metal hydroxide sludge that may be produced by the process.
- Recommendation: Monitor progress as the technology is further developed and demonstrated.

Supporting Technologies and Information

- Technology. Development and use of a variety of remotely controlled in-situ electropolishing fixtures to decontaminate reactor primary coolant system piping and other major plant components.
 - Organization: Kraftwerk Union AG/FRG
 - Comments: In-situ electropolishing is a U.S. technology that has been adapted by KWU for remote operations and used extensively for a number of dose-reduction applications.
 - Recommendation: Maintain awareness of the technology represented by these development/application activities.
- Technology. Evaluation of the use of lasers to cut metal components and concrete, and development of a prototype system for the remote laser cutting of radioactive structures.
 - Organizations: Fiat TTG S.p.A./Italy; CEA, CEN Saclay/France; Government Industrial Research Institute/Japan
 - Comments: These development and demonstration programs can provide valuable additional information on the application of industrial CO₂ laser technology to the remote cutting of metal and concrete, including robotic adaptations, cost, and control of contamination and particulate emissions.
 - Recommendation: Review the results of these studies for worker radiation dose reduction and process application information.

- Technology. Remote cutting of pipe using linear shaped charges
 - Organization: Battelle-Institut e.V.; Kernforschungszentrum Karlsruhe GmbH/FRG
 - Comments: The unique aspect of this work is the development of detailed information addressing safety, environmental impact and licensing considerations that could facilitate the wider use of this technology for worker radiation dose-reduction purposes.
 - Recommendation: Maintain awareness of the information developed by the ongoing research work.
- Technology. Development/demonstration/application of other remote operations technology
 - Sub-Technology: Development and demonstration of advanced robotic remote handling systems for decommissioning applications including underwater arc saw and plasma arc torch cutting systems.
 - Organization: Japan Atomic Energy Research Institute/Japan
 - Sub-Technology: Development of a remote-controlled sawing/coring robot for cutting activated concrete.
 - Organization: Shimizu Construction Co. Ltd./Japan
 - Sub-Technology: Development of a prototype system for remote underwater plasma arc cutting.
 - Organization: CEA, CEN Cadarache/France
 - Sub-Technology: Adaptation of remotely-operated industrial equipment (hydraulic excavator, generator, general purpose tracked vehicle, hydraulic telescopic boom) and development of advanced sensor feedback systems for decommissioning applications.
 - Organization: Central Electricity Generating Board/United Kingdom

- Comments: Use of remote operations technology is essential to reduce worker radiation dose associated with the dismantlement of major reactor systems and components. This technology is under active development in the U.S. However, the extensive foreign programs in this area, while facility-specific in some cases, offer a technology and application experience base that could be valuable for future U.S. dose-reduction efforts.
- Recommendation: Maintain awareness of the information developed through these research and demonstration programs.

DISCUSSION

As noted in the previous section, no developed foreign technologies directly applicable to major U.S. decommissioning needs for LWRs were identified. One reason is that demonstrated technologies that are useful for decontamination/maintenance/repair activities at operating plants, such as the low oxidation state metal ion (LOMI) chemical decontamination process developed in the United Kingdom, already have been made available to U.S. utilities by foreign firms and their U.S. subsidiaries, or via licensing agreements with U.S. service organizations.

Several potentially applicable decommissioning technologies were identified that still are in the conceptual or R&D/demonstration stage. These should be monitored and periodically reassessed as further development and demonstration studies are conducted. As in the past, some of these technologies with applicability to power reactor station operational needs are expected to be transferred to the U.S. via the service firms serving nuclear utilities. Other technologies more relevant to dismantlement operations may similarly be transferred to support the major refurbishment activities associated with life extension efforts for nuclear power plants. In some cases, the developed technologies will be generally applicable to U.S. needs, but additional U.S. work may be required to adapt the technology to meet unique U.S. requirements, such as the removal of chromium from decontamination electrolytes.

The following discussion presents the evaluation of each reactor decommissioning area with an identified incentive for improvement, and an overview evaluation of corresponding available, identified and needed technology.

1. Minimization of Contaminated Metal Volumes

The significant costs associated with the management of contaminated metal waste can be reduced by 1) minimizing the amount of metal classified as contaminated waste by segregating noncontaminated material followed by decontaminating amenable wastes to radioactivity levels that are low enough to permit unrestricted use, and 2) reducing container requirements and final waste volumes through size reduction, compaction, melting and careful packaging of the waste. The technologies and their status are discussed below.

- Monitoring of metallic waste for compliance with release criteria for initial segregation or after decontamination:

Some specialized foreign technology adaptations were identified, but no new technology was identified that is not available or under development in the U.S. Major advances in field monitoring equipment and methods could have significant cost benefits for decommissioning, since the inability to completely and inexpensively monitor items can substantially increase radioactive waste disposal volumes.

- Decontamination to release levels:

A few potentially interesting foreign techniques (e.g., using aggressive acids, decontamination pastes and gels, vapor phase transport separation) were identified for further assessment. As noted earlier, the potentially most important technical contribution that was found for waste minimization could be the development of easily processed electrolytes and/or effective purification processes for the secondary wastes from demonstrated decontamination techniques such as electropolishing.

- Size reduction, compaction, melting and packaging:

Supercompaction is a developed and applied commercial technology, and is expected to play a major role in minimizing metal waste disposal volumes. Although initially developed and demonstrated in Europe, the technology in improved form is available from U.S. firms. Melt-refining for controlled reuse of metals and melting for volume reduction of metals also have been investigated in the U.S. Size reduction and packaging technologies are domestically available.

2. Minimization of Contaminated Concrete Volumes

The high costs associated with the management of contaminated concrete waste can be reduced by minimizing the amount of concrete removed to achieve

the specified residual radiation levels. Depending on the established criteria, this also could include segregation of some of the removed nonradioactive concrete for on-site disposal at reduced cost. The technologies and their status are discussed below.

- Survey/sampling to determine the required removal depth and to monitor progress in meeting the established criteria:

No unique foreign technology was identified. Additional work in this area could be beneficial, particularly the development of new or improved methods to monitor radioactivity levels during concrete removal activities to permit closer control of the surface removal operations.

- Concrete removal:

Two new methods (microwave heating and a milling cutter) were identified for removing contaminated concrete surface layers. These may, when fully developed and demonstrated, have cost or control advantages over current techniques that could facilitate selective removal of the contaminated concrete. Dust control is a major problem that must be included in any evaluation of concrete removal methods.

3. Demolition of Reinforced Concrete Structures

No unique or improved foreign technology for demolishing heavily reinforced concrete structures was identified. However, an extensive foreign information base on abrasive water jet cutting, mechanical cutting and explosive demolition is being developed that could be a valuable resource for the U.S. use of similar technologies.

4. Reduction of Worker Radiation Dose

The high collective worker radiation dose associated with the detachment, removal and segmentation of major reactor systems and components can be reduced by decontaminating these systems and components to reduce radiation levels, by the development of improved cutting techniques, and through the application of remote operations technology. The technologies and their status are discussed below.

- Decontamination of major reactor systems and components:

Chemical decontamination of major reactor systems and components to reduce radiation dose associated with special maintenance operations is in widespread use at U.S. nuclear power stations, with some of the important technology and services coming from or provided by foreign organizations. Some modifications are expected to be made for decommissioning applications, since cost, effectiveness, and waste management considerations may dictate the selection of different processes or application procedures than those used for operating plants where outage time and corrosion are major concerns. The two system decontamination approaches [use of abrasive particles and Ce(IV)] identified for further assessment may have advantages for decommissioning-related applications, particularly since damage due to excessive corrosion or the use of an abrasive would not be of concern.

- Improved cutting techniques:

Three techniques (combined gouging/gas cutting, rotary disc knife cutting and electrochemical segmenting) were identified that should be evaluated after further development and demonstration for possible advantages over currently available technology. Valuable information also is expected to be developed on the laser cutting of metals and concrete, and the remote cutting of pipe using shaped charges.

- Remote operations technology:

No unique technology was identified, but an extensive and valuable information base reflecting both R&D and large-scale demonstrations is being developed for remote underwater cutting and segmenting operations, the remote sawing and coring of concrete, the remote decontamination of system components, and the adaptation of remotely operated industrial equipment for decommissioning applications.

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions, observations and recommendations derived from this review of foreign decommissioning technology are:

1. There are no presently identified, fully developed foreign technologies directly applicable to major U.S. decommissioning needs that are not currently available in the U.S.
2. There are a number of potentially applicable technologies that should be monitored and periodically reassessed as further development and demonstration studies are conducted. Based on the results of this ongoing monitoring program, the useful technologies should be accessed using the channels and procedures outlined in Appendix C.
3. No specific decommissioning technology needs were identified that are not addressed to some degree either by the foreign technology development work or by existing U.S. technology or development programs.
4. There is a substantial body of potentially useful additional information available from foreign sources. The ~70 foreign decommissioning technologies selected for evaluation in this study represent just a small part of the information base that was reviewed.
5. The majority of the foreign work reviewed for this study appeared relevant to the major technology need areas identified for power reactor decommissioning, thus confirming the general validity of the need identification process and the specific areas selected.

Based on the outcome of the current domestic and foreign R&D work, the technology need areas that might warrant future R&D emphasis would include improved monitoring methods for metallic wastes to assure compliance with release criteria, better survey/sampling methods for contaminated concrete surfaces to guide removal operations, and cost-effective treatment processes for secondary decontamination wastes. In addition, the progress of the ongoing international decommissioning technology development and demonstration programs should continue to be monitored and technically assessed.

REFERENCES

- International Atomic Energy Agency (IAEA). August 1985. Decontamination of Nuclear Facilities to Permit Operation, Inspection, Maintenance, Modification or Plan Decommissioning, International Atomic Energy Agency, Vienna.
- Nuclear Energy Agency (NEA). November 1986. Decommissioning of Nuclear Facilities: Feasibility, Needs and Costs, OECD Nuclear Energy Agency, Paris.
- Dak, H. D., G. M. Holter, W. E. Kennedy, Jr., and G. J. Konzek. June 1980. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory.
- Smith, R. I., G. J. Konzek and W. E. Kennedy, Jr. June 1978. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-D130, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory.
- Smith, R. I., G. J. Konzek, E. S. Murphy, and E. K. Elder. May 1985. Estimated Costs for Decommissioning Nuclear Power Facilities. EPRI NP-4012, Final Report. Prepared by Pacific Northwest Laboratory for the Electric Power Research Institute.

GLOSSARY

Abbreviations, acronyms, terms, and definitions used in this study and directly related to nuclear fuel cycle facilities decommissioning work and associated technology are defined in this section. The section is divided into two parts. The first contains abbreviations and acronyms and the second contains terms and definitions (including those used in a special sense for this study). Common terms covered adequately in standard dictionaries and many terms common to the nuclear industry are not included.

ABBREVIATIONS AND ACRONYMS

BWR	Boiling Water Reactor
CEC	Commission of European Communities
D&D	Decontamination and Decommissioning
DOE	U.S. Department of Energy
FRG	Federal Republic of Germany (West Germany)
HEPA	High Efficiency Particulate Air filter
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
JAERI	Japan Atomic Energy Research Institute
JPDR	Japan Power Demonstration Reactor
LOMI	Low Oxidation State Metal Ion
LWR	Light Water Reactor
NRC	U.S. Nuclear Regulatory Commission
OECD/NEA	Organization for Economic Cooperation and Development/Nuclear Energy Agency
PNL	Pacific Northwest Laboratory
PWR	Pressurized Water Reactor
R&D	Research and Development
RPV	Reactor Pressure Vessel

GLOSSARY DEFINITIONS

Activation	The process of inducing radioactivity by irradiation.
Anticontamination (Anti-C) Clothing	Special clothing worn in a radioactively contaminated area to prevent personal contamination.
Biological Shield	Massive and heavily reinforced concrete structure within a PWR facility used to support the reactor vessel and provide missile and radiation protection.
Cask (or Flask)	A massive transport container providing shielding for radioactive materials and holding one or more liners.
Chemical Decontamination	Decontamination accomplished by the use of chemical solutions to remove surface films containing radioactive materials.
Containment	The retention of radioactive material in such a way that it is effectively prevented from becoming dispersed in excessive quantities.
Contamination, Radioactive	A radioactive substance in a material or a place where it is undesirable.
Decommission	To permanently remove (as a facility) from service.
Decontamination	Removal or reduction of radioactive contamination.
Decontamination Factor	The ratio of initial content of contaminating radioactive material to the final content as a consequence of a decontamination process. (The term may refer to a specified radionuclide or to gross radioactivity.)
Dismantling:	The removal from a site of all fuel assemblies, radioactive fluids/waste, and other materials having activities above accepted unrestricted activity levels. The facility owner may then have unrestricted use of the site with no requirements for a license. If the owner so desires, the remainder of the facility may be dismantled and all vestiges removed and disposed of.
Dose	A general term denoting the quantity of radiation or the radiation energy absorbed by a medium.
Drywell	Portion of a BWR primary containment not containing the suppression pool.
Electromechanical Decontamination	Refers to the anodic removal of a mechanically resistant, radioactive surface layer under the influence of electricity and chemicals (electropolishing).

Liner	A disposable container for disposal of radioactive wastes; frequently used within shielded shipping casks during transportation.
Low-Level Waste (LLW)	Radioactive waste not classified as high-level waste, transuranic waste, spent nuclear fuel or byproduct material.
Mixed Low-Level Radioactive and Hazardous Waste (Mixed LLW)	Waste that satisfies the definition of low-level radioactive (LLW) in the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPA) and contains hazardous waste that either 1) is listed as a hazardous waste in Subpart D or 40 CFR Part 261 or 2) causes the LLW to exhibit any of the hazardous waste characteristics identified in Subpart C of 40 CFR Part 261.
Noncontaminated	Condition when the radioactive contamination present is below the allowable standards set by regulatory agencies.
Nonradioactive	Radioactive levels (whether in the form of radiation dose rate, concentration of radioactive material contained within a matrix, or radioactive material deposited on surfaces) sufficiently low enough to be beyond regulatory concern or jurisdiction.
Off-gas Treatment	The removal of radioactive components or chemical pollutants from gases prior to their release under controlled conditions into the atmosphere.
Oxyacetylene	Oxygen and acetylene gases used in fuel cutting torches for material, piping and equipment removal.
Primary Wastes	As-generated forms and quantities of waste.
Radioactive Waste	Any material that contains or is contaminated with radionuclides at concentrations or radioactive levels greater than the exempt quantities established by regulatory authorities.
Radioactivity	The property of certain nuclides of spontaneously emitting subatomic particles or electromagnetic radiation.
Secondary Wastes	Forms and quantities of all wastes that result from applying waste treatment technologies to primary wastes.
Shallow-Ground Disposal	Disposal of radioactive waste, with or without engineered barriers, above or below the ground surface, where the final protective covering is a generally a few meters thick.

Release Levels	Radioactive levels sufficiently low to permit release and treatment as nonradioactive material.
Shielding	A material interposed between a source of radiation and personnel or equipment, etc. for protection from radiation. Common shielding materials are concrete, water, and lead.
Shipping Cask	A shielding container used for transporting and handling high-level and medium-level nuclear materials.
Surface Contamination	Contamination resulting from the disposition and attachment of foreign materials to a surface.
Transuranic Waste	Waste containing nuclides with atomic numbers above 92 - having quantities above agreed limits. The limits are established by national regulatory bodies.
Unrestricted Area	The condition of a nuclear facility after decommissioning is complete and the facility license is terminated. At this time the general public would be allowed use of the facility without radiation protection controls.
Waste Management	All activities, administrative and operational, that are involved in the conditioning, transportation, storage, and disposal of waste.
Waste Treatment	<p>Operations intended to benefit safety or economy by changing the waste characteristics. Four basic treatment concepts are defined:</p> <ul style="list-style-type: none"> • volume reduction • immobilization of radioactivity • change of composition • removal of radioactivity from the waste.

APPENDIX A

COST AND DOSE ESTIMATING BASES

APPENDIX A

COST AND DOSE ESTIMATING BASES

The cost and occupational radiation dose evaluations used in this study are based primarily on comprehensive studies on the technology, safety and costs of decommissioning commercial nuclear power plants that were conducted for the U.S. Nuclear Regulatory Commission (NRC) by Pacific Northwest Laboratory (Smith et al. 1978, Oak et al. 1980). This information was supplemented and updated with estimates from a study for the Electric Power Research Institute to develop estimates for several decommissioning alternatives with potential for increasing decommissioning costs (Smith et al. 1985).

The results of the quantitative estimates for immediate dismantlement of the reference PWR and the reference BWR, described in the Smith 1978 and Oak 1980 references, respectively, are presented in Table A.1. The cost percent and dose percent values shown in the table are the percentages of the total cost and total dose for the entire decommissioning operation, including demolition of uncontaminated structures and site restoration. It should be recognized that the NRC does not recognize these latter two items as legitimate decommissioning costs in the Smith 1978 and Oak 1980 references because they concern facilities that are neither radioactive nor contaminated. However, they are included in this study for completeness.

The individual estimates of the cost and of the dose for each of the PWR and the BWR decommissioning activities shown in Table A.1 are combined and averaged for presentation in Table 2 in the main body of this report.

The estimates presented in Table A.1 indicate that the major cost area in commercial nuclear power reactor decommissioning, thus representing the greatest potential for cost savings through improved technology, is management of radioactive decommissioning wastes. Tables A.2 and A.3 present detailed estimates of radioactive waste types, volumes, and waste management costs for the reference PWR and BWR, respectively. The percentages shown in each table are the percentages of the total cost for the immediate dismantlement of the

respective reactors, including demolition of uncontaminated structures and site restoration but excluding any allowance for contingency (Smith et al. 1978, Oak et al. 1980). Subsequently, the estimates for each element in the tables are combined and averaged for presentation in Table 3 in the main body of this report.

TABLE A.1. Estimated Cost and Dose Distribution for Decommissioning Activities for Two Reference Light Water Reactors

Decommissioning Activity	Evaluations			
	PWR(a)		BWR(b)	
	% Total Cost (c)	% Total Dose (d)	% Total Cost (e)	% Total Dose (f)
1. Planning/Engineering/Management				
1.1 Pre-Decommissioning	7.46	0	6.42	0
1.2 Decommissioning	6.73	0	8.68	0
2. Preparatory Operations				
2.1 Physical Inventory of Property	(g)	(h)	(g)	(h)
2.2 Radiological Characterization				
2.2.1 Site Survey/Sampling	(h)	(h)	(h)	(h)
2.2.2 Facility Survey/Sampling	0.07	0.90	0.01	0.08
2.2.3 Inventory Calculation	(g)	0	(g)	0
2.3 Hazardous Mat'ls Characterization	(g)	(h)	(g)	(h)
2.4 Site Modifications ⁽ⁱ⁾	(h)	(h)	0.61	1.41
2.5 Long-Lead Time Activities				
2.5.1 Obtain Licenses/Permits	0.14	0	0.10	0
2.5.2 Procurements/Subcontracting	(g)	0	(g)	0
2.6 Worker Training	(h)	(h)	(h)	(h)
3. Direct Decommissioning Operations				
3.1 Decontamination				
3.1.1 Fluid Systems	0.17	1.13	0.16	2.13
3.1.2 Hardware/Components				
3.1.3 Facility Surfaces				
3.1.4 Soil	(h)	(h)	(h)	(h)
3.2 Hazardous Mat'ls Removal/Handling	(h)	(h)	(h)	(h)
3.3 Disassembly/Removal				
3.3.1 Electrical Equipment/HVAC	0.72	1.25	0.26	0.97
3.3.2 Fluid Systems/Components	7.72	63.35	8.32	74.56
3.3.2.1 Detachment/Removal				
3.3.2.2 Segmentation				
3.3.3 Concrete	2.35	5.58	0.92	2.43
3.4 Interim Radiological Surveys	0.12	0.53	0.08	0.34
3.5 Demolition/Disposal (Nonradioactive)				
3.5.1 Conventional Structures	0.45	0	2.97	0
3.5.2 Heavily Reinforced Structures	12.71	0	16.76	0
3.6 Equipment/Facility Maintenance	0.01	2.04	(h)	0
4. Radioactive Waste Management				
4.1 Radworker Practices/Contam'n Control	(h)	(h)	(h)	(h)
4.2 Treatment of Liquid Waste and Packaging of Residuals	(h)	(h)	0.02	1.11
4.3 Volume Reduction of Solid Wastes	(h)	(h)	(h)	(h)
4.4 Waste Categorization/Segregation	(h)	(h)	(h)	(h)
4.5 Packaging of Dry Solid Wastes	0.20	2.43	0.09	2.06
4.6 Waste Containers	10.75	(h)	5.95	(h)
4.7 Waste Transport ^(j)	6.00	8.38	5.51	6.12
4.8 Waste Disposal	22.16	(h)	20.74	(h)
4.9 Treatment for Recycle/Reuse	(h)	(h)	(h)	(h)

TABLE A.1. (contd)

Decommissioning Activity	Evaluations			
	PWR ^(a)		BWR ^(b)	
	% Total Cost ^(c)	% Total Dose ^(d)	% Total Cost ^(e)	% Total Dose ^(f)
5. Facility Release Characterization				
5.1 Site Final Survey/Sampling	(h)	0	(h)	0
5.2 Facility Final Survey/Sampling	0.12	0	0.01	0
6. Site Restoration	0.12	0	0.63	0
7. Miscellaneous	22.00 ^(k)	14.39 ^(l)	21.77 ^(m)	8.78 ⁽ⁿ⁾
TOTALS ^(o)	100	100	100	100

- (a) The reference pressurized water reactor is described in Smith 1978.
- (b) The reference boiling water reactor is described in Oak 1980.
- (c) The percentages of total cost are based on an adjusted total cost of \$81.1 million in 1986 dollars, including demolition of uncontaminated structures and site restoration but excluding any allowance for contingency.
- (d) The percentages of total dose are based on an adjusted total decommissioning worker radiation dose of 1,181 person-rem, including transportation workers dose.
- (e) The percentages of total cost are based on an adjusted total cost of \$109.3 million in 1986 dollars, including demolition of uncontaminated structures and site restoration but excluding any allowance for contingency.
- (f) The percentages of total dose are based on an adjusted total occupational radiation dose of 1,879 person-rem, including transportation workers dose.
- (g) Cost is included as part of activity 1.1.
- (h) Not quantified or treated analytically in the reference studies.
- (i) Includes activities such as installing new HEPA filters, enlarging the suppression chamber access (BWR), and installing a temporary radwaste system.
- (j) Includes cask rental costs.
- (k) Comprised of the following categories, together with their respective percentages of total cost: specialty contractors (1.07%), nuclear insurance (1.87%), miscellaneous supplies (4.26%), special equipment (1.62%), energy (8.20%), and other expenses (4.98%).
- (l) The percentage shown could vary upward by a factor of two or more depending on 1) shut-down radiation/contamination levels, and 2) the application of ALARA considerations (CP&L 1976). In the reference used, both plant and contractor manpower were utilized and therefore it is very difficult to establish either average exposure rates or types of personnel utilized during the referenced refueling outage. The basic assumption used in Smith et al. 1978 is that once the reactor is defueled, the reactor vessel head will be replaced in preparation for the RCS, CVCS, and related systems chemical decontamination work.
- (m) Comprised of the following categories, together with their respective percentages of total cost: specialty contractors (0.52%), nuclear insurance (1.39%), miscellaneous supplies (2.87%), special equipment (2.95%), energy (6.47%), and other expenses (7.57%).
- (n) Consists of an allowance of up to 1 rem per year for selected management and support staff whose radiation doses are not specifically estimated, together with an allowance of 5% of the total explicitly estimated task radiation dose, to account for any omissions and uncertainties in the analyses.
- (o) Totals do not always equal exactly 100% because of the rounding of individual entries in the table.

TABLE A.2. Estimates of Radioactive Waste Types, Volumes, and Distribution of Decommissioning Costs for a Reference PWR^(a)

PWR Table No. (a) in Ref.	Type of Waste	Burial Vol. m ³	Costs, 1986 \$M ^(b)						Total \$M	% of Total D&D Cost ^(c)
			Container	Transportation		Disposal				
				Cask Rental	Freight	Handling	Burial	Surcharges		
G.4-3	Activated Concrete	707	0.13	--(d)	0.16	--	0.62	--	0.92	1.13
	Activated Metals	484	2.83	0.17	0.56	0.12	0.43	1.43	5.53	6.82
	TOTAL Activated	1,191	2.96	0.17	0.73	0.12	1.05	1.43	6.45	7.95
G.4-4: Reactor Bldg.	Contam. Concrete	1,076	0.35	--	0.25	--	0.95	--	1.55	1.91
	Contam. Metals	1,492	0.49	--	0.31	0.37	1.31	--	2.48	3.06
	TOTAL Contam.	2,568	0.84	--	0.56	0.37	2.26	--	4.03	4.97
G.4-5: Other Bldgs.	Contam. Concrete	9,555	3.17	--	2.21	--	8.41	--	13.78	17.00
	Contam. Metals	3,955	1.30	--	0.44	--	3.48	--	5.21	6.43

TABLE A.2. (contd)

PWR Table No. (a) in Ref.	Type of Waste	Burial Vol. m ³	Costs, \$1986 \$M ^(b)						Total \$M	% of Total D&D Cost ^(d)
			Container	Transportation		Disposal				
				Cask Rental	Freight	Handling	Burial	Surcharges		
G.4-5: Other Bldgs. (contd)	TOTAL Contam.	13,510	4.47	--	2.65	--	11.89	--	18.99	23.43
G.4-6:	Dry Radwaste ^(e)	286	0.03	0.04	0.20	0.04	0.25	--	0.57	0.70
	Wet Radwaste ^(f)	332	0.42	0.12	0.40	0.09	0.29	0.19	1.50	1.85
	TOTAL Radwaste	618	0.45	0.16	0.60	0.13	0.54	0.19	2.07	2.55
TOTALS		17,887	8.71	0.33	4.53	0.62	15.74	1.62	31.55	38.90

(a) See Smith et al. 1978 for a description and additional details.

(b) Costs do not include a contingency allowance.

(c) The percentages of total cost are based on an adjusted total estimated cost of \$81.1 million in 1986 dollars, including demolition of uncontaminated structures and site restoration but excluding any allowance for contingency.

(d) A dash indicates that no cost was assigned to this item in Smith et al. 1978.

(e) Dry solid radioactive waste in this study includes discarded contaminated materials used in the decommissioning operations such as plastic sheeting, rags, and anticontamination clothing. The volumes reflect a five-fold mechanical compaction in standard 55-gallon steel drums. Steel, concrete and other materials that were from the operating nuclear power station are not included in this category.

(f) Wet solid radioactive waste in this study results from the processing of chemical decontamination solutions and contaminated water volumes. The wastes are solidified and encapsulated in steel cask liners for disposal.

TABLE A.3. Estimates of Radioactive Waste Types, Volumes, and Distribution of Decommissioning Costs for a Reference BWR^(a)

BWR Table No. (a) in Ref.	Type of Waste	Burial Vol. m ³	Costs, 1986M ^(b)						Total \$M	% of Total D&D Cost ^(c)
			Container	Transportation		Disposal				
				Cask Rental	Freight	Handling	Burial	Surcharges		
I.3-3	Activated Concrete	90	0.14	--(d)	0.05	0.05	0.08	--	0.32	0.29
	Activated Metals	138	0.53	0.41	1.05	0.30	0.12	4.52	6.93	6.34
	TOTAL Activated	228	0.67	0.41	1.10	0.35	0.20	4.52	7.25	6.63
I.3-4:	Contam. Concrete	1,676	0.54	--	0.45	0.15	1.48	--	2.61	2.39
	Contam. Metals	15,543	4.35	--	2.35	0.50	13.67	--	20.87	19.10
	TOTAL Contam.	17,219	4.89	--	2.80	0.65	15.15	--	23.48	21.49
I.3-5:	Dry Radwaste ^(e)	678	0.08	0.14	0.30	0.10	0.61	--	1.23	1.13

TABLE A.3. (contd)

BWR Table No. (a) in Ref.	Type of Waste	Burial Vol. m ³	Costs, 1986 ^(b)						Total \$M	% of Total D&D Cost ^(d)
			Container	Transportation		Disposal				
				Cask Rental	Freight	Handling	Burial	Surcharges		
I.3-5: (contd)										
	Wet Radwaste ^(f)	814	0.86	0.29	0.99	0.21	0.72	0.16	3.22	2.95
	TOTAL Radwaste	1,492	0.95	0.43	1.29	0.31	1.33	0.16	4.45	4.08
TOTALS		18,939	6.50	0.84	5.18	1.31	16.68	4.68	35.18	32.20

(a) See Oak et al. 1980 for a description and additional details.

(b) Costs do not include a contingency allowance.

(c) The percentages of total cost are based on an adjusted total estimated cost of \$109.3 million in 1986 dollars, including demolition of uncontaminated structures and site restoration but excluding any allowance for contingency.

(d) A dash indicates that no cost was assigned to this item in Oak et al. 1980.

(e) Dry solid radioactive waste in this study includes discarded contaminated materials used in the decommissioning operations such as plastic sheeting, rags, and anticontamination clothing. The volumes reflect a five-fold mechanical compaction in standard 55-gallon steel drums. Steel, concrete and other materials that were from the operating nuclear power station are not included in this category.

(f) Wet solid radioactive waste in this study results from the processing of chemical decontamination solutions and contaminated water volumes. The wastes are solidified and encapsulated in steel cask liners for disposal.

REFERENCES FOR APPENDIX A

- Carolina Power and Light Company (CP&L). January 1976. "Radiation Exposure Breakdown During the H. B. Robinson Unit 2 Refueling Outage in 1975." Memorandum dated January 6, 1976, File NG-3600X1, Serial NG-76-013, Carolina Power & Light, Raleigh, North Carolina.
- Oak, H. D., G. M. Holter, W. E. Kennedy, Jr., and G. J. Konzek. June 1980. Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station. NUREG/CR-0672, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory.
- Smith, R. I., G. J. Konzek, E. S. Murphy, and E. K. Elder. May 1985. Estimated Costs for Decommissioning Nuclear Power Facilities. EPRI NP-4012, Final Report. Prepared by Pacific Northwest Laboratory for the Electric Power Research Institute.
- Smith, R. I., G. J. Konzek and W. E. Kennedy, Jr. June 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.

APPENDIX B

SELECTED FOREIGN DECOMMISSIONING TECHNOLOGIES

APPENDIX B

SELECTED FOREIGN DECOMMISSIONING TECHNOLOGIES

Foreign decommissioning technologies of potential interest to the U.S. were identified through personal contact with foreign technical experts; by reviewing recent IAEA and OECD/NEA reports, bulletins and research abstracts; and by reviewing foreign trip reports, industry briefs, trade journal articles, D&D-related bibliographies, and several hundred foreign D&D literature references (including information from the IAEA data base) obtained through the Remedial Action Program Information Center.

Specific foreign technologies that address the prioritized U.S. major need areas identified for the decommissioning of light water reactors were selected from the numerous references reviewed. The selection was based on apparent technical uniqueness and/or possible value in the U.S. as sources of otherwise unavailable decommissioning information.

The identified foreign technologies are organized and listed in this appendix under the general headings used for the decommissioning activities outline presented in Table 1. Technologies related to remote/automated operations are grouped with the appropriate decommissioning activity.

1. Planning/Engineering/Management

Technology: Development of a model and computerized code system for planning and managing reactor decommissioning operations.
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

2. Preparatory Operations

Technology: Comparison of calculated and measured radiological survey data for the WAGR.
Organization: United Kingdom Atomic Energy Authority
Ref. Date: 1985

Technology: Comparison of calculated and measured radioactivation and depth distribution data for the Lingen and Gundremmingen biological shields.

Organizations: Kernkraftwerk Lingen GmbH; Kernkraftwerk RWE-Bayernwerk GmbH/FRG; CEA, CEN Saclay/France
Ref. Date: 1984

Technology: Computer programs to facilitate the measurement of low-level gamma contamination.
Organization: Imperial College/United Kingdom
Ref. Date: 1987

Technology: Development and verification of a computerized code system for estimation of radioactive inventories.
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

3. Direct Decommissioning Operations

Technology: Reactor primary system decontamination using suspended abrasive particles to enhance or replace chemical cleaning action.
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

Technology: Reactor primary system decontamination using a one-step decontamination process based on Ce (IV).
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

Technology: Use of gas agitation to enhance the chemical cleaning of reactor piping.
Organization: Toshiba Corporation/Japan
Ref. Date: 1985

Technology: Decontamination of components to release levels using aggressive chemicals with ultrasonic enhancement.
Organization: Ente Nazionale per l'Energia Elettrica/Italy
Ref. Date: 1982-1987

Technology: Decontamination using various modifications of water ice blasting.
Organizations: Mitsubishi Heavy Industries, Ltd.; Kurtia Water Industries Ltd.; Ishikawajima-Harima Heavy Industries Co., Ltd./Japan; Wroclaw Technical University/Poland; University of British Columbia
Ref. Dates: 1982-1984

Technology: Further development of dry ice blasting decontamination technology.
Organization: Power Reactor and Nuclear Fuel Development Corporation/Japan
Ref. Date: 1985

Technology: Decontamination of metal surfaces using plasma arc gouging.
 Organization: Hitachi Ltd./Japan
 Ref. Date: 1983

Technology: Decontamination of metal surfaces by thermal cycling and mechanical shock to form and spall surface oxides.
 Organization: Toshiba Corporation/Japan
 Ref. Date: 1983

Technology: Decontamination of surfaces using an electric discharge to activate reactive gases.
 Organizations: Battelle-Institut e.V.; ALKEM/FRG
 Ref. Dates: 1982/1983

Technology: Decontamination using strippable pastes containing aggressive chemicals.
 Organizations: Max Morant Chemische Fabrik; NUKEM/FRG
 Ref. Dates: 1983/1987

Technology: Decontamination using strippable coatings containing decontamination agents.
 Organization: Fujikurakase Kasei Co., Ltd./Japan
 Ref. Date: 1984

Technology: Decontamination using gel-based media containing decontamination agents.
 Organization: CEA, CEN Saclay, Cadarache/France
 Ref. Date: 1984/1987

Technology: Decontamination of metal surfaces using neutral electrolytes and alternating current electrolysis.
 Organization: Hitachi Ltd./Japan
 Ref. Dates: 1984/1985

Technology: Electrochemical decontamination of metal surfaces using electrolyte-saturated pads.
 Organizations: Toshiba Corporation/Japan; Sociezed Travaux en Lilieu Ionisant/France
 Ref. Date: 1982/1987

Technology: Decontamination of reactor primary system piping by in-situ electropolishing using remotely controlled fixtures.
 Organization: Kraftwerk Union AG/FRG
 Ref. Date: 1987

Technology: Development of a robot for decontaminating reactor well and maintenance pit surfaces.
 Organization: Chubu Electric Power Co., Inc./Japan
 Ref. Date: 1984

Technology: Development of a remotely operated ultrasonic decontamination system for fuel transfer pool surfaces.
 Organization: Central Research Institute of Electric Power Industry/
 Japan
 Ref. Date: 1984

Technology: Use of high-pressure water jets to decontaminate primary system piping.
 Organization: United Kingdom Atomic Energy Establishment
 Ref. Date: 1984

Technology: High-pressure water jet decontamination studies.
 Organization: Eidgenoessisches Institut fuer Reaktorforschung/
 Switzerland
 Ref. Date: 1984

Technology: Slurry decontamination process using regenerated constituents.
 Organization: Hitachi Ltd./Japan
 Ref. Date: 1983

Technology: Removal of contaminated concrete surface layers using a milling cutter with accurate control of cutting depth.
 Organization: Sato Kogyo Co., Ltd./Japan
 Ref. Date: 1987

Technology: Microwave spalling of contaminated concrete.
 Organizations: Japan Atomic Energy Research Institute/Japan; Building Research Establishment/United Kingdom
 Ref. Date: 1987

Technology: Removal of contaminated concrete by thermal cycling plus use of a binder to control dust.
 Organization: Hitachi Ltd./Japan
 Ref. Date: 1985

Technology: Removal of contaminated concrete surface layers by flame scarfing.
 Organization: Salzgitter AG/FRG
 Ref. Date: 1984

Technology: Development of a rack-torch unit for remote decontamination of concrete.
 Organization: Societe de Travaux in Lilieu Ionisant/France
 Ref. Date: 1987

Technology: Evaluation of concrete decontamination using a plasma-augmented burner.
 Organization: Societe Bertin & Cie/France
 Ref. Date: 1987

Technology: Selective removal of contaminated concrete using explosive demolition techniques.
Organizations: Battelle-Institut eV; Noell (G.G.) GmbH/FRG; Taylor Woodrow Construction Limited/United Kingdom
Ref. Dates: 1983-1987

Technology: Combined gouging and gas cutting torch for underwater cutting of reactor pressure vessels.
Organization: Government Industrial Research Institute/Japan
Ref. Dates: 1982-1986

Technology: Combined plasma arc/gas cutting of clad pressure vessel steel.
Organization: University of Hannover/FRG
Ref. Dates: 1982-1984

Technology: Further development and demonstration of underwater plasma arc cutting.
Organizations: Japan Atomic Energy Research Institute; Ishikawajima-Harima Heavy Industries Co., Ltd.; Kawasaki Heavy Industries Ltd./Japan
Ref. Dates: 1982-1987

Technology: Development of advanced robotic remote handling systems for underwater cutting and other decommissioning applications.
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

Technology: Development of a prototype system for remote underwater plasma arc cutting.
Organization: CEA, CEN Cadarache/France
Ref. Date: 1987

Technology: Development and demonstration of an underwater arc saw cutting system.
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

Technology: Laser cutting of metal components and concrete.
Organization: Fiat TTG S.p.A./Italy
Ref. Date: 1984-1987

Technology: Development of a prototype system for remote laser cutting of radioactive structures.
Organization: CEA, CEN Saclay/France
Ref. Date: 1987

Technology: Remote control pyrotechnic device to cut plates and tubes.
Organization: CEA, CEN Paris/France
Ref. Date: 1983

Technology:	Explosive cutting of pipe using shaped charges (including safety, environmental impact and licensing considerations).
Organization:	Battelle-Institut e.V./FRG
Ref. Date:	1987
Technology:	Electrochemical technique for segmenting metal components.
Organization:	Kernkraftwerk RWE-Bayernwerk/FRG
Ref. Date:	1987
Technology:	Liquid meal embrittlement (fissuration cutting) technique for segmenting metal components.
Organization:	CEA, CEN Grenoble/France
Ref. Date:	1986
Technology:	Inside disc cutter system for remote cutting of pipe.
Organization:	Kawasaki Heavy Industries Ltd./Japan
Ref. Date:	1985
Technology:	In-situ arc cutting of tubes and pipes from the inside.
Organization:	Field Automation/France
Ref. Date:	1987
Technology:	Adaptation of remotely operated industrial equipment for decommissioning applications.
Organization:	Central Electricity Generating Board/United Kingdom
Ref. Date:	1987
Technology:	Development of a single-frequency illumination system to facilitate remote viewing of flame cutting operations.
Organization:	United Kingdom Atomic Energy Authority
Ref. Date:	1987
Technology:	Segmenting of components using large, stationary saws.
Organization:	CEC/Luxembourg
Ref. Date:	1984
Technology:	Remote controlled sawing/coring robot for cutting activated concrete.
Organization:	Shimizu Construction Co., Ltd./Japan
Ref. Date:	1987
Technology:	Localized concrete cutting using blasting techniques.
Organization:	Swedish Cement and Concrete Research Institute
Ref. Date:	1983
Technology:	Abrasive water jet cutting of concrete using iron grit.
Organization:	Japan
Ref. Date:	1984

Technology: Explosive demolition techniques for heavily reinforced and prestressed concrete structures (including safety, environmental impact and licensing considerations).
Organizations: Taylor Woodrow Construction Ltd./United Kingdom; Battelle-Institut e.V.; Kernforschungszentrum Karlsruhe/FRG
Ref. Dates: 1985/1987

4. Waste Management

Technology: Development of an easy-to-process electrolyte for electropolishing.
Organization: Kraftanlagen Heidelberg/FRG
Ref. Date: 1987

Technology: Purification of decontamination electrolytes by diffusion dialysis.
Organization: Shinko-Pfandler Co., Ltd./Japan
Ref. Date: 1984

Technology: Purification of decontamination electrolytes by electrodeposition.
Organization: Shinko-Pfandler Co., Ltd./Japan
Ref. Date: 1985

Technology: Purification of decontamination electrolytes using anionic exchange resins.
Organization: Mitsubishi Heavy Industries Ltd./Japan
Ref. Date: 1984

Technology: Purification of decontamination electrolytes by diffusion osmosis and diaphragm electrolysis.
Organization: Mitsubishi Heavy Industries Ltd./Japan
Ref. Date: 1985

Technology: Enhancement of electrolyte purification processes by phosphorous acid reduction.
Organization: Mitsubishi Heavy Industries Ltd./Japan
Ref. Date: 1985

Technology: Volume reduction of chemical decontamination wastes by neutralization.
Organization: Mitsubishi Kakoi Kaisha Ltd./Japan
Ref. Date: 1985

Technology: Purification of liquid decontamination wastes by activated carbon electrolysis.
Organization: Hitachi Ltd./Japan
Ref. Date: 1984

Technology: Volume reduction of organic decontamination wastes using ozone and UV irradiation.

Organization: UGC Corporation/Japan
Ref. Date: 1985

Technology: Melting and melt-refining of metal waste for volume reduction, to facilitate assay, and/or for recycle.
Organizations: British Steel Corporation/United Kingdom; Kernforschungsanlage Juelich GmbH; Nuclear Ingenieur-Service GmbH; Siempelkamp giesserei GmbH and Company/ FRG; and Seri-Renault Ingenierrie/France
Ref. Dates: 1984-1987

Technology: Decontamination of metallic waste by zone refining.
Organization: Hitachi Ltd./Japan
Ref. Date: 1985

Technology: Decontamination of stainless steel by vapor phase transport separation.
Organization: CEA, DMG Grenoble/France
Ref. Date: 1987

5. Release Characterization

Technology: Development of an extremely sensitive gamma scanner for low-level waste.
Organization: Japan Atomic Energy Research Institute
Ref. Date: 1987

Technology: Optimization of measurement techniques for very low-level radioactive material.
Organization: Kraftwerk Union AG/FRG
Ref. Date: 1987

Technology: Automated measuring system for release of decommissioning wastes.
Organization: NIS Nuklear-Ingenieur-Service GmbH/FRG
Ref. Date: 1987

APPENDIX C

FOREIGN TECHNOLOGY EXCHANGE CONSIDERATIONS

APPENDIX C

FOREIGN TECHNOLOGY EXCHANGE CONSIDERATIONS

Cooperative exchange of technology with other countries and with multinational agencies (e.g. the CEC) is done routinely in numerous technical areas, including the nuclear power field and the specific area of decommissioning of nuclear facilities. Cooperative exchange of technology is usually done through the mechanism of bilateral agreements or multilateral agreements that are set for a specific length of time, commonly about 5 years.

The DOE currently has bilateral exchange agreements on nuclear facility decommissioning technology with five countries (Canada, Federal Republic of Germany, France, Japan, and the United Kingdom). The DOE also participates in a cooperative program on decommissioning with the NEA through a liaison committee and a technical advisory group. The DOE participates in a coordinated research program on decommissioning with the IAEA, as well as in IAEA technical committees to develop state-of-technology and international consensus technical reports. DOE participation in these activities of these multinational groups provides a forum for general knowledge of what technology is being developed in other countries.

The DOE also has bilateral agreements in spent fuel and high-level radioactive waste management with 8 countries (the same 5 countries identified above plus Belgium, Sweden, and Switzerland), as well as an agreement with the CEC. Decommissioning technology is included in most of the agreements in the more general field of radioactive waste management.

Thus, there is considerable experience and precedence in technology exchange with other countries or multinational agencies in decommissioning and related fields. Where it is determined that technology exchange and cooperation with almost any of the non-Communist bloc countries would be beneficial to the U.S., it is likely that it could be implemented.

Plans for cooperative exchange of technical information should take into account many factors, including the three identified here that tend to inhibit cooperative exchange:

- U.S. technology is generally well documented and available publicly, in a significant level of detail. It is available to virtually any enterprise for the purchase costs of the documents. As a result, the U.S. frequently has very little new to offer in cooperative exchanges.
- Private enterprise in the U.S. and in most western countries is relatively aggressive in obtaining and commercializing new or improved technologies. Generally speaking, private industry will quickly pick up and market U.S. or foreign technology to a world-wide market if business growth and/or profits will result.
- A number of other countries develop nuclear technology through government/private corporations or through government subsidies, and make available the technology to others only on a commercial basis. This concept tends to restrict technology exchange with those governments.

Nevertheless, cooperative exchange of technologies has and will continue to take place to the benefit of the U.S. nuclear power industry.

Following is a general listing of the types of cooperative exchange that may be considered for implementation when planning technical exchanges with other countries.

- Exchange listings of documents on specific subjects.
- Exchange specific documents on specific subjects, including plans, R&D results, data.
- Exchange identification of private organizations with specific expertise or interest. This could involve DOE providing liaison for U.S. businesses.
- Obtain information by review of existing literature.

- Carry out visits, briefings, consultations among appropriate experts on specific subjects to obtain technology details.
- Exchange reviews of and comments on national plans, facilities and hardware, R&D results, data, etc.
- Exchange identification of international organizations and their contact persons who may have information of use to the various parties.
- Exchange visiting scientists to work temporarily in the other country to assist them and to learn first-hand about their technology.
- Carry out joint development and/or demonstration programs.
- Telephone consultations among technical experts
- Exchange technical models and computer codes for use in analysis.
- Exchange materials, samples, or equipment for evaluation or testing.
- Carry out joint seminars on subjects of interest.
- Participate in international technical conferences.
- Co-develop technical reports on technical issues or subjects.
- Co-develop feasibility reports, state-of-the art reports, survey reports.
- Participate in coordinated research programs on specific subjects.
- Outright purchase of technology.

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