NUREG/CR-1754
Addendum 1

Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities

Compendium of Current Information

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Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Cost and safety information is developed for the conceptual decommissioning of non-fuel-cycle nuclear facilities that represent a significant decommissioning task in terms of decontamination and/or disposal activities. Reference facilities examined in this study include six types of laboratories and three site elements associated with materials facilities that require some decommissioning effort. Decommissioning of these reference facilities and sites can be accomplished using techniques and equipment that are in common industrial use. Since decommissioning technology for non-fuel-cycle nuclear facilities has not changed appreciably since publication of NUREG/CR-1754, essentially the same technology assumed in that study is used in this study.

For the reference laboratory-type facilities, the study approach is to first evaluate the decommissioning of representative components (e.g., hoods, glove boxes, building surfaces, exhaust system ductwork, etc.) that are common to many laboratory facilities. Reference laboratories are then analyzed using data for individual components (the unit-component approach) to provide information about the costs and safety of decommissioning entire facilities. DECON is the decommissioning alternative evaluated for the reference laboratories because it results in release of the facility for unrestricted use as soon as possible. For a facility, DECON requires that contaminated components either be: 1) decontaminated to unrestricted release levels or 2) packaged and shipped to an authorized disposal site.

The costs of decommissioning facility components are generally estimated to be in the range of $1,000 to $12,000, depending on the type of component, the type and amount of radioactive contamination, the DECON options chosen, and the quantity of radioactive waste generated from decommissioning operations. Estimated costs for decommissioning the example laboratories range from $100,000 to $150,000. On the basis of estimated decommissioning costs for facility components, the costs of decommissioning typical non-fuel-cycle laboratory facilities are estimated to range from about $20,000 for the decommissioning of a small room containing one or two moderately contaminated fume hoods to more than $1 million for the decommissioning of an industrial plant containing several laboratories in which radiochemicals and sealed radioactive sources are prepared.

For the reference sites of this study, the basic decommissioning alternatives are: 1) site stabilization followed by long-term care and 2) removal of the waste or contaminated soil to an authorized disposal site. Cost estimates made for decommissioning three reference sites range from about $69,000 for the removal of a contaminated drain line and hold-up tank to more than $31 million for the removal of a tailings pile that contains radioactive residue from ore-processing operations in which tin slag is processed for the recovery of rare metals.

Total occupational radiation doses generally range from 0.001 to 1.0 man-rem for decommissioning the laboratory facilities of this study. An exception

exists when decommissioning operations create significant quantities of airborne radioactivity as in the case of the reference ^{241}Am laboratory, where inhalation of airborne radioactivity is estimated to result in a total decommissioning worker dose of 40 to 50 man-rem. For decommissioning operations in an environment with a potential for high inhalation exposure to radiation, workers may be required to wear protective respiratory equipment, which would greatly reduce the occupational doses.

An addition to this study, not present in the original study, is the inclusion of a section (Appendix E) providing a simplified procedure for estimating decommissioning costs of non-fuel-cycle nuclear facilities. The purpose of this procedure is to provide NRC staff with the means to easily generate their own estimate of decommissioning costs for a given facility for comparison against a licensee's submittal.

The results of this study do not change any of the conclusions given in NUREG/CR-1754. However, an additional conclusion of this study is that rapidly escalating costs for disposal of radioactive wastes have necessitated the use of advanced volume-reduction technologies to minimize the volumes of radioactive waste that need to be disposed.

FOREWORD

BY

NUCLEAR REGULATORY COMMISSION STAFF

The Nuclear Regulatory Commission (NRC) has issued regulations related to the decommissioning of nuclear facilities.[1] As part of this activity, the NRC initiated two series of studies through technical assistance contracts. These contracts were undertaken to develop information to support the preparation of new standards covering decommissioning.

The first series of studies covers the technology, safety and costs of decommissioning reference nuclear facilities.[2-25] Light water reactors (LWRs) and fuel-cycle and non-fuel-cycle facilities were included. Facilities of current design on typical sites were selected for the studies. Separate reports were prepared as the studies of the various facilities were completed.

The second series of studies covers supporting information on the decommissioning of nuclear facilities.[26-30] This series includes an annotated bibliography on decommission and studies on facilitation and radiation survey methods appropriate for decommissioning, as well as an examination of regulations applicable to decommissioning.

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

The information provided in this report on decommissioning of reference non-fuel-cycle nuclear facilities will be used as part of the NRC information base to develop regulatory guides for implementing the decommissioning rule amendments.

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TABLES

1.0 INTRODUCTION

This report contains the results of a study sponsored by the Nuclear Regulatory Commission (NRC) to conceptually decommission non-fuel-cycle nuclear facilities. The primary purpose of the study is to provide a current compendium of relevant information on the technology, safety, and costs for decommissioning such radioactive materials facilities. The information provided in this report revises and/or updates the information already provided in the original document with the same title (NUREG/CR-1754). This information is intended for use by NRC staff as background data in evaluating licensee cost estimates and decommissioning plans, as required by the final decommissioning rule. It is also intended for use by materials licensees in planning for the decommissioning of their facilities.

The example facilities decommissioned in this study are the same as those used in NUREG/CR-1754 and are considered representative of actual facilities. The reference laboratory facilities include individual laboratories that are representative of facilities for 1) the manufacture of radiochemicals and sealed sources and 2) institutional laboratories where radioisotopes are used. The study approach used for these facilities is to describe the decommissioning of components such as fume hoods, glove boxes, building surfaces, exhaust system ductwork, etc., that are common to many facilities. Example laboratories are then analyzed using data for individual components (the unit-component approach) to provide representative information about the costs and safety of decommissioning entire facilities. This study analyzes the decommissioning of example laboratories by the DECON (immediate decontamination to unrestricted release) options of: 1) decontamination of equipment and building surfaces to unrestricted release levels and 2) disposal of contaminated components and material at authorized burial sites.

The reference sites are actually site elements for which some effort would be required to remove the radioactive contamination. The site elements analyzed include a contaminated underground drain line and hold-up tank, a contaminated ground surface, and a tailings pile/evaporation pond containing the radioactive residue from ore processing operations in which rare metals are recovered from ores containing licensable quantities of thorium and uranium. Analysis of the decommissioning requirements for these site elements is intended to provide examples to assist in estimating the requirements and costs of decommissioning sites with similar radioactive contamination. The decommissioning alternatives analyzed for these sites are: 1) site stabilization followed by long-term care and 2) removal of the waste or contaminated soil to an authorized disposal site.

Estimates are made of manpower requirements, work schedules, material and equipment needs, waste management requirements, and occupational radiation doses for decommissioning facility components, example laboratory facilities, and site elements by the decommissioning alternatives described previously. Decommissioning techniques are chosen that represent current technology and that conform to the principle of keeping public and occupational radiation doses as low as reasonably achievable (ALARA). Decontamination and decommissioning technology for non-fuel-cycle nuclear facilities has not changed appreciably since publication of the base study (NUREG/CR-1754); therefore, the technology assumed in that study was used for this study, with the addition of more effective volume-reduction technology.

Following this introductory chapter, a summary of the important information and results of this study is presented in Chapter 2. Chapter 3 contains a review of decommissioning experience at three non-fuel-cycle nuclear facilities. Advanced volume-reduction technologies are covered in Chapter 4. Chapters 5, 6 and 7 present the results of the analyses for decommissioning facility components, reference facilities, and reference sites, respectively. The study results are discussed in Chapter 8. Appendices A through C provide the details of the decommissioning analyses set forth in the main report. The cost estimating bases utilized in the study are presented in Appendix D. Finally, a procedure for easily estimating decommissioning costs for non-fuel-cycle nuclear facilities is provided in Appendix E.

2.0 SUMMARY

The objective of this study is to provide a current compendium of relevant information on the technology, safety, and costs for decommissioning non-fuel-cycle nuclear facilities. The information in this report revises and/or updates the information already provided in the original document on the same subject.[1] The study is intended to provide background information for use by NRC staff in evaluating licensee cost estimates and decommissioning plans, as required by the final decommissioning rule. A procedure for use by NRC staff in estimating decommissioning costs of non-fuel-cycle nuclear facilities is provided in Appendix E. This procedure is also intended for use by materials licensees in planning for the decommissioning of their facilities. This chapter provides a brief discussion of the results of the study; a more detailed presentation of results follows in later chapters.

2.1 DECOMMISSIONING ALTERNATIVES

The decommissioning alternatives available to materials licensees have not changed since publication of NUREG/CR-1754.[1] The basic alternatives are immediate decontamination to unrestricted release (DECON), safe storage followed by radioactive decay or decontamination to unrestricted release (SAFSTOR), and entombment with radioactive decay to unrestricted release (ENTOMB).

DECON of a facility requires that contaminated components either be: 1) decontaminated to unrestricted release levels or 2) packaged and shipped to an authorized disposal site. The approach used to analyze laboratory decommissioning is to first describe the decommissioning of representative components (e.g., fume hoods, glove boxes, building surfaces, exhaust system ductwork, etc.) that are common to many laboratories. Example laboratories are then analyzed using data for individual components (the unit-component approach) to provide information about the costs and safety of decommissioning entire facilities.

For the reference sites of this study, the basic decommissioning alternatives are: 1) site stabilization followed by long-term care (similar to SAFSTOR) and 2) removal of the waste or contaminated soil to an authorized disposal site (DECON). For a site that contains a tailings pile/evaporation pond, a combination of these alternatives is also possible in which the tailings pile/evaporation pond is stabilized and used as a temporary waste storage site.

ENTOMB is not considered a viable decommissioning alternative due to the urban or suburban location of most materials licensee laboratory facilities.

2.2 REVIEW OF DECOMMISSIONING EXPERIENCE

A number of non-fuel-cycle nuclear facilities have been decommissioned in the intervening years between publication of NUREG/CR-1754[1] and this report. A few of these facilities of particular relevance to this study are discussed, including: a cobalt-60 irradiation facility, an alpha-contaminated heavy isotope separation laboratory, and a depleted uranium manufacturing facility and a depleted uranium and thorium waste pond.

2.3 REVIEW OF ADVANCED VOLUME-REDUCTION TECHNOLOGIES

The rapidly escalating cost for disposing of radioactive waste at the available shallow-land burial grounds has created an incentive to reduce the volume of waste that must be shipped to a disposal site as much as possible. Two emerging, but not necessarily commercially available, technologies offer potentially significant volume reduction of generated radioactive waste: supercompaction and incineration. Supercompaction is capable of volume-reducing most dry-active waste (DAW), including trash and metal waste. On the other hand, while incineration can yield even higher volume reduction of trash and combustible materials, incineration is not applicable to metal waste, and has encountered significant public opposition to its implementation.

2.4 CHARACTERIZATION OF REFERENCE FACILITIES AND SITES

The reference facilities and sites analyzed in this study are the same as those assumed in NUREG/CR-1754.[1] The reference laboratories include:

- a laboratory for the manufacture of ^{3}H-labeled compounds
- a laboratory for the manufacture of ^{14}C-labeled compounds
- a laboratory for the manufacture of ^{125}I-labeled compounds
- a laboratory for the manufacture of ^{137}Cs sealed sources
- a laboratory for the manufacture of ^{241}Am sealed sources
- a reference institutional user laboratory.

These facilities are described in detail in Section 7 of NUREG/CR-1754.[1]

Several facility components are common to the reference laboratories. These components include fume hoods, glove boxes, hot cells, laboratory workbenches, sinks and drains, ventilation ductwork, filters, and building surfaces (floors, walls, and ceilings). Some of these components experience significant radioactive contamination during the operational phase of the laboratory. Release of a laboratory for unrestricted use and termination of the radioactive material license require either that: 1) a contaminated component be decontaminated to unrestricted release levels, with wastes packaged and shipped to a waste disposal site or 2) the entire component be packaged and shipped to an authorized disposal site.

The reference sites include:

- a site with a contaminated drain line and hold-up tank
- a site with a contaminated ground surface
- a tailings pile containing uranium and thorium residues.

Section 7.3 of NUREG/CR-1754[1] describes each of these sites in detail.

2.5 DECOMMISSIONING OF FACILITY COMPONENTS

Facility components may be decommissioned by decontamination to unrestricted release levels or by disposal at a shallow-land burial ground. The facility components for which decommissioning analyses are made and the DECON options analyzed are shown in Table 2.1. A summary of estimated costs for decommissioning facility components is given in Table 2.2. A summary of estimated occupational radiation doses for decommissioning facility components is given in Table 2.3. Components are assumed to be located in a room that measures 6 m by 10 m, with walls 3 m high.

Contamination levels on facility components before decontamination are given in NUREG/CR-1754.[1] Decontamination procedures are described in Appendix B of that document. Decontamination is assumed to reduce removable surface contamination to the unrestricted release levels specified in the NRC Guidelines of Reference 1.

TABLE 2.1. DECON Options for Facility Components

	DECON Option	
Facility Component	Clean to Unrestricted Release Levels	Dismantle and Package for Disposal
Fume Hood	x[a]	x
Glove Box	x	x
Small Hot Cell	x	x
Laboratory Workbench	x	x
Sink and Drain	x	x
Ventilation Ductwork		x
Building Surfaces[b]	x	

(a) An "x" indicates that the facility component can be decommissioned by the indicated option.
(b) Some contaminated material such as floor tiles or concrete chipped from walls might be packaged and shipped for disposal.

TABLE 2.2. Summary of Estimated Costs for Decommissioning Facility Components

Facility Component and DECON Option	Estimated Costs ($ thousands)[a] to Decommission Component with Indicated Contaminant				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Fume Hood					
Decontamination	6.0	5.9	6.2	6.2	7.7
Packaging and Disposal w/o Volume Reduction	9.5	9.5	9.5	9.5	10.2
Packaging and Disposal w/ Supercompaction	6.5	6.5	6.5	6.5	7.1
Packaging and Disposal w/ Incineration	7.0	7.0	7.0	7.0	7.7
Glove Box					
Decontamination	4.4	4.1	4.5	--	5.7
Packaging and Disposal w/o Volume Reduction	4.0	4.0	4.0	--	4.5
Packaging and Disposal w/ Supercompaction	3.8	3.8	3.8	--	4.6
Packaging and Disposal w/ Incineration	4.0	4.0	4.0	--	4.7
Small Hot Cell					
Decontamination	--	--	--	8.6	--
Packaging and Disposal w/o Volume Reduction w/o Lead Salvage	--	--	--	10.1	--
Packaging and Disposal w/o Volume Reduction w/ Lead Salvage	--	--	--	12.0	--
Packaging and Disposal w/ Supercompaction w/ Lead Salvage	--	--	--	11.9	--
Packaging and Disposal w/ Incineration w/ Lead Salvage	--	--	--	12.3	--
Laboratory Workbench					
Decontamination	2.0	2.1	2.1	2.1	2.1
Packaging and Disposal w/o Volume Reduction	9.0	9.0	9.0	9.0	9.0
Packaging and Disposal w/ Supercompaction	4.7	4.7	4.7	4.7	4.7
Sink and Drain					
Decontamination	--	1.3	1.3	1.3	--
Packaging and Disposal w/o Volume Reduction	--	2.3	2.3	2.3	--
Packaging and Disposal w/ Supercompaction	--	1.9	1.9	1.9	--
Ventilation Ductwork					
Packaging and Disposal w/o Volume Reduction	11.8	11.8	11.8	11.8	12.3
Packaging and Disposal w/ Supercompaction	6.1	6.1	6.1	6.1	7.1
Packaging and Disposal w/ Incineration	6.9	6.9	6.9	6.9	7.9
Walls					
Decontamination	19.5	19.5	21.4	21.9	21.4
Floor					
Decontamination	8.8	8.8	8.8	8.8	8.5

(a) Costs are in January 1988 dollars and include a 25% contingency.

Disposal is postulated to be by shallow-land burial at a site located 800 km from both the laboratory being decommissioned and from the centrally located supercompaction facility. The supercompaction facility is postulated to be located 350 km from the laboratory. Wastes are packaged in 208-ℓ steel drums or in plywood boxes and are shipped by truck either to the disposal site or to the supercompaction facility. Both the contaminated components and the decommissioning wastes, with the exception of contaminated liquids, are disposed of in this manner. Contaminated liquids are solidified on-site and always shipped directly to the disposal site.

TABLE 2.3. Summary of Estimated Occupational Radiation Doses for Decommissioning Facility Components

Facility Component and DECON Option	Estimated Occupational Doses (man-rem) to Decommission Component with Indicated Contaminant				
	^{3}H	^{14}C	^{125}I	^{137}Cs (a)	^{241}Am (a)
Fume Hood					
Decontamination	1×10^{-2}	1×10^{-5}	4×10^{-5}	1×10^{-1}	1×10^{-1}
Packaging and Disposal w/o Volume Reduction	2×10^{-2}	2×10^{-5}	7×10^{-5}	3×10^{-1}	2×10^{-1}
Packaging and Disposal w/ Supercompaction	4×10^{-2}	4×10^{-5}	1×10^{-4}	5×10^{-1}	3×10^{-1}
Packaging and Disposal w/ Incineration	4×10^{-2}	4×10^{-5}	1×10^{-4}	5×10^{-1}	3×10^{-1}
Glove Box					
Decontamination	2×10^{-3}	5×10^{-7}	1×10^{-2}	--	4×10^{0}
Packaging and Disposal w/o Volume Reduction	3×10^{-3}	1×10^{-6}	2×10^{-2}	--	6×10^{0}
Packaging and Disposal w/ Supercompaction	5×10^{-3}	2×10^{-6}	3×10^{-2}	--	8×10^{0}
Packaging and Disposal w/ Incineration	5×10^{-3}	2×10^{-6}	3×10^{-2}	--	8×10^{0}
Small Hot Cell					
Decontamination	--	--	--	3×10^{0}	--
Packaging and Disposal w/o Volume Reduction w/o Lead Salvage	--	--	--	4×10^{0}	--
Packaging and Disposal w/o Volume Reduction w/ Lead Salvage	--	--	--	8×10^{0}	--
Packaging and Disposal w/ Supercompaction w/ Lead Salvage	--	--	--	9×10^{0}	--
Packaging and Disposal w/ Incineration w/ Lead Salvage	--	--	--	9×10^{0}	--
Laboratory Workbench					
Decontamination	4×10^{-7}	4×10^{-7}	7×10^{-6}	2×10^{-5}	[illegible] $\times 10^{-3}$
Packaging and Disposal w/o Volume Reduction	7×10^{-7}	7×10^{-7}	1×10^{-5}	3×10^{-5}	3×10^{-3}
Packaging and Disposal w/ Supercompaction	1×10^{-6}	1×10^{-6}	2×10^{-5}	5×10^{-5}	5×10^{-3}
Sink and Drain					
Decontamination	--	4×10^{-7}	6×10^{-6}	4×10^{-5}	--
Packaging and Disposal w/o Volume Reduction	--	6×10^{-7}	9×10^{-6}	6×10^{-5}	--
Packaging and Disposal w/ Supercompaction	--	7×10^{-7}	1×10^{-5}	8×10^{-5}	--
Ventilation Ductwork					
Packaging and Disposal w/o Volume Reduction	2×10^{-6}	2×10^{-5}	8×10^{-5}	3×10^{-3}	2×10^{-2}
Packaging and Disposal w/ Supercompaction	3×10^{-6}	3×10^{-5}	1×10^{-4}	5×10^{-3}	3×10^{-2}
Packaging and Disposal w/ Incineration	3×10^{-6}	3×10^{-5}	1×10^{-4}	5×10^{-3}	3×10^{-2}
Walls					
Decontamination	5×10^{-5}	2×10^{-5}	5×10^{-4}	8×10^{-4}	1×10^{-1}
Floor					
Decontamination	2×10^{-6}	8×10^{-6}	8×10^{-5}	3×10^{-4}	7×10^{-2}

(a) Occupational exposures for work with ^{137}Cs and ^{241}Am contamination could be reduced 1 or 2 orders of magnitude if workers used protective respiratory equipment.

It is assumed that components contaminated with ^{241}Am can be disposed of by shallow-land burial. If contamination levels exceed 100 nCi/gram of waste, it may be necessary to decontaminate the component prior to packaging it for disposal. Alternatively, it may be necessary to provide for interim storage of the contaminated component, since facilities for the permanent disposal of transuranic wastes are not yet available.

Decommissioning costs include the costs of staff labor, equipment and supplies, and waste management (the packaging, volume reduction, transportation, and disposal of wastes). All costs are expressed in January 1988 dollars. Total costs include a 25% contingency.

Decommissioning of facility components is assumed to be performed by employees of the owner/operator of the facility. Staff labor costs are determined by multiplying the man-days required to decommission a component by the costs per man-day given in Appendix D. To determine the total time required to decommission a component, an estimate is made of the time required for efficient performance of the work by a postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc.

The base-case scenario for determining the requirements and costs of disposal of facility components assumes that current decommissioning practice is followed and that components are packaged and shipped intact with a minimum of sectioning (i.e., cutting) or compaction. To provide a basis for cost comparisons, estimates are made of the additional expense of volume-reduction procedures and of cost savings resulting from a decrease in the volume of waste shipped to the disposal site. For the decommissioning of a small hot cell, the cost savings resulting from salvaging lead bricks is also estimated. Costs of these alternatives are summarized in Section 5.2.

An estimate of occupational dose is made for the decommissioning of each facility component. The occupational dose is evaluated by multiplying the estimated worker dose rate for a component by the man-days required to decommission the component. The estimated worker dose rates that form the bases of occupational dose calculation are given in Section 8.1 of NUREG/CR-1754[1] and include contributions from both direct exposure and inhalation. The worker dose rates used in this study are in reasonable agreement with experience at typical radioactive materials laboratories.

2.6 DECOMMISSIONING OF REFERENCE FACILITIES

Estimates are made of time and manpower requirements, occupational radiation doses, and total costs for DECON of the six reference laboratories listed in Section 2.4. The decommissioning analyses for these laboratories use cost and safety data for the decommissioning of facility components summarized in Section 2.5. Costs of planning and preparation and of a final radiation survey of the decommissioned facility are added to the basic decontamination costs of the individual components. Decommissioning requirements and costs for the six reference laboratories are summarized in Table 2.4.

Decommissioning is preceded by a period of planning and preparation that includes activities to ensure that decommissioning is performed in a safe and cost-effective manner in accordance with all applicable federal, state, and local regulations. Planning and preparation activities include the preparation

TABLE 2.4. Summary of Estimated Requirements and Costs for DECON of Six Reference Laboratories that Process or Use Radioisotopes

Parameter	Requirement or Cost for Reference Laboratory[a]					
	^{3}H Laboratory	^{14}C Laboratory	^{125}I Laboratory	^{137}Cs Laboratory	^{241}Am Laboratory	Institutional Laboratory
DECON w/o Volume Reduction						
Time (days)	71	62	61	60	81	70
Manpower (man-days)	279	235	230	226	336	270
Occupational Dose[b] (man-rem)	0.1	0.001	0.1	6	40	0.1
Costs ($ thousands)[c]						
Staff Labor	67.0	56.3	55.3	54.6	80.9	64.9
Equipment	4.7	4.2	3.5	8.8	4.7	4.4
Supplies	8.5	10.3	9.5	9.4	12.9	9.3
Waste Management	68.7	54.7	37.4	33.3	52.0	54.1
Totals	149	126	106	106 19[d]	150	133
DECON w/Volume Reduction						
Time (days)	76	65	64	61	86	73
Manpower (man-days)	305	251	257	234	359	283
Occupational Dose[b] (man-rem)	0.1	0.001	0.1	6	50	0.1
Costs ($ thousands)[c]						
Staff Labor	73.3	60.2	59.6	56.5	86.0	68.1
Equipment	5.1	4.4	3.8	8.9	4.9	4.6
Supplies	9.1	10.9	10.1	9.4	12.9	9.3
Waste Management	40.7	34.7	26.1	24.9	35.1	33.3
Totals	128	110	100	100 19[d]	139	115

(a) The listed value represents the requirement or cost for both planning and preparation and the actual decommissioning of the laboratory.
(b) Estimated on the assumption that workers do not use protective respiratory equipment. Doses could be reduced by 1 or 2 orders of magnitude through the use of this equipment. This is a likely alternative for the ^{241}Am laboratory.
(c) Costs are in January 1988 dollars and include a 25% contingency.
(d) Credit for lead salvage.

of documentation for regulatory agencies, an initial radiation survey to determine the radiological condition of the laboratory, and the development of detailed work plans.

DECON options postulated for the components of the reference laboratories are arbitrary but are believed to represent reasonable approaches to the decommissioning of particular components. Some fume hoods and glove boxes are assumed to be decontaminated to unrestricted release levels, while other hoods and glove boxes are packaged for disposal, depending on the magnitude and type of surface contamination. Laboratory workbenches and other components such as refrigerators, storage cabinets, etc., are assumed to be decontaminated to unrestricted release levels. Sinks are decontaminated, and drain lines are packaged for disposal. Ventilation ductwork is sectioned and packaged for disposal. Building surfaces are generally assumed to be decontaminated to unrestricted use levels.

The decommissioning activities evaluated in this report do not include consideration of significantly off-normal conditions, such as spread of contamination within the structural walls or beneath the primary covering of the floors of the facility. Because of the unique characteristics of such situations, they cannot be evaluated in the same generic manner as is done for the normal conditions. If these types of conditions exist in a facility, specific analyses by the owner will be necessary to estimate the costs of these additional cleanup operations, which would then be added to the estimates developed using the methodology and unit cost factors presented in this report.

The final decommissioning activity is a comprehensive radiological survey to document levels of radioactivity remaining in the facility after DECON is completed and to certify that these levels are less than those specified for unrestricted release.

Decommissioning is assumed to be performed by employees of the owners or operators of the laboratories. The basic decommissioning work crew includes a foreman and three technicians, assisted by a health physicist. Craftsmen (electricians, pipefitters, etc.) are added to this crew on a part-time basis to perform specific tasks. Staff labor costs are postulated to include the salary of a supervisor on a half-time basis.

Costs for decommissioning the reference laboratories include the costs of staff labor, equipment, suppliers, and waste management. Costs are estimated for planning and preparation, for the actual decommissioning, and for the termination survey. Total costs listed in Table 2.4 are the sum of all of these costs. All costs are expressed in January 1988 dollars and include a 25% contingency.

Estimates of occupational radiation dose are made by multiplying worker dose rates given in Section 8.1 of NUREG/CR-1754[1] by the estimated man-days required to decommission a facility.

2.7 DECOMMISSIONING OF REFERENCE SITES

Estimates are made of time and manpower requirements, occupational radiation doses, and total costs for decommissioning the three reference sites listed in Section 2.4. For the site with a contaminated underground drain line and hold-up tank and for the site with a contaminated ground surface, estimates are made of the requirements and costs for removal of the radioactively contaminated material. For the site with a tailings pile containing uranium and thorium residues, estimates are made of requirements and costs for both the site stabilization and the removal options. Decommissioning requirements and costs for the three reference sites are summarized in Table 2.5.

Because concentrations of radioactivity are low and inhalation of resuspended particulates either is not a serious consideration or can be protected against by the use of respiratory equipment, removal of the waste and

1

IMAGE EVALUATION TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

TABLE 2.5. Summary of Estimated Manpower Requirements, Costs, and Radiation Doses for Decommissioning Three Reference Sites

Site	Requirement or Cost			
	Time (days)	Manpower (man-days)	Costs[a] ($ thousands)	Occupational Radiation Dose (man-rem)
Underground Drain Line & Hold-up Tank	17	72	69	0.04
Contaminated Ground Surface	42	203	1,829	0.14
Tailings Pile				
Stabilization Option	32	174	334	0.08
Long-Term Care (Annually)	10	27	12	0.01
Removal Option	139	1,657	31,249	1.0

(a) Costs are in January 1988 dollars and include a 25% contingency.

contaminated soil is accomplished with standard earthmoving equipment. Radioactive material is packaged in plastic-lined plywood boxes for shipment to a shallow-land disposal site.

For the site with a contaminated tailings pile, site stabilization is assumed to include the following procedures. The pile is covered with a 50-mm-thick layer of asphalt. This asphalt layer is then covered with 1 m of soil. The soil is mounded slightly at the center of the pile to allow water to drain from the soil cover and to prevent the accumulation of runoff from rainfall or snow melt. After compaction and contouring of the soil cover, the area is seeded with grass.

Decommissioning activities include a radiological survey to assess the condition of the site before site stabilization or removal operations begin and restoration of the site by backfilling and planting vegetation after waste removal is completed. A final radiation survey to verify that the radioactivity remaining on the site is less than release limits is performed prior to release of a site for unrestricted use. Decommissioning is assumed to be performed by a contractor hired by the owner or operator of the site.

Decommissioning costs include the costs of staff labor, equipment, supplies, soil sample analyses, waste management, and a contractor's fee. Total costs shown in Table 2.5 are the sum of planning and preparation, actual decommissioning, and termination survey costs. All costs are expressed in early 1988 dollars and include a 25% contingency. Approximately 90% of the cost of decommissioning a site with contaminated ground surface, and approximately 96%

of the cost of the removal option for decommissioning a tailings pile is related to waste management (i.e, the packaging, transportation, and disposal of soil and waste exhumed for the site).

Occupational radiation doses are estimated on the basis of an assumed average dose rate of 0.1 mrem/hr to decommissioning workers. This exposure level was estimated on the basis of experience at tailings sites and low-level waste burial grounds and chosen conservatively.

2.8 STUDY CONCLUSIONS

The major conclusions of this study have not changed since publication of NUREG/CR-1754.[1] However, a couple of new conclusions can be added to the conclusions of that document. These are:

- Decommissioning costs have increased considerably since publication of NUREG/CR-1754 due primarily to rapidly escalating costs for disposal of radioactive waste generated during decommissioning operations at the available shallow-land burial sites.
- New, commercially available radioactive waste volume-reduction technology can significantly reduce the costs of waste disposal and, hence, the costs from decommissioning operations.

2.9 REFERENCES

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

3.0 REVIEW OF DECOMMISSIONING EXPERIENCE

Since publication of NUREG/CR-1754,[1] several commercial and Department of Energy (DOE) facilities have been decommissioned.[2-5] A few of these facilities of particular relevance to this study are discussed in this chapter.

3.1 DECOMMISSIONING EXPERIENCE AT INTERNATIONAL NUTRONICS[2]

The International Nutronics cobalt-60 irradiation facility located at Dover, New Jersey, was commissioned as a commercial irradiation facility in 1970 after obtaining a license from the Atomic Energy Commission (AEC). International Nutronics acquired the facility from Radiation Service Associates in 1981 and ceased operations in 1983, at which time a decommissioning program for the facility was initiated. During operations, the facility provided gamma irradiation services for sterilization, physical and chemical effects processing, and radiation effects testing.

The operations facility building, which housed both the irradiation cells and operational offices, was a 15 x 24 x 5 meter cinder block structure with concrete floors. The irradiation cells were made of concrete blocks in which was positioned a cylindrical source array comprising more than fifty cobalt-60-encapsulated sources to perform in-air irradiations. When not performing irradiations, the sources were stored in a carbon steel storage tank containing 5-meter-deep water. While the maximum cobalt-60 source strength utilized at the facility was 400,000 curies, only 59,777 curies existed when decommissioning operations were initiated.

The decommissioning program comprised four steps:

- removal of the cobalt-60 sources
- dismantlement of the irradiation cell
- removal of the source storage tank
- decontamination of the facility building and environment.

The entire effort was directed toward reducing residual contamination levels below those specified in NRC guidelines for decontamination of facilities prior to release for unrestricted use.[6]

The removal of the cobalt-60 sources involved an elaborate program to package the sources and then place them in an approved Type B shipping cask with an internal liner. Since the shipping cask was approved for only 13,000 curies per shipment, four shipments were required. The sources were shipped to a facility with hot cell and encapsulation facilities where, after they were inspected and their integrity verified, they were again utilized for irradiation studies.

The source storage tank was decontaminated as much as possible before it was sectioned and packaged for disposal. However, since the contact dose rate still exceeded 1.5 rem per hour, the process of sectioning the tank was fairly complex. An electric hacksaw was used in the sectioning operation.

Dismantlement of the concrete irradiation cell involved removing the concrete blocks and packaging them in either metal or wooden containers. All equipment and materials resulting from this operation were packaged and disposed of as radioactive waste unless surveys revealed their contamination levels were below the values necessary for unrestricted release.

Decontamination of the facility building and environment entailed both removal of building components and soil, and surface cleaning and removal. Decontamination of floor and wall surfaces was performed by either total removal or selective removal by scabbling, using jackhammers and scabblers, respectively. Soil was removed as determined necessary.

The entire decontamination operation was completed in 1986 and approved by the NRC for unrestricted radiological release.

3.2 DECOMMISSIONING EXPERIENCE AT UKAEA-HARWELL[3]

The United Kingdom Atomic Energy Agency (UKAEA) Hermes isotope separation facility located at Harwell, United Kingdom, was first used in experiments to separate heavy metal isotopes in the 1950s. A decommissioning program for the facility was initiated in 1983.

The primary source of contamination in the laboratory was from alpha particles. For this reason, the individuals performing the decontamination operations had to wear full pressurized air suits to prevent inhalation of the alpha particles. The primary steps to decontaminating the laboratory were:

- remove equipment
- remove glass and steel wall partitions
- decontaminate the laboratory.

Equipment removal involved segmenting the electromagnetic device used to separate the heavy metal isotopes by gas gouging and cutting, removing the concrete plinth supporting the electromagnetic device using concrete breakers, and chopping up an overhead runway beam using electric cutting equipment.

Paint stripping was used to decontaminate the laboratory walls while scabbling was used to decontaminate the concrete floor. The glass and steel wall panels were removed and packaged for disposal.

The entire decontamination operation was completed in 1987 with the facility being returned to laboratory use and declared a nonrestricted area.

3.3 DECOMMISSIONING EXPERIENCE AT AEROJET ORDINANCE TENNESSEE[4,5]

Aerojet Ordinance Tennessee has decommissioned two of its facilities over the last few years:

- a depleted uranium manufacturing facility located at Compton, California, that produced GAU-8 armor penetrators from depleted uranium

- an inactive evaporation pond located at Jonesboro, Tennessee, that had been used to process liquid wastes containing depleted uranium and thorium.

The depleted uranium manufacturing facility was located in a 5800-m^2 masonry commercial structure with 2.4-m-high ceilings and a concrete floor. Decontamination operations primarily involved removal of equipment and contaminated piping. Standard methods such as scrubbing, strippable coatings, vacuuming, wiping, and scabbling were used to clean the ceiling, walls, and floor. The entire decommissioning operation was started and completed in 1987 and the facility was released for uncontrolled use.

Decommissioning of the inactive evaporation pond utilized on-site disposal of the contaminated soil and proceeded in two stages:

- construction of a rockfilled berm around a portion of the pond

- excavation of contaminated soil and entombment of the soil in a clay cell.

Construction of the rockfilled berm consisted of standard methods for clearing, stripping, excavation, and rock placement. Closure of the pond involved excavation of contaminated soil from the bottom of the pond, preparation of the ground for use as a disposal site, placement of the contaminated soil on the prepared ground, and sealing the disposal site by covering the contaminated soil with layers of clay and topsoil followed by the planting of grass.

3.4 REFERENCES

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

2. B. J. Thomas. 1987. "Decommissioning of International Nutronics Cobalt-60 Irradiation Facility." In Proceedings of the 1987 International Decommissioning Symposium, Vol. 1, pp. III-68-III-76.

3. "Cleaning Up Hermes, an Alpha-Contaminated Facility." Nuclear Engineering International, August 1987.

4. D. E. Bernhardt, et al. 1987. "Decontamination and Decommissioning of Depleted Uranium Manufacturing Facility." In Proceedings of the 1987 International Decommissioning Symposium, Vol. 1, pp. III-176-III-188.

5. D. E. Bernhardt, et al. 1987. "Closure for a Depleted Uranium and Thorium Waste Pond." In Proceedings of the 1987 International Decommissioning Symposium, Vol. 1, pp. III-189-III-199.

6. U.S. Nuclear Regulatory Commission. 1982. Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material. Washington, D.C.

4.0 REVIEW OF ADVANCED VOLUME-REDUCTION TECHNOLOGIES

A considerable quantity of low-level radioactive waste (LLW) can be generated during decommissioning of non-fuel-cycle nuclear facilities. The rapid escalation in the costs of disposing of LLW at the existing shallow-land burial grounds over the last several years has correspondingly led to a pronounced escalation in the costs of decommissioning non-fuel-cycle nuclear facilities. The disposal costs can, however, be significantly reduced by taking steps to reduce the volume of the waste to be shipped to the disposal site. These steps include:

- significant preplanning and preparation to maintain waste volume generation as low as reasonably achievable
- establishment of procedures to segregate radioactive waste from non-radioactive waste
- applying volume-reduction techniques to the radioactive waste before shipment to the disposal site.

The first two steps are management and planning procedures to maintain the quantity of radioactive waste generated to begin with as low as possible. The latter step involves mechanically reducing the volume of the generated radioactive waste that must go to the LLW disposal site.

The purpose of this chapter is to investigate new volume-reduction technologies applicable to the decommissioning of non-fuel-cycle nuclear facilities. Because these facilities are generally laboratories that require only a small-scale decommissioning effort (usually of less than one-half year duration), only new volume-reduction technologies that require a minimum expenditure are reviewed. Older, well-developed volume-reduction technologies, such as waste compactors and metal and pipe sectioning equipment, are not discussed. Supercompactors and incinerators appear to be the two technologies available presently that could significantly reduce the volume of generated dry-active waste (DAW).

4.1 SUPERCOMPACTORS

Supercompactors operate on the same principle as regular compactors. However, whereas regular compactors generally apply a press force of a few hundred pounds per square inch, the press force of supercompactors reaches up to 10,000 pounds per square inch and higher. Consequently, significant volume-reduction factors are achievable and are dependent on the type of waste stream being compacted. For this study, supercompactor volume-reduction factors are defined as the ratio of the original waste container volume (including the container) to the final waste container volume (again including the container). According to this definition, therefore, two 208-ℓ drums compacted into one 208-ℓ drum has a volume-reduction factor (VRF) of 2.

The waste streams of interest from decommissioning operations include trash, filters, and sectioned metal waste. 208-ℓ drums containing uncompacted trash and filters can generally be supercompacted to a VRF of 4 or 5. However, 208-ℓ drums containing precompacted trash and filters can only be supercompacted to a VRF of 2 or 3. Even a VRF of 2 may be unachievable if significant quantities of plastics are present in the trash. This study assumes a VRF of 2 for precompacted waste.

Sectioned metal waste may be packaged in drums or boxes. The VRF achievable with metal waste varies significantly with how densely it is packed in the container. A VRF of 2.5 for metal waste is assumed for this study.

In general, the supercompactor takes the incoming waste, including the containers, and compresses everything into 208-ℓ (55-gal) drums. This technology is currently available to radioactive waste generators in three forms (1-4):

- permanent on-site installation (purchase)
- temporary on-site installation of a mobile facility (lease)
- regional facilities (pay-as-you-go).

Given the small-scale decommissioning operations that are the subject of this report, sending the waste to a regional supercompaction facility was considered the most cost-effective alternative.

4.2 INCINERATORS

Incineration technology has existed for many years. Only in the last several years, however, have attempts been made to apply this technology to incineration of LLW. As with supercompaction, incineration can yield significant volume-reduction factors that depend on the type of waste stream being incinerated. Incinerator volume-reduction factors only include the waste itself and not any containers. The volume-reduction factors achievable with incineration range from 80-100 for uncompacted trash and filters to 10-20 for precompacted trash and filters. A VRF of 10 is assumed for this study. Metal waste cannot be incinerated.

The extremely high volume-reduction factors possible with incineration, combined with the rapidly escalating costs of radioactive waste disposal, have provided an incentive to pursue this technology despite its inherently high costs. However, this technology has not gained widespread use due to regulatory and socio-political hurdles.

Incineration is currently offered or available to radioactive waste generators in three forms[3,5,6]:

- permanent on-site installation (purchase)
- temporary on-site installation of a mobile facility (lease)
- regional facilities (pay-as-you-go).

Given the small-scale decommissioning operations that are the subject of this report, sending the waste to a regional incineration facility was considered the most cost-effective alternative. However, because no such facilities currently exist (and probably will not for awhile), and because mobile incinerators have been built and operated, a mobile incinerator was judged to be the next most preferable alternative.

4.3 REFERENCES

1. P. C. Williams, W. S. Phillips, and P. Pals. 1986. "Supercompactor Force Effectiveness As Related To Dry Active Waste Volume Reduction," In Proceedings of the Waste Management '86 Symposium, Volume 3, pp. 419-432.

2. "Two-Trailer-Mounted SuperPak Supercompactors." Nuclear News, November 1987, p. 58.

3. C. R. Bowles, et. al. 1986. "Startup Experience and Operations of a Central Facility with an Incinerator and Super-Compactor," In Proceedings of the Waste Management '86 Symposium, Volume 3, pp. 275-278.

4. "Supercompaction Begun at CNSI Illinois Site." Nuclear News, June 1987, p. 83.

5. DiSalvo, Raymond and W. Zielenbach. 1987. "What It Took To Get An NRC License for Centralized Incineration," In Proceedings of the Waste Management '87 Symposium, Volume 3, pp. 285-290.

6. R. E. Sauer. 1986. "A Commercial Regional Incinerator Facility for Treatment of Low-Level Radioactive Waste." In Proceedings of the Waste Management '86 Symposium, Volume 3, pp. 283-290.

5.0 DECOMMISSIONING OF FACILITY COMPONENTS

Several facility components are common to the reference nuclear material processing and use laboratories described in Section 7 of NUREG/CR-1754.[1] These components include fume hoods, glove boxes, laboratory workbenches, hot cells, sinks and drains, ductwork, filters, and building surfaces such as floors, walls and ceilings. Some of these components experience significant radioactive contamination during the operational phase of a laboratory. Release of a laboratory for unrestricted use and termination of the radioactive material license requires that contaminated components either be 1) decontaminated to unrestricted release levels or 2) packaged and shipped to an authorized disposal site. The requirements and costs for decommissioning facility components by these DECON options are summarized in this chapter.

Removal of contamination that has penetrated to the interior of structural walls or beneath the primary surfacing on floors is not included in these generic analyses because the effort and cost of removal in these instances is very situation-specific.

Facility components common to the reference processing and use laboratories and the radioisotopes postulated to contaminate those components are shown in Table 5.1. Information in the table is based on the facility descriptions in Section 7 of NUREG/CR-1754.[1] DECON options for the different facility components are shown in Table 5.2. Analyses of these options are made to determine:

- decontamination procedures
- disassembly and disposal procedures
- manpower requirements
- packaging and shipping requirements
- decommissioning costs
- occupational radiation exposures.

The technical approach used to estimate requirements, costs, and occupational safety for decommissioning facility components is described in Section 5.1. Decommissioning analyses for individual components are presented in Section 5.2.

Cost and safety information for decommissioning the reference processing and use laboratories is presented in Chapter 6, based on the cost and occupational radiation dose estimates for decommissioning individual facility components developed in this chapter. This unit-component approach to the analysis of decommissioning is designed to provide data and examples to assist users of this study to estimate the requirements, costs, and safety of decommissioning other non-fuel-cycle nuclear facilities.

TABLE 5.1. Contaminated Facility Components Common to the Reference Processing and Use Laboratories

Facility Component	Type of Contamination ^{3}H	^{14}C	^{124}I	^{137}Cs	^{241}Am
Fume Hood	x[(a)]	x	x	x	x
Glove Box	x	x	x		x
Small Hot Cell				x	
Laboratory Workbench	x	x	x	x	x
Sinks and Drains		x	x	x	
Ventilation Ductwork	x	x	x	x	x
Building Surfaces	x	x	x	x	x

(a) An "x" indicates that the facility component is contaminated with the indicated isotope.

TABLE 5.2. DECON Options for Facility Components

Facility Component	DECON Option: Clean to Unrestricted Release Levels	Dismantle and Package for Disposal
Fume Hood	x[(a)]	x
Glove Box	x	x
Small Hot Cell	x	x
Laboratory Workbench	x	x
Sinks and Drains	x	x
Ventilation Ductwork		x
Building Surfaces[(b)]	x	

(a) An "x" indicates that the facility component can be decommissioned by the indicated option.
(b) Some contaminated material such as floor tiles or concrete chipped from walls might be packaged and shipped for disposal.

5.1 TECHNICAL APPROACH

The technical approach and some key bases used to define requirements and estimate costs and safety of decommissioning facility components are discussed in this section.

This study analyzes four alternative decommissioning scenarios:

- decontamination to unrestricted release levels
- disassembly and disposal of contaminated facility components without volume reduction
- disassembly and disposal of contaminated facility components using sectioning, compaction, and supercompaction
- disassembly and disposal of contaminated facility components using sectioning, compaction, and incineration.

The base-case scenario for determining the requirements and costs of disassembly and disposal for contaminated facility components assumes that components are packaged and shipped intact with a minimum of sectioning (i.e., cutting) and compaction. This approach reduces the time and costs of packaging, but maximizes disposal site costs that are determined on a per-unit-volume basis. To provide a basis for cost comparisons, estimates are made in Section 5.2 of the additional expense of waste segregation and volume-reduction procedures and of cost savings resulting from a reduction in the volume of waste shipped to the disposal site. This latter approach will require that bulky items such as fume hoods, glove boxes, and ductwork be cut up and supercompacted and that combustible wastes be segregated, compacted, and supercompacted or incinerated prior to being packaged for shipment to the disposal site.

The authorized disposal site is assumed to be a shallow-land burial ground located 800 km from the laboratory being decommissioned and from the centrally located supercompactor facility. The supercompactor facility is assumed to be located 350 km from the laboratory being decommissioned. Transportation of radioactive waste to the supercompactor facility and disposal site is assumed to be by exclusive-use truck. Transport of the waste is made in accordance with applicable federal, state, and local regulations.

5.1.1 Cost Estimates

Estimates of costs for both the decontamination option and the disassembly and disposal option are made for each facility component listed in Table 5.1. Costs include manpower, equipment and supplies, and waste management costs. Some key bases and assumptions for estimating costs are given in Appendix A. Unit costs are listed in Appendix D. All costs are expressed in January 1988 dollars and include a 25% contingency.

Decontamination of facility components is assumed to be performed by employees of the owner/operator of the facility. Manpower costs are determined by multiplying the man-days required to decommission a component by the costs per man-day shown in Appendix D. To determine the total time required to decommission a component, an estimate is made of the time required for efficient performance of the work by a postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc. (ancillary time).

The time required to complete a particular decommissioning task is usually estimated on the basis of a work crew consisting of a foreman and two technicians. The technicians are assumed to have had some experience working with radiochemicals, to be trained in radiological safety procedures, and to be capable of operating radiation survey equipment as well as the tools and equipment used to decontaminate the facility. Craftsmen such as electricians, pipefitters, sheet metal workers, etc., are assumed to be added to a work crew as the situation requires.

Several small equipment items such as wet-dry vacuums, power scrubbers, and steam cleaning equipment are used for decontaminating facility components. Because an equipment item is only used for a few days, it is not considered reasonable to charge its entire cost to the decommissioning of one component. However, some fraction of the cost of the equipment must be charged to each operation. To estimate equipment costs, a 1-year equipment lifetime is assumed and a charge of x/250 of the cost of the item is made, where x is the number of days required to decontaminate the component. Radiation survey equipment and equipment for the analysis of wipe samples are assumed to be readily available and not chargeable to decommissioning because such equipment is also used during the operation of the facility.

Waste management costs include supercompaction or incineration costs, container costs, transportation costs, and waste disposal charges. Transportation charges are based on the fraction of a truckload required to transport the decommissioning wastes from an individual facility component. It is assumed that one truckload consists of one hundred-twenty 208-ℓ steel drums or eighty 208-ℓ drums of supercompacted waste or 30 m^3 of plywood boxes. Because supercompaction, incineration, transportation, and waste disposal operations are contracted activities, manpower costs for these operations are included in the total costs of these items.

5.1.2 Occupational Radiation Dose Estimates

Estimates of occupational radiation doses for the decontamination option, the disassembly and disposal option without volume reduction, and the disassembly and disposal options with volume reduction are made for each facility component listed in Table 5.1. The estimated worker dose rates that form the bases for occupational dose calculations are given in Section 8 of NUREG/CR-1754.[1]

5.2 DECOMMISSIONING ANALYSES

Results of analyses of time and manpower requirements, total costs, and occupational radiation doses for decommissioning facility components are presented in this section. The analyses are performed for the various facility components and for the DECON options shown in Table 5.2. Total costs include the costs of manpower, equipment and supplies, and waste management (e.g., the packaging, transportation, and disposal of radioactive waste).

Details of time and manpower requirements and of estimated total costs for decommissioning facility components are presented in Appendix A. Appendix A also summarizes the key bases and assumptions used in estimating the requirements and costs of decommissioning. Unit costs of manpower, equipment, and supplies, and waste management activities are given in Appendix D.

Requirements and costs for the decontamination option are based on the cleaning of laboratory components to reduce residual surface contamination to unrestricted release levels. These contamination levels, as reported in NUREG/CR-1754, have not changed for this analysis.

Finally, many of the decontamination solutions that might be used during decontamination operations contain hazardous organic solvents. When used for decontamination, these solvents will also become radioactive. The resultant mixed waste product will therefore be subject to both the Resource Conservation and Recovery Act (RCRA) regulations and NRC regulations on final disposal. Since no existing disposal sites have as yet been approved for disposal of mixed waste, other, possibly more costly, decontamination methods may need to be used. However, for this analysis, a mixed waste disposal site is assumed to be available for the same cost as a low-level waste disposal site.

5.2.1 Fume Hoods

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a fume hood by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated hood at an authorized shallow-land burial site are shown in Table 5.3, summarized from Section A.1 of Appendix A. The reference fume hood decommissioned in this study had exterior dimensions of 1.5 m wide by 0.9 m deep by 2.1 m high.

A work crew that includes a foreman and two technicians is assumed to perform the work. Postulated procedures used to decontaminate the fume hoods are listed in Section E.1 of NUREG/CR-1754.[1]

The estimated total costs of decontamination of fume hoods range from about $5,900 to $7,700. Manpower costs represent between 30 and 45% of the total costs of decontamination. About one-third of the manpower costs are for the radiation surveys needed to establish residual contamination levels prior to starting decontamination operations and to verify compliance with unrestricted release guidelines when decontamination is completed. An increase (or decrease) of 1 day in the total time required to decontaminate a fume hood to unrestricted release levels would increase (or decrease) the total cost of decontamination by about $700.

Requirements and costs for the packaging and disposal option are shown (Table 5.3) for three cases: a case in which the hood is packaged without sectioning, a case in which the hood is sectioned and supercompacted and other wastes are compacted and supercompacted, and a case in which the hood is sectioned and other wastes are compacted and incinerated to reduce the volume of radioactive material shipped to a shallow-land burial ground. Total costs

TABLE 5.3. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of a Fume Hood[a]

DECON Option	Contaminant ^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Time (days)	3.0	2.6	3.0	3.0	4.9
Manpower (man-days)	9.0	7.9	9.0	9.0	14.6
Costs ($ thousands)[b]	6.0	5.9	6.2	6.2	7.7
Occupational Dose (man-rem)	1×10^{-2}	1×10^{-5}	4×10^{-5}	1×10^{-1}	1×10^{-1}
Packaging and Disposal w/o Volume Reduction					
Time (days)	2.5	2.5	2.5	2.5	3.4
Manpower (man-days)	8.5	8.5	8.5	8.5	11.6
Costs ($ thousands)[b]	9.5	9.5	9.5	9.5	10.2
Occupational Dose (man-rem)	2×10^{-2}	2×10^{-5}	7×10^{-5}	3×10^{-1}	2×10^{-1}
Packaging and Disposal w/Supercompaction					
Time (days)	4.0	4.0	4.0	4.0	4.9
Manpower (man-days)	14.5	14.5	14.5	14.5	17.6
Costs ($ thousands)[b]	6.5	6.5	6.5	6.5	7.1
Occupational Dose (man-rem)	4×10^{-2}	4×10^{-5}	1×10^{-4}	5×10^{-1}	3×10^{-1}
Packaging and Disposal w/Incineration					
Time (days)	4.0	4.0	4.0	4.0	4.9
Manpower (man-days)	14.5	14.5	14.5	14.5	17.6
Costs ($ thousands)[b]	7.0	7.0	7.0	7.0	7.7
Occupational Dose (man-rem)	4×10^{-2}	4×10^{-5}	1×10^{-4}	5×10^{-1}	3×10^{-1}

(a) Summarized from Section A.1.
(b) Costs are in January 1988 dollars.

for the three cases are significantly different. The added costs of sectioning and volume reduction are more than offset by waste management cost savings. High disposal costs make volume reduction a viable alternative to merely packaging the hood as a unit, since sectioning the hood would result in more efficient use of the shallow-land burial ground. Supercompaction appears to be preferable to incineration for volume reduction since both the hood and compactible waste can be supercompacted while only compactible waste can be incinerated and because incineration is considerably more expensive than supercompaction.

It is assumed that hoods contaminated with ^{241}Am can be disposed of by shallow-land burial. This may not be the case if the residual contamination level is greater than 100 nCi/gram of waste, equivalent to an average surface contamination on the interior surfaces of a steel hood of about 4×10^7 d/m/100 cm^2. If the average surface contamination exceeds this value, it may be necessary to partially decontaminate the hood or to provide for interim storage of the contaminated hood, since facilities for the permanent disposal of transuranic wastes are not yet available.

Occupational radiation doses are estimated by multiplying the appropriate dose rates (from Section 8 of NUREG/CR-1754) by the man-days required to decommission the fume hood. To estimate occupational doses for decontamination, because the exposure rate will decrease as the component is cleaned, the average dose rates are assumed to be one-half the values used for the packaging and disposal options. Occupational radiation doses for both the decontamination option and the packaging and disposal option are all estimated to be less than 0.5 man-rem.

5.2.2 Glove Boxes

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a glove box by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated glove box at an authorized shallow-land burial site are shown in Table 5.4, summarized from Section A.2 of Appendix A. The reference glove box decommissioned in this study had exterior dimensions of 0.9 m wide by 0.6 m deep by 0.6 m high.

A work crew consisting of a foreman and one technician is assumed to perform the work. Postulated procedures used to decontaminate the glove boxes are listed in Section E.2 of NUREG/CR-1754.[1]

The estimated total costs of decontamination of glove boxes range from about \$4,100 to \$5,700. Manpower costs represent about 30 to 40% of the total cost of decontamination. An increase (or decrease) of 1 day in the total time required to decontaminate a glove box to unrestricted release levels would increase (or decrease) the total cost of decontamination by about \$500.

Requirements and costs for the packaging and disposal option are shown (Table 5.4) for the case in which the glove box is packaged without sectioning, for the case in which the glove box is sectioned and supercompacted and other wastes are compacted and supercompacted, and for the case in which the glove box is sectioned and other wastes are compacted and incinerated to reduce the volume of radioactive material shipped to a shallow-land burial ground. Total costs for the four cases are approximately the same. The added costs of sectioning and volume reduction are almost entirely offset by waste management cost savings. This is due to the relatively small volume of waste generated and, therefore, small potential savings from volume reduction.

The costs of packaging and disposal of a glove box contaminated with ^{241}Am are estimated to be slightly higher than the costs of packaging and disposal of

TABLE 5.4. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of a Glove Box[a]

DECON Option	Contaminant				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Time (days)	2.6	1.9	2.6	--[b]	5.2
Manpower (man-days)	5.2	3.8	5.2	--	10.5
Costs ($ thousands)[c]	4.4	4.1	4.5	--	5.7
Occupational Dose (man-rem)	2×10^{-3}	5×10^{-7}	1×10^{-2}	--	4×10^{0}
Packaging and Disposal w/o Volume Reduction					
Time (days)	1.9	1.9	1.9	--[b]	2.6
Manpower (man-days)	5.2	5.2	5.2	--	7.5
Costs ($ thousands)[c]	4.0	4.0	4.0	--	4.5
Occupational Dose (man-rem)	3×10^{-3}	1×10^{-6}	2×10^{-2}	--	6×10^{0}
Packaging and Disposal w/Supercompaction					
Time (days)	2.6	2.6	2.6	--[b]	3.8
Manpower (man-days)	7.5	7.5	7.5	--	10.9
Costs ($ thousands)[c]	3.8	3.8	3.8	--	4.6
Occupational Dose (man-rem)	5×10^{-3}	2×10^{-6}	3×10^{-2}	--	8×10^{0}
Packaging and Disposal w/Incineration					
Time (days)	2.6	2.6	2.6	--[b]	3.8
Manpower (man-days)	7.5	7.5	7.5	--	10.9
Costs ($ thousands)[c]	4.0	4.0	4.0	--	4.7
Occupational Dose (man-rem)	5×10^{-3}	2×10^{-6}	3×10^{-2}	--	8×10^{0}

(a) Summarized from Section A.2.
(b) There are no glove boxes in the reference ^{137}Cs laboratory facility.
(c) Costs are in January 1988 dollars.

glove boxes contaminated with other radioisotopes. This is due primarily to the need to remove some contamination from inside surfaces prior to packaging to ensure that the 100 nCi/gram of transuranic waste limitation currently in effect at shallow-land burial grounds is not exceeded.

Occupational radiation doses are estimated by multiplying the appropriate dose rates (from Section 8 of NUREG/CR-1754) by the man-days required to decommission the glove box. To estimate occupational doses for decontamination, because the exposure rate will decrease as the component is cleaned, the average dose rates are assumed to be one-half the values used in the packaging and disposal options. Except for glove boxes contaminated with ^{241}Am, occupational radiation doses for both the decontamination option and the packaging and disposal option are all estimated to be less than 0.03 man-rem. The estimated occupational radiation dose for decommissioning a glove box contaminated with ^{241}Am is in the range of 1 to 10 man-rem. This estimated worker dose is due primarily to inhalation and would be reduced by one or two orders of magnitude through the use of protective respiration equipment.

5.2.3 Small Hot Cell

The only reference laboratory that contains a hot cell is the laboratory for the manufacture of ^{137}Cs sealed sources described in Section 7.1.4 of NUREG/CR-1754.[1]

Estimated manpower requirements, costs, and occupational radiation doses for decommissioning the reference hot cell by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of cell components at an authorized disposal site are presented in Table 5.5, summarized from Section A.3 of Appendix A. The reference hot cell decommissioned in this study was a 1.2-m cube (inside dimensions) with a 0.1-m wall thickness.

The total cost of the decontamination option is estimated to be about $8,600 and the total occupational radiation dose is estimated to be about 3 man-rem. For this option, it is assumed that the cell liner has been effective in preventing the contamination of all but a few of the lead bricks. If most of the bricks are contaminated, 2 or 3 additional days may be required to inspect and decontaminate the bricks at an additional cost of about $1,600.

Costs and occupational radiation doses for the packaging and disposal option are shown for the case in which there is no lead salvage all of the bricks are packaged and shipped to an approved mixed-waste burial ground[a] and for the cases in which the bricks are monitored and decontaminated with 65% of the bricks reclaimed and sold for salvage. Credit for lead salvage is based on a value of $1.25 per kilogram of lead. It is evident that the value of the lead bricks makes their reclamation an important consideration in the decommissioning operation.

As with glove boxes, there appears to be very little incentive for volume reduction of the wastes generated in the decommissioning of a small hot cell.

(a) Lead is classified as a hazardous waste product falling under the RCRA regulations. Lead generated from decommissioning operations is considered a mixed chemical-radioactive waste falling under both RCRA and NRC regulations. No existing disposal sites have as yet been approved for disposal of mixed waste, posing a special problem when disposing of radioactively contaminated lead. The cost of disposal at a mixed waste disposal ground was assumed to be the same as at a low-level waste disposal site.

TABLE 5.5. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of a Small Hot Cell[a]

Parameter	DECON Option				
	Decontamination	Packaging and Disposal without Lead Salvage	Packaging and Disposal without Volume-Reduction with Lead Salvage	Packaging and Disposal with Supercompaction with Lead Salvage	Packaging and Disposal with Incineration with Lead Salvage
Time (days)	5.3	3.4	7.9	8.6	8.6
Manpower (man-days)	15.8	12.4	25.1	28.1	28.1
Costs ($ thousands)[b]	8.6	10.1	12.0	11.9	12.3
Occupational Dose (man-rem)	3×10^0	4×10^0	8×10^0	9×10^0	9×10^0
Credit for Lead ($ thousands)	--	--	9.3	9.3	9.3

(a) Summarized from Section A.3.
(b) Costs are in January 1988 dollars.

Most of the decommissioning cost is for labor while only about 20% of the cost is for waste management. The small quantity of waste generated does not leave much room for savings from volume reduction.

5.2.4 Laboratory Workbenches

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a laboratory workbench by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated workbench at an authorized shallow-land burial site are shown in Table 5.6, summarized from Section A.4 of Appendix A. The reference laboratory workbench decommissioned in this study was 0.9 m high by 0.75 m wide by 4.6 m long.

Decontamination is performed by a work crew consisting of a foreman and one technician. The total cost for the decontamination option is estimated to

TABLE 5.6. Summary of Estimated Requirements, Total Costs, and Occupational Radiation Doses for DECON of a Laboratory Workbench[(a)]

DECON Option	Contaminant				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Time (days)	1.1	1.1	1.1	1.1	1.1
Manpower (man-days)	2.3	2.3	2.3	2.3	2.3
Costs ($ thousands)[(b)]	2.0	2.1	2.1	2.1	2.1
Occupational Dose (man-rem)	4×10^{-7}	4×10^{-7}	7×10^{-6}	2×10^{-5}	2×10^{-3}
Packaging and Disposal w/o Volume Reduction					
Time (days)	1.5	1.5	1.5	1.5	1.5
Manpower (man-days)	4.1	4.1	4.1	4.1	4.1
Costs ($ thousands)[(b)]	9.0	9.0	9.0	9.0	9.0
Occupational Dose (man-rem)	7×10^{-7}	7×10^{-7}	1×10^{-5}	3×10^{-5}	3×10^{-3}
Packaging and Disposal w/Supercompaction					
Time (days)	2.2	2.2	2.2	2.2	2.2
Manpower (man-days)	6.4	6.4	6.4	6.4	6.4
Costs ($ thousands)[(b)]	4.7	4.7	4.7	4.7	4.7
Occupational Dose (man-rem)	1×10^{-6}	1×10^{-6}	2×10^{-5}	5×10^{-5}	5×10^{-3}

(a) Summarized from Section A.4.
(b) Costs are in January 1988 dollars.

be about \$2,100, and occupational radiation doses are estimated to range from less than 1×10^{-6} man-rem to 2×10^{-3} man-rem, depending on the type of contamination. During decontamination of the workbench, most of the radiation dose to workers is from radioactive contamination on the floor and walls of the room in which the workbench is located.

For the packaging and disposal without volume-reduction option, an electrician and a pipefitter are temporarily added to the work crew to disconnect services. A second technician is added to the crew to assist in packaging the workbench. The bench is cut into two sections, each 2.3 m long, for ease of packaging. The total cost of the option is estimated to be about \$9,000, and occupational radiation doses are estimated to range from about 1×10^{-6} man-rem to 3×10^{-3} man-rem.

By utilizing volume reduction, the cost for the packaging and disposal option can be reduced significantly. This cost, which assumes volume reduction by sectioning and supercompaction, is about \$4,700. The incineration option is not possible since no combustible waste is generated.

5.2.5 Sinks and Drains

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning sinks and drains by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated sinks and associated piping at an authorized shallow-land burial site are shown in Table 5.7, summarized from Section A.5 of Appendix A. The reference sink and drain decommissioned in this study had a drain line with a diameter of 0.12 m and length of 10 m.

Sinks are located in the reference laboratories for the preparation of ^{14}C- or ^{125}I-labeled compounds and the laboratory for the manufacture of ^{137}Cs sealed sources. The sinks are used for personal cleanliness and for washing or rinsing non-contaminated glassware or glassware previously decontaminated. Contaminated liquids are not purposely discharged to the sanitary sewer via these sinks. Hence, the sinks are anticipated to have low levels of radioactive contamination.

A work crew that includes a foreman and one technician is assumed to perform the work. The total cost of the decontamination option is estimated to be about \$1,300, and occupational radiation doses are estimated to range from 4×10^{-7} man-rem to 4×10^{-5} man-rem.

For the packaging and disposal without volume reduction option, a contaminated sink, a trap, and 10 m of 0.12-m-diameter steel pipe are packaged and shipped to the shallow-land burial ground. A pipefitter is temporarily added to the work crew to disconnect the sink and cut the pipe. A second technician is added to the work crew to assist in packaging the components. The total cost of this packaging and disposal option is estimated to be about \$2,300, and occupational radiation doses are estimated to range from 6×10^{-7} man-rem to 6×10^{-5} man-rem.

TABLE 5.7. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of Sinks and Drains[a]

DECON Option	Contaminant ^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Time (days)	--[b]	1.2	1.2	1.2	--[b]
Manpower (man-days)	--	2.3	2.3	2.3	--
Costs ($ thousands)[c]	--	1.3	1.3	1.3	--
Occupational Dose (man-rem)	--	4×10^{-7}	6×10^{-6}	4×10^{-5}	--
Packaging and Disposal w/o Volume Reduction					
Time (days)	--[b]	1.3	1.3	1.3	--[b]
Manpower (man-days)	--	3.8	3.8	3.8	--
Costs ($ thousands)[c]	--	2.3	2.3	2.3	--
Occupational Dose (man-rem)	--	6×10^{-7}	9×10^{-6}	6×10^{-5}	--
Packaging and Disposal w/Supercompaction					
Time (days)	--[b]	1.7	1.7	1.7	--[b]
Manpower (man-days)	--	4.9	4.9	4.9	--
Costs ($ thousands)[c]	--	1.9	1.9	1.9	--
Occupational Dose (man-rem)	--	7×10^{-8}	1×10^{-5}	8×10^{-5}	--

(a) Summarized from Section A.5.
(b) There are no sinks or drains in the reference ^{3}H or ^{241}Am laboratory facilities.
(c) Costs are in January 1988 dollars.

If sectioning and supercompaction were used to reduce the volume of waste to be disposed, then the cost for the packaging and disposal option could be reduced to about $1,900. This reduction is at the expense of a slight increase in occupational radiation doses, however.

5.2.6 Ventilation Ductwork

Dirt and grime that accumulate on inside surfaces of ventilation ductwork make decontamination very difficult. Therefore, the usual practice when decommissioning a laboratory where radioactive materials have been processed is to package the ductwork for disposal at a shallow-land burial ground. Estimated time and manpower requirements, total costs, and occupational radiation doses for this DECON option are shown in Table 5.8, summarized from Section A.6 of Appendix A. The estimates are based on the packaging and disposal of 20 m of 0.20-m-diameter sheet metal ductwork plus 20 m of 0.25-m by 0.60-m rectangular

TABLE 5.8. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of Ventilation Ductwork[(a)]

DECON Option	Contaminant ^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging and Disposal w/o Volume Reduction					
Time (days)	3.8	3.8	3.8	3.8	4.5
Manpower (man-days)	9.8	9.8	9.8	9.8	12.0
Costs ($ thousands)[(b)]	11.8	11.8	11.8	11.8	12.3
Occupational Dose (man-rem)	2×10^{-6}	2×10^{-5}	2×10^{-5}	3×10^{-3}	2×10^{-2}
Packaging and Disposal w/Supercompaction					
Time (days)	5.2	5.2	5.2	5.2	6.4
Manpower (man-days)	14.2	14.2	14.2	14.2	17.6
Costs ($ thousands)[(b)]	6.1	6.1	6.1	6.1	7.1
Occupational Dose (man-rem)	3×10^{-6}	3×10^{-5}	1×10^{-4}	5×10^{-3}	3×10^{-2}
Packaging and Disposal w/Incineration					
Time (days)	5.2	5.2	5.2	5.2	6.4
Manpower (man-days)	14.2	14.2	14.2	14.2	17.6
Costs ($ thousands)[(b)]	6.9	6.9	6.9	6.9	7.9
Occupational Dose (man-rem)	3×10^{-6}	3×10^{-5}	1×10^{-4}	5×10^{-3}	3×10^{-2}

(a) Summarized from Section A.6.
(b) Costs are in January 1988 dollars.

sheet metal ductwork. Both the case in which the ductwork is packaged without compaction and the cases in which the ductwork is compacted before being packaged for shipment are evaluated.

The total costs of packaging and disposal are estimated to be $11,800 without compaction of the ductwork, $6,100 with compaction and supercompaction of the ductwork, and $6,900 with compaction of the ductwork and incineration of combustible wastes. Costs for the packaging of ductwork contaminated with ^{241}Am are estimated to be higher because of added precautions that increase the time needed to section and compact ductwork contaminated with this isotope. For the volume-reduction options, the additional costs of sectioning, supercompaction, and incineration are more than offset by the savings in waste management costs.

Occupational radiation doses are estimated to be less than 0.1 man-rem. The highest worker exposures are associated with the packaging of ^{241}Am-contaminated ductwork. These radiation exposures can be reduced one or two orders of magnitude if workers use protective respiratory equipment.

5.2.7 Building Surfaces

Building surfaces include walls and floors. Decontamination to unrestricted release levels is the DECON option evaluated for these surfaces. Contaminated material such as floor tiles or concrete chipped from walls is packaged and shipped to a shallow-land burial ground.

The reference laboratory rooms for these evaluations are assumed to measure 6 m by 10 m with walls 3 m high.

5.2.7.1 Walls

Estimated time and manpower requirements, total costs, and occupational radiation doses for decontamination of the walls of the reference laboratories to unrestricted release levels are shown in Table 5.9, summarized from Section A.7.1 of Appendix A.

A work crew that includes a foreman and two technicians is assumed to perform the work. The walls in the ^{3}H and ^{14}C laboratories are steam-cleaned, while the walls in the other laboratories are scrubbed with a decontaminating solution. Steam cleaning of the walls is estimated to require less time than decontamination by scrubbing. Walls in the ^{125}I and ^{241}Am laboratories are sealed with epoxy paint and acrylic paint, respectively. These walls are easier to decontaminate and require less recleaning of hot spots than the walls in the other laboratories that are covered with latex enamel paint.

The total costs of decontamination are estimated to range from about \$19,500 to \$21,900, depending on the type of contamination and the type of wall

TABLE 5.9. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of Walls[a]

DECON Option	Contaminant ^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Time (days)	9.8	9.8	10.5	11.2	10.5
Manpower (man-days)	29.2	29.2	31.5	33.8	31.5
Costs (\$ thousands)[b]	19.5	19.5	21.4	21.9	21.4
Occupational Dose (man-rem)	5×10^{-5}	2×10^{-5}	5×10^{-4}	8×10^{-4}	1×10^{-1}

(a) Summarized from Section A.7.1.
(b) Costs are in January 1988 dollars.

covering. Manpower costs represent about one-third of those total costs. Decommissioning waste (cleaning supplies and solidified decontamination liquids) is packaged for disposal in twenty-four 208-ℓ drums.

Occupational radiation doses are estimated to range from 2×10^{-5} man-rem to 1×10^{-1} man-rem. The occupational dose from cleaning the walls for the ^{241}Am laboratory can be reduced one or two orders of magnitude if workers use protective respiratory equipment.

5.2.7.2 Floors

Estimated time and manpower requirements, total costs, and occupational radiation doses for decontamination of the floors of the reference laboratories to unrestricted release levels are shown in Table 5.10, summarized from Section A.7.2 of Appendix A.

A work crew that includes a foreman and two technicians is assumed to perform the work. All of the floors are covered with asphalt tile except the floor in the ^{241}Am laboratory, which is covered with linoleum with heat-treated seams. Because the linoleum is free from cracks, it is easier to decontaminate and requires less recleaning than do the asphalt tile floors.

The total costs of decontamination are estimated to be $8,800 for the asphalt tile floors and $8,500 for the linoleum floor. Manpower costs represent about one-quarter of these total costs. Wastes from decontamination operations include four 208-ℓ drums of cleaning supplies and eight 208-ℓ drums of solidified liquids.

Occupational radiation doses are estimated to range from 2×10^{-6} man-rem to 7×10^{-2} man-rem. The occupational dose from cleaning the floor of the ^{241}Am laboratory can be reduced by worker use of protective respiratory equipment.

TABLE 5.10. Summary of Estimated Manpower Requirements, Total Costs, and Occupational Radiation Doses for DECON of Floors[a]

DECON Option	Contaminant ^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Time (days)	3.4	3.4	3.4	3.4	3.0
Manpower (man-days)	10.1	10.1	10.1	10.1	9.0
Costs ($ thousands)[b]	8.8	8.8	8.8	8.8	8.5
Occupational Dose (man-rem)	2×10^{-6}	8×10^{-6}	8×10^{-5}	3×10^{-4}	7×10^{-2}

(a) Summarized from Section A.7.2.
(b) Costs are in January 1988 dollars.

5.3 REFERENCES

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

6.0 DECOMMISSIONING OF REFERENCE FACILITIES

Estimated time and manpower requirements, occupational radiation doses, and total costs for decommissioning example laboratories that process or use radioisotopes are summarized in this chapter. The analysis uses cost and safety data for decommissioning laboratory components summarized in Chapter 5. The reference laboratories are described in Section 7 of NUREG/CR-1754[1] and include:

- a laboratory for the manufacture of ^{3}H-labeled compounds
- a laboratory for the manufacture of ^{14}C-labeled compounds
- a laboratory for the manufacture of ^{125}I-labeled compounds
- a laboratory for the manufacture of ^{137}Cs sealed sources
- a laboratory for the manufacture of ^{241}Am sealed sources
- a laboratory for preparing labeled compounds and radioactive sources and using these materials in experiments with small animals (the reference institutional user laboratory).

The technical approach used for this analysis is described in Section 6.1. The results of decommissioning analyses for the six reference laboratories are presented in Section 6.2. Details of manpower and of waste management requirements and costs for decommissioning the six reference laboratories are given in Appendix B.

6.1 TECHNICAL APPROACH

The technical approach and some key bases used to define requirements and to estimate costs and safety of decommissioning the six example radioactive materials laboratories are discussed in this section.

6.1.1 Costs

Costs for decommissioning the reference laboratories include the costs of staff labor, equipment, supplies, and waste management (the packaging, transportation, and disposal of radioactive waste). Estimates of costs for decommissioning the reference laboratories are based on estimates of costs for decommissioning laboratory components summarized in Chapter 5 from Appendix A. Some key bases and assumptions for estimating decommissioning costs are given in Appendix A. Cost estimating bases are listed in Appendix D. All costs are expressed in January 1988 dollars and include a 25% contingency.

Decommissioning of the reference laboratories is assumed to be performed by employees of the owners or operators of these laboratories. The basic decommissioning work crew is assumed to include a foreman and three technicians, assisted by a health physicist. Craftsmen (electricians, pipefitters, etc.) are added to this crew on a part-time basis to perform specific tasks. Manpower costs are postulated to include the salary of a supervisor on a half-time basis.

Staff labor costs are determined by multiplying the man-days required to decommission the laboratory by the cost per man-day shown in Appendix D. To determine the total time requirement for decommissioning, an estimate is made of the time required for efficient performance of the work by the postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc. (ancillary time).

In estimating the requirements and costs of decommissioning the reference laboratories, two options are analyzed. The first option assumes that components intended for shallow-land burial (fume hoods, glove boxes, ventilation ductwork, etc.) are packaged with a minimum of sectioning (i.e., cutting) and no compaction. (Fume hoods and glove boxes are packaged without sectioning, while other components such as drain lines and ventilation ductwork are sectioned for ease of handling and packaging in boxes that are approximately 1 m long.) This minimizes the time and manpower costs of packaging operations, but maximizes the volume of radioactive waste shipped to the shallow-land burial ground. It, therefore, maximizes transportation and waste disposal charges that are determined on a volume basis.

The second option assumes that components intended for shallow-land burial are sectioned and supercompacted at a centrally located supercompaction facility. Other compactible wastes in this option are assumed to be compacted on site and then sent to the supercompaction facility for supercompaction.

Some of the reference laboratories contain sinks into which low-level radioactive liquids are discharged. These liquids normally go to a hold-up tank that might be buried on the site. When a laboratory with a contaminated sink is decommissioned, it may also be necessary to remove the contaminated drain line and hold-up tank. The cost of removal of the drain line and hold-up tank is not included in the cost analyses of decommissioning the reference laboratories summarized in this section. However, the cost of decommissioning a site on which these items are buried is estimated in Chapter 7 to be about $69,200. This cost should be added to the cost of decommissioning the laboratory for those cases where removal of the drain line and hold-up tank is required.

6.1.2 Occupational Radiation Dose Estimates

Estimates of occupational radiation dose are made for the decommissioning of each reference laboratory. The estimated worker dose rates that form the bases for occupational dose calculations are shown in Section 8.1 of NUREG/CR-1754.(1) These dose rates are in reasonable agreement with experience at typical radioactive materials laboratories.

6.2 DECOMMISSIONING ANALYSES

Results of analyses of time and manpower requirements, occupational doses, and total costs for decommissioning the six reference laboratories are presented in this section. Two options are analyzed: DECON without volume reduction of the low-level wastes and DECON with volume reduction that includes sectioning and compaction on the laboratory site and supercompaction at a centrally located site. Requirements and costs for the planning and preparation phase, for the actual decommissioning phase, and for the final radiation survey to demonstrate compliance with unrestricted release guidelines are presented.

Details of manpower and waste management requirements and costs are given in Appendix B. Appendix B also contains descriptions of the DECON options postulated for decommissioning the various components and building surfaces of each reference laboratory.

6.2.1 Laboratory for the Manufacture of ^{3}H-Labeled Compounds

The reference laboratory for the manufacture of ^{3}H-labeled compounds is described in detail in Section 7.1.1 of NUREG/CR-1754.(1) The floor area of the laboratory is 10 m by 12 m.

Estimated time and manpower requirements, occupational radiation doses, and costs for decommissioning the reference ^{3}H laboratory are shown in Table 6.1, summarized from Section B.1 of Appendix B for both DECON options.

Planning and preparation is estimated to require about 6 weeks and 70 man-days of effort prior to the start of decommissioning operations. Decommissioning operations for the no-volume-reduction option are estimated to require about 7 weeks and 186 man-days of effort and to result in a total occupational radiation dose of about 0.1 man-rem. Including volume reduction increases the time for decommissioning operations to about 8 weeks and 212 man-days of effort with no significant increase in occupational radiation dose.

The total cost of decommissioning the reference laboratory is estimated to be about $149,000 for the no-volume-reduction option and $128,100 if volume reduction is included. Planning and preparation activities account for about 13% of the total cost for the no-volume-reduction option and 15% for the second option. Approximately 44% and 56% of the total cost is for staff labor (including planning and preparation activities) and approximately 47% and 32% is for waste management for the first and second options, respectively.

TABLE 6.1. Summary of Estimated Values of Manpower Requirements, Occupational Radiation Doses, and Costs for Decommissioning the Reference Laboratory for the Manufacture of ^3H-Labeled Compounds

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Total
DECON w/o Volume Reduction				
Time (days)	30	36	5	71
Manpower (man-days)	70	186	23	279
Occupational Dose (man-rem)	--	0.1	--	0.1
Cost ($ thousands)[a]				
Staff Labor	14.19	35.33	4.11	53.63
Equipment	--	3.74	--	3.74
Supplies	1.57	5.09	0.16	6.82
Waste Management	--	54.98	--	54.98
Subtotals	15.76	99.14	4.27	119.17
25% Contingency	3.94	24.79	1.07	29.79
Totals	19.7	123.9	5.3	149.0
DECON w/ Volume Reduction				
Time (days)	30	41	5	76
Manpower (man-days)	70	212	23	305
Occupational Dose (man-rem)	--	0.1	--	0.1
Costs ($ thousands)[a]				
Staff Labor	14.19	40.32	4.11	58.62
Equipment	--	4.05	--	4.05
Supplies	1.57	5.54	0.16	7.27
Waste Management	--	32.55	--	32.55
Subtotals	15.76	82.46	4.27	102.49
25% Contingency	3.94	20.62	1.07	25.62
Totals	19.7	103.1	5.3	128.1

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

6.2.2 Laboratory for the Manufacture of ^{14}C-Labeled Compounds

The reference laboratory for the manufacture of ^{14}C-labeled compounds is described in detail in Section 7.1.2 of NUREG/CR-1754.(1) The floor area of the laboratory is 10 m by 8 m.

Estimated time and manpower requirements, occupational radiation doses, and costs for decommissioning the reference ^{14}C laboratory are shown in Table 6.2, summarized from Section B.2 of Appendix B for both DECON options.

Planning and preparation is estimated to require about 6 weeks and 66 man-days of effort prior to the start of decommissioning operations. Decommissioning operations are estimated to require about 6 weeks and 146 man-days of effort, and to result in a total occupational radiation dose of about 0.001 man-rem. Including volume reduction increases that time for decommissioning operations to about 7 weeks and 162 man-days of effort and no significant increase in occupational radiation exposure.

The total cost of decommissioning the reference laboratory is estimated to be about $125,500 for the no-volume-reduction option and $110,100 if volume reduction is included. Planning and preparation activities account for about 15% of the total cost for the no-volume-reduction option and 17% for the second option. Approximately 44% and 54% of the total cost is for staff labor (including planning and preparation activities) and approximately 44% and 32% is for waste management for the first and second options, respectively.

6.2.3 Laboratory for the Manufacture of ^{125}I-Labeled Compounds

The reference laboratory for the manufacture of ^{125}I-labeled compounds is described in detail in Section 7.1.3 of NUREG/CR-1754.(1) The floor area of the laboratory is 6 m by 8 m.

Estimated time and manpower requirements, occupational radiation doses, and costs for decommissioning the reference ^{125}I laboratory are shown in Table 6.3, summarized from Section B.3 of Appendix B for both DECON options.

TABLE 6.2. Summary of Estimated Values of Manpower Requirements, Occupational Radiation Doses, and Costs for Decommissioning the Reference Laboratory for the Manufacture of ^{14}C-Labeled Compounds

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Total
DECON w/o Volume Reduction				
Time (days)	28	29	5	62
Manpower (man-days)	66	146	23	235
Occupational Dose (man-rem)	--	0.001	--	0.001
Cost ($ thousands)[(a)]				
Staff Labor	13.37	27.58	4.11	45.06
Equipment	--	3.32	--	3.32
Supplies	1.57	6.53	0.16	8.26
Waste Management	--	43.74	--	43.74
Subtotals	14.94	81.17	4.27	100.38
25% Contingency	3.74	20.29	1.07	25.10
Totals	18.7	101.5	5.3	125.5
DECON w/ Volume Reduction				
Time (days)	28	32	5	65
Manpower (man-days)	66	162	23	251
Occupational Dose (man-rem)	--	0.001	--	0.001
Costs ($ thousands)[(a)]				
Staff Labor	13.37	30.66	4.11	48.14
Equipment	--	3.50	--	3.50
Supplies	1.57	6.95	0.16	8.68
Waste Management	--	27.76	--	27.76
Subtotals	14.94	68.87	4.27	88.08
25% Contingency	3.74	17.22	1.07	22.02
Totals	18.7	86.1	5.3	110.1

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

TABLE 6.3. Summary of Estimated Values of Manpower Requirements, Occupational Radiation Doses and Costs for Decommissioning the Reference Laboratory for the Manufacture of ^{125}I-Labeled Compounds

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Total
DECON w/o Volume Reduction				
Time (days)	29	29	3	61
Manpower (man-days)	66	150	14	230
Occupational Dose (man-rem)	--	0.1	--	0.1
Cost ($ thousands)[(a)]				
Staff Labor	13.37	28.40	2.46	44.23
Equipment	--	2.82	--	2.82
Supplies	1.57	5.90	0.16	7.63
Waste Management	--	29.96	--	29.96
Subtotals	14.94	67.08	2.62	84.64
25% Contingency	3.74	16.77	0.66	21.16
Totals	18.7	83.85	3.3	105.8
DECON w/ Volume Reduction				
Time (days)	29	32	3	64
Manpower (man-days)	66	178	14	257
Occupational Dose (man-rem)	--	0.1	--	0.1
Costs ($ thousands)[(a)]				
Staff Labor	13.37	31.83	2.46	47.66
Equipment	--	3.00	--	3.00
Supplies	1.57	6.35	0.16	8.08
Waste Management	--	20.87	--	20.87
Subtotals	14.94	62.05	2.62	79.61
25% Contingency	3.74	15.51	0.66	19.90
Totals	18.7	77.6	3.3	99.5

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

Planning and preparation is estimated to require about 6 weeks and 66 man-days of effort prior to the start of decommissioning operations. Decommissioning operations are estimated to require about 6 weeks and 150 man-days of effort, and to result in a total occupational radiation dose of about 0.1 man-rem. Including volume reduction increases the time for decommissioning operations to about 7 weeks and 178 man-days of effort and results in no significant increase in occupational radiation exposure.

The total cost of decommissioning the reference laboratory is estimated to be about $105,800 for the no-volume-reduction option and $99,500 if volume reduction is included. Planning and preparation activities account for about 17% of the total cost for the no-volume-reduction option and 19% for the second option. Approximately 51% and 59% of the total cost is for staff labor (including planning and preparation activities) and approximately 36% and 27% is for waste management for the first and second options, respectively.

6.2.4 Laboratory for the Manufacture of ^{137}Cs Sealed Sources

The reference laboratory for the manufacture of ^{137}Cs sealed sources is described in detail in Section 7.1.4 of NUREG/CR-1754.[1] The floor area of the laboratory is 6 m by 8 m.

Estimated time and manpower requirements, occupational radiation doses, and costs for decommissioning the reference ^{137}Cs laboratory are shown in Table 6.4, summarized from Section B.4 of Appendix B for both DECON options.

Planning and a preparation is estimated to require about 6 weeks and 62 man-days of effort prior to the start of decommissioning operations. Decommissioning operations are estimated to require about 6 weeks and 150 man-days of effort and to result in a total occupational radiation dose of about 6.0 man-rem. Including volume reduction increases the time for decommissioning operations to 158 man-days of effort and results in no significant increase in occupational radiation exposure.

The total cost of decommissioning the reference laboratory is estimated to be about $106,100 for the no-volume-reduction option and $99,700 if volume reduction is included. Planning and a preparation activities account for about 17% of the total cost for the no-volume-reduction option and 18% for the second option. Approximately 51% and 56% of the total cost is for staff labor (including planning and preparation activities) and approximately 32% and 25% is for waste management for the fist and second options, respectively.

Costs for decommissioning the reference ^{137}Cs laboratory are estimated on the basis that the small hot cells are dismantled and the lead bricks are surveyed for residual contamination and decontaminated when it is practical to do

TABLE 6.4. Summary of Estimated Values of Manpower Requirements, Occupational Radiation Doses, and Costs for Decommissioning the Reference Laboratory for the Manufacture of ^{137}Cs Sealed Sources

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Total
DECON w/o Volume Reduction				
Time (days)	28	29	3	60
Manpower (man-days)	62	150	14	226
Occupational Dose (man-rem)	--	6	--	6
Cost ($ thousands)(a)				
Staff Labor	12.82	28.40	2.46	43.68
Equipment	--	7.02	--	7.02
Supplies	1.57	5.81	0.16	7.54
Waste Management	--	26.61	--	26.61
Subtotals	14.39	67.84	2.62	84.85
25% Contingency	3.60	16.96	0.66	21.21
Totals	18.0	84.8	3.3	106.1
Credit for Lead Salvage ($ thousands)	--	--	--	18.7
DECON w/ Volume Reduction				
Time (days)	28	30	3	61
Manpower (man-days)	62	158	14	234
Occupational Dose (man-rem)	--	6	--	6
Costs ($ thousands)(a)				
Staff Labor	12.82	29.94	2.46	45.22
Equipment	--	7.11	--	7.11
Supplies	1.57	5.81	0.16	7.54
Waste Management	--	19.89	--	19.89
Subtotals	14.39	62.75	2.62	79.76
25% Contingency	3.60	15.69	0.66	19.94
Totals	18.0	78.4	3.3	99.7
Credit for Lead Salvage ($ thousands)	--	--	--	18.7

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

so.[a] A credit of $18,700 is shown in Table 6.4 for the salvage of 65% of the lead bricks from the two hot cells. This is based on an estimated value of $1.25 per kilogram of lead. It is evident that salvage of the lead bricks can result in a fairly significant reduction in the net cost of decommissioning this laboratory.

6.2.5 Laboratory for the Manufacture of ^{241}Am Sealed Sources

The reference laboratory for the manufacture of ^{241}Am sealed sources is described in detail in Section 7.1.5 of NUREG/CR-1754.[1] The floor area of the laboratory is 7 m by 9 m.

Estimated time and manpower requirements, occupational radiation doses, and costs for decommissioning the reference ^{241}Am laboratory are shown in Table 6.5, summarized from Section B.5 of Appendix B for both DECON options.

Planning and preparation is estimated to require about 6 weeks and 68 man-days of effort prior to the start of decommissioning operations. Decommissioning operations are estimated to require about 10 weeks and 245 man-days of effort, and to result in a total occupational radiation dose of about 40 man-rem. Including volume reduction increases the time for decommissioning operations to 268 man-days of effort and results in an increase in total occupational radiation dose to about 50 man-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $150,400 for the no-volume-reduction option and $138,900 if volume-reduction is included. Planning and preparation activities account for about 13% of the total cost for the no-volume-reduction option and 14% for the second option. Approximately 53% and 61% of the total cost is for staff labor (including planning and preparation activities) and approximately 35% and 26% is for waste management for the first and second options, respectively.

6.2.6 Institutional User Laboratory

The reference institutional user laboratory is described in detail in Section 7.2 of NUREG/CR-1754.[1] The floor area of the laboratory is 11 m by 16 m.

Estimated time and manpower requirements, occupational radiation doses, and costs for decommissioning the reference institutional user laboratory are shown in Table 6.6, summarized from Section B.6 of Appendix B for both DECON options.

(a) Lead is classified as a hazardous waste product falling under the Resource Conservation and Recovery Act (RCRA) regulations. Lead generated from decommissioning operations is considered a mixed chemical radioactive waste falling under both RCRA and NRC regulations. No existing disposal sites have as yet been approved for disposal of mixed waste, posing a special problem when disposing of radioactively contaminated lead.

TABLE 6.5. Summary of Estimated Values of Manpower Requirements, Occupational Radiation Doses, and Costs for Decommissioning the Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Total
DECON w/o Volume Reduction				
Time (days)	30	46	5	81
Manpower (man-days)	68	245	23	336
Occupational Dose[a] (man-rem)	--	40	--	40
Cost ($ thousands)[b]				
Staff Labor	13.91	46.70	4.11	64.72
Equipment	--	3.75	--	3.75
Supplies	1.57	8.56	0.16	10.29
Waste Management	--	41.57	--	41.57
Subtotals	15.48	100.58	4.27	120.33
25% Contingency	3.87	25.15	1.07	30.08
Totals	19.4	125.7	5.3	150.4
DECON w/ Volume Reduction				
Time (days)	30	51	5	86
Manpower (man-days)	68	268	23	359
Occupational Dose[a] (man-rem)	--	50	--	50
Costs ($ thousands)[b]				
Staff Labor	13.91	50.78	4.11	68.80
Equipment	--	3.94	--	3.94
Supplies	1.57	8.56	0.16	10.29
Waste Management	--	28.10	--	28.10
Subtotals	15.48	91.38	4.27	111.13
25% Contingency	3.87	22.85	1.07	27.78
Totals	19.4	114.2	5.3	138.9

(a) Estimated on the assumption that workers do not use protective respiratory equipment. Doses could be reduced by 1 or 2 orders of magnitude through the use of this equipment.
(b) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

TABLE 6.6. Summary of Estimated Values of Manpower Requirements, Occupational Radiation Doses, and Costs for Decommissioning the Reference Institutional User Laboratory

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Total
DECON w/o Volume Reduction				
Time (days)	30	32	8	70
Manpower (man-days)	70	164	36	270
Occupational Dose (man-rem)	--	0.1	--	0.1
Cost ($ thousands)[(a)]				
Staff Labor	14.19	31.17	6.58	51.94
Equipment	--	3.50	--	3.50
Supplies	1.57	5.72	0.16	7.45
Waste Management	--	43.28	--	43.28
Subtotals	15.76	83.67	6.74	106.17
25% Contingency	3.94	20.92	1.69	26.54
Totals	19.7	104.6	8.4	132.7
DECON w/ Volume Reduction				
Time (days)	30	35	8	73
Manpower (man-days)	70	177	36	283
Occupational Dose (man-rem)	--	0.1	--	0.1
Costs ($ thousands)[(a)]				
Staff Labor	14.19	33.67	6.58	54.44
Equipment	--	3.68	--	3.68
Supplies	1.57	5.72	0.16	7.45
Waste Management	--	26.63	--	26.63
Subtotals	15.76	69.70	6.74	92.20
25% Contingency	3.94	17.43	1.69	23.05
Totals	19.7	87.1	8.4	115.3

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

Planning and preparation is estimated to require about 6 weeks and 70 man-days of effort prior to the start of decommissioning operations. Decommissioning operations are estimated to require about 7 weeks and 164 man-days of effort, and to result in a total occupational radiation dose of about 0.1 man-rem. Including volume reduction increases the time for decommissioning operations to 177 man-days of effort and results in no significant increase in occupational radiation dose.

The total cost of decommissioning the reference laboratory is estimated to be about $132,700 for the no-volume-reduction option and $115,300 if volume reduction is included. Planning and preparation activities account for about 15% of the total cost for the no-volume-reduction option and 17% for the second option. Approximately 48% and 58% of the total cost is for staff labor (including planning and preparation activities) and approximately 41% and 29% is for waste management for the first and second options, respectively.

6.3 REFERENCES

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

7.0 DECOMMISSIONING OF REFERENCE SITES

Information on the technology, costs, and occupational radiation doses for decommissioning several example sites is presented in this chapter. The reference sites chosen for analysis are 1) a site with a contaminated underground drain line and hold-up tank, 2) a site with a contaminated ground surface, and 3) a tailings pile/evaporation pond containing uranium and thorium residues. These sites are described in Section 7.3 of NUREG/CR-1754.[1]

The technical approach used to estimate requirements, costs, and safety is described in Section 7.1. The results of decommissioning analyses for individual sites are presented in Section 7.2. Details of decommissioning the reference sites are presented in Appendix C.

7.1 TECHNICAL APPROACH

The technical approach and most key bases used to define requirements and estimate costs and safety of decommissioning the reference sites have not changed since publication of NUREG/CR-1754[1] and can be found in Section 10.1 of that document. New or revised bases are discussed below.

7.1.1 Cost Estimates

Cost estimates are made in this study for the decommissioning of three example sites, namely: 1) a site with a contaminated drain line and hold-up tank, 2) a site with a contaminated ground surface, and 3) a tailings pile containing uranium and thorium residues. For the first two sites, it is assumed that unrestricted release of the sites is desirable. Therefore, costs are estimated for exhumation of the contaminated waste and soil and disposal of the material at a shallow-land burial ground. For the tailings pile/evaporation pond, costs are estimated for both the site stabilization and the removal options. Costs are expressed in January 1988 dollars and include a 25% contingency. Some key bases and assumptions for estimating costs are given in Appendix C. Cost estimating bases are given in Appendix D.

Total costs include the costs of manpower, equipment, materials, and waste management (the packaging, transportation, and disposal of radioactive material removed from the site). Because transportation to and disposal at a shallow-land burial ground are contracted activities, manpower costs for transportation and disposal are included in the total costs of these items.

Manpower costs are determined by multiplying the man-days required to decommission a site by the cost per man-day shown in Table D.1 of Appendix D. For ease in evaluating time and manpower requirements, site decommissioning is divided into a sequence of tasks or steps. For the site stabilization option, these steps are:

- planning and preparation (including initial site survey)
- mobilization/demobilization
- site stabilization
- revegetation

For the removal option, these steps are:

- planning and preparation (including initial site survey)
- mobilization/demobilization
- remove overburden
- exhume and package contaminated material
- transport and dispose of contaminated material at a shallow-land burial ground
- backfill and restore site
- final site survey.

To determine the total time required to decommission a site, an estimate is made of the time required for efficient performance of the work by the postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc. (ancillary time).

The owner/operator of a site is assumed to perform his own site survey. (Soil samples are analyzed by a commercial laboratory.) Site stabilization or waste and soil removal activities are assumed to be performed by a contractor hired by the owner/operator of the site. The impact on decommissioning costs of utilizing a contractor is discussed in Section D.1 of NUREG/CR-1754.(1) The contractor is anticipated to receive payment consisting of reimbursement for expenses (i.e., manpower, equipment, and material costs), plus a fee to provide a reasonable profit for this efforts. For this study, the contractor's fee is calculated on the basis of 8% of the sum of his manpower, equipment, materials, and package costs. This rate is judged to be reasonable for the size and complexity of the decommissioning projects. Transportation and disposal tasks are performed by separate contractors hired by the site owner/operator.

Overhead rates applied to staff labor are expected to be significantly higher for the decommissioning contractor than they are for the site owner/operator. These higher overhead rates apply because of the larger ratio of supervisory and support personnel to direct labor that usually exists in contractor organizations and because of travel and living expenses associated with having personnel in the field rather than in an office. In Table D.1, an overhead rate of 110% is applied to direct staff labor for all contractor personnel. The work crew for site decommissioning operations consists of a supervisor (assigned to the project on a half-time basis), a foreman, equipment operators, truck drivers, and technicians who are part of the contractor's staff; and a health physicist from the owner/operator's staff.

Monthly charges for equipment owned by the decommissioning contractor are calculated on the basis of 6% of the capital cost of the equipment and include allowances for equipment depreciation, maintenance and operating expenses (e.g., fuel, lubrication, etc.), the cost of decontamination following use, and return on investment. The equipment costs do not include the operator's wage. Weekly charges are estimated to be approximately one-third of the monthly charges.

Mobilization and demobilization costs are determined by estimating the times required for these activities. Costs of manpower and equipment are adjusted to include these time periods as well as the actual time spent decommissioning the site.

7.2 DECOMMISSIONING ANALYSES

Results of analyses of time and manpower requirements, total costs, and occupational radiation doses for decommissioning three reference sites are presented in this section. The sites and the decommissioning options evaluated are shown in Table 7.1. Total costs of decommissioning include the costs of manpower, equipment, materials, waste management (e.g., the packaging, transportation, and disposal of radioactive waste), and contractor's fees, where applicable.

Details of time and manpower requirements and of total costs for decommissioning the reference sites are presented in Appendix C.

TABLE 7.1. Decommissioning Options for Sites

Site	Decommissioning Option: Site Stabilization	Decommissioning Option: Removal
Underground Drain Line and Hold-up Tank		x[a]
Contaminated Ground Surface		x
Tailings Pile/Evaporation Pond	x	x

(a) An "x" indicates that the site is decomissioned by the indicated option.

7.2.1 Contaminated Underground Drain Line

The reference contaminated underground drain line consists of 20 m of 0.1-m-diameter cast-iron pipe and a 1.5-m-diameter by 2-m-high cylindrical steel tank.

Estimated time and manpower requirements, total costs, and occupational radiation doses for removal of a contaminated drain line, hold-up tank, and soil are presented in Table 7.2, summarized from Section C.1 of Appendix C. Of the total of 17 work days required for this waste removal operation, 5 work days are required for planning and preparation activities (including the initial radiation survey) that precede the actual decommissioning operations. The total cost of decommissioning is estimated to be about $69,300. Occupational radiation doses are estimated to total about 0.04 man-rem, based on an average worker dose rate of 0.1 mrem/hr.

TABLE 7.2. Summary of Estimated Manpower Requirements, Costs, and Occupational Radiation Doses for the Removal of a Contaminated Drain Line and Hold-Up Tank

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Totals
Time (days)	5	10	2	17
Manpower (man-days)	14	51	7	72
Occupational Dose (man-rem)	--	0.04	--	0.04
Costs ($ thousands)(a)				
Staff Labor	3.51	13.36	1.44	18.31
Equipment	4.15	11.55	0.80	16.50
Materials	0.28	2.40	0.14	2.82
Soil Analyses	4.80	--	1.60	6.40
Contractor's Fee	--	3.07	--	3.07
Waste Management		8.34	--	8.34
Subtotals	12.7	38.7	4.0	55.4
25% Contingency	3.2	9.7	1.0	13.9
Totals	15.9	48.4	5.0	69.3

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

Details of waste removal operations are given in Section G.2 of NUREG/CR-1754.[1] The drain line is cut into 2-m sections for ease of packaging. The hold-up tank is packaged as a unit without cutting. After removal from the ground, the drain line, hold-up tank, and 2 m^3 of contaminated soil are packaged in plastic-lined plywood boxes and shipped by truck to a shallow-land burial ground for disposal.

Cost details are presented in Table C.2 of Appendix C. Manpower costs represent about one-third of the total decommissioning cost. Costs of the initial and final site surveys (including manpower, equipment, and soil analysis costs) are about 28% of the total cost.

7.2.2 Contaminated Ground Surface

The reference site containing contaminated ground surface occupies an area of about 40,000 m^2 and contains approximately 1000 m^3 of contaminated ground surface.

Estimated time and manpower requirements, total costs, and occupational radiation doses for the removal of contaminated soil from the surface of a reference site are presented in Table 7.3, summarized from Section C.2 of Appendix C. Of the total of 42 work days required for this waste removal operation, 20 work days are required for planning and preparation activities (including the initial site survey) that precede the actual decommissioning operations. The total cost of radiological surveys, removal of the contaminated soil, and restoration of the site is estimated to be about $1,829,000. Occupational radiation doses are estimated to total about 0.14 man-rem, based on an average worker dose rate of 0.1 mrem/hr.

Details of site survey and waste removal operations are given in Section G.3 of NUREG/CR-1754.[1] The reference site occupies 4 x 10^4 m^2 (approximately 10 acres). It is assumed to be contaminated with radioactive residue from uranium processing operations, with the residue originally trucked to the site from another location for use as fill material. Following a radiological survey to locate concentrations of fill material, approximately 1000 m^3 of contaminated soil is removed from the site. This soil is packaged in plastic-lined plywood boxes and shipped to a shallow-land burial ground. The site is then backfilled and graded and a final radiological survey is performed to verify the suitability of the site for unrestricted release. The operations for decommissioning this reference site are believed to be typical of requirements for the decommissioning of sites where operations included onsite burial of radioactive waste. The costs for onsite disposal could, however, be considerably less than costs for disposal at a shallow-land burial ground.

Cost details are presented in Table C.4 of Appendix C. Manpower costs represent only about 3% of the total decommissioning cost, with waste management costs (costs of packaging, transportation, and disposal of the exhumed soil) accounting for about 89% of the total decommissioning cost. Costs of the initial and final site surveys (including manpower, equipment, and soil analysis costs) are about 7% of the total cost.

TABLE 7.3. Summary of Estimated Manpower Requirements, Costs, and Occupational Radiation Doses for the Removal of Contaminated Soil from a Reference Site

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Totals
Time (days)	20	17	5	42
Manpower (man-days)	70	110	23	203
Occupational Dose (man-rem)	--	0.14	--	0.14
Costs ($ thousands)[a]				
Staff Labor	16.36	29.64	4.44	50.44
Equipment	8.30	29.30	0.80	38.40
Materials	1.64	17.15	0.41	19.20
Soil Analyses	72.00	--	4.80	76.80
Contractor's Fee	--	16.17	--	16.17
Waste Management	--	1262.57	--	1262.57
Subtotals	98.3	1354.8	10.5	1463.6
25% Contingency	24.6	338.7	2.6	365.9
Totals	122.9	1693.5	13.1	1829

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

7.2.3 Tailings Pile/Evaporation Pond

The reference tailings pile/evaporation pond is located on a 20,000 m^2 site and has dimensions of 100 m long by 50 m deep, with a 2.5 to 1 slope on each side.

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a tailings pile/evaporation pond by the option of stabilization are presented in Table 7.4, summarized from Section C.3 of Appendix C. The annual requirements and costs of long-term care following stabilization are also shown in Table 7.4. The cost of stabilization is estimated to be about $334,000, and the occupational radiation dose for this option is estimated to be 0.08 man-rem. The annual cost of long-term care is estimated to be about $12,000, and the annual occupational radiation dose is estimated to be about 0.01 man-rem.

TABLE 7.4. Summary of Estimated Manpower Requirements, Costs, and Occupational Radiation Doses for Stabilization of a Reference Tailings Pile/Evaporation Pond

Parameter	Site Stabilization: Planning & Preparation	Site Stabilization: Decommissioning	Site Stabilization: Totals	Long-Term Care (Annual Values)
Time (days)	20	12	32	10
Manpower (man-days)	70	104	174	27
Occupational Dose (man-rem)	--	0.08	0.08	0.01
Costs ($ thousands)[a]				
Staff Labor	15.71	27.18	42.89	5.19
Equipment	4.15	32.50	36.65	1.60
Materials	1.60	158.78	160.38	0.80
Soil Analyses	7.90	--	7.90	1.60
Contractor's Fee	--	19.20	19.20	--
Waste Management	--	--	--	--
Subtotals	29.4	237.7	267.0	9.2
25% Contingency	7.4	59.4	66.8	2.3
Totals	36.8	297.1	334	12

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

Requirements and costs for removal of the pile/pond are shown in Table 7.5. The cost of removal of the pile/pond and its disposal at a shallow-land burial ground is estimated to be about $31 million, and the occupational radiation dose for this option is estimated to be 1.0 man-rem.

The tailings pile/evaporation pond is described in Section 7.3 of NUREG/CR-1754.[1] The pile contains the residue from ore refinery operations in which tin slag is processed for the recovery of niobium and tantalum. The tin slag is estimated to contain 0.2 wt% U_3O_8 and 0.5 wt% ThO_2. The sludge from processing operations, which contains essentially all of the thorium and uranium, is pumped to a settling pond, where the water is allowed to evaporate, converting the sludge to a glassy solid. Additional information about the reference tailings pile (or pond) and its contents is shown in Table 7.6.

Decommissioning begins with planning and preparation activities that include a radiological survey to determine the radiological condition of the

TABLE 7.5. Summary of Estimated Manpower Requirements, Costs, and Occupational Radiation Doses for Removal of a Reference Tailings Pile/Evaporation Pond

Parameter	Planning & Preparation	Decommissioning	Final Radiation Survey	Totals
Time (days)	20	114	5	139
Manpower (man-days)	70	1,569	18	1,657
Occupational Dose (man-rem)	--	1.0	--	1.0
Costs ($ thousands)[a]				
Staff Labor	15.71	418.98	3.79	438.48
Equipment	4.15	157.80	1.60	163.55
Materials	1.60	124.58	0.80	126.98
Soil Analyses	7.90	--	3.15	11.05
Contractor's Fee	--	200.52	--	201.54
Waste Management	--	24,058.70	--	24,058.70
Subtotals	29.4	24,960.6	9.3	25,000.3
25% Contingency	7.4	6,240.2	2.3	6,250.1
Totals	36.8	31,200.8	11.6	31,250

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

TABLE 7.6. Some Characteristics of the Reference Tailings Pile/Evaporation Pond

Parameter	Value
Volume of Pond	16,400 m^3
Weight of Residue	4.1×10^7 kg
U_3O_8 Concentration	0.2 wt%
Contained U_3O_8	8.2×10^4 kg
ThO_2 Concentration	0.5 wt%
Contained ThO_2	2.0×10^5 kg

pile/pond and the site where the pile/pond is located. The site survey includes measurements of gamma radiation levels, measurements of the rate of radon emanation from the pile/pond, and the analysis of soil samples.

For the site stabilization option, the following procedures are assumed. The pile/pond is covered with a 50-mm-thick layer of asphalt. This asphalt layer is then covered with 1 m of soil. The soil is mounded slightly at the center to allow water to drain from the soil cover and to prevent the accumulation of runoff from rainfall or snow melt. After compaction and contouring of the soil cover, the area is seeded with grass.

About one-half of the total cost of the site stabilization option is for the asphalt and the soil used to establish the cover over the pile/pond. Manpower costs represent about 16% of the total cost of this option.

Long-term care activities include administrative control, site maintenance, environmental surveillance, and vegetation management. Manpower costs represent almost 60% of the estimated annual cost of long-term care.

For the removal option, conventional earthmoving equipment is used to exhume the pile/pond. Approximately 16,400 m^3 of residue and 3,000 m^3 of potentially contaminated soil are packaged in 1.2-m by 1.2-m by 2.4-m (3.4-m^3) plastic-lined plywood boxes and shipped to a shallow-land burial ground for disposal. After the pile/pond is removed, the site is backfilled and graded and grass is planted. The site is then surveyed to verify its suitability for unrestricted release.

Approximately 81% of the total cost of the disposal option is for disposal of the exhumed material. Waste management costs could be reduced by about $1.6 million if the contaminated material was transported to the shallow-land burial ground in plastic-lined 10-m^3-capacity dump trucks instead of being packaged in plywood boxes.

7.3 REFERENCES

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

8.0 DISCUSSION OF RESULTS

The results of this study have not changed any of the conclusions arrived at in NUREG/CR-1754.[1] The decommissioning technology assumed in that report is still applicable to the decommissioning of non-fuel-cycle nuclear facilities. However, a couple of new conclusions have developed since NUREG/CR-1754 was published in 1981. These conclusions are:

1. Decommissioning costs have increased considerably since publication of NUREG/CR-1754, due primarily to rapidly escalating costs for disposal of radioactive wastes generated during decommissioning operations at the available shallow-land burial sites.

2. New, commercially available radioactive waste volume-reduction technology can significantly reduce the costs of waste disposal and, hence, the costs of decommissioning operations.

Each of these conclusions is discussed below.

8.1 DECOMMISSIONING COSTS

Costs are estimated for the decommissioning of facility components (hoods, glove boxes, ductwork, building surfaces, etc.) by the DECON options of 1) decontamination to unrestricted release levels and 2) disposal at an authorized burial site. Cost estimates for individual components are then used as bases for estimating the costs of decommissioning several reference laboratories (described in Section 7 of Reference 1).

The costs of decommissioning facility components are generally estimated to be in the range of \$1,000 to \$12,000, depending on the type of component, type and amount of radioactive contamination, the DECON option chosen, and the quantity of radioactive waste generated from decommissioning operations. Estimated costs for decommissioning the reference laboratories range from about \$100,000 to about \$150,000. Costs of decommissioning laboratory facilities depend on several factors, including:

- the size of the laboratory
- laboratory design and construction
- the type and amount of radioactive contamination
- the DECON option used
- operating practices during the lifetime of the facility

- the quantity of radioactive waste generated from decommissioning operations

- the extent to which radioactive waste volume reduction is used.

On the basis of estimated decommissioning costs for facility components, decommissioning a small room containing one or two moderately contaminated fume hoods is estimated to cost about $20,000. The cost of decommissioning an entire industrial plant containing several laboratories used to prepare radiochemicals and radioactive sources could well exceed $1 million.

Costs estimates are made for decommissioning three reference sites. Costs are estimated to range from about $69,000 for the removal of a contaminated drain line to more than $31 million for the removal of a tailings pile/evaporation pond. Costs for the latter site depend to a significant extent on the quantity of contaminated soil that needs to be removed for disposal at an authorized disposal site.

8.2 VOLUME-REDUCTION TECHNOLOGY

Utilizing volume-reduction technology during decommissioning operations to reduce the quantity of radioactive waste that needs to be disposed of can significantly reduce disposal costs. The use of sectioning, compaction, and supercompaction during decommissioning of the reference laboratories yielded savings of between $10,000 and $30,000 over decommissioning operations utilizing no volume reduction. No savings from volume reduction were possible during decommissioning of the reference sites because very little, if any, of the radioactive waste was volume-reducible.

While incineration of radioactive wastes can significantly reduce the volume of waste that needs to be disposed of, it is also very expensive. In fact, it may cost more to incinerate the waste than to just dispose of it. However, incineration costs are strongly related to economies-of-scale, which is one reason why regional radioactive waste incineration facilities have been planned by several different companies. None of these companies have been successful as of yet, however, in overcoming the numerous hurdles to starting-up such a facility.

One additional point of interest is that while both supercompaction and incineration can significantly reduce waste volumes, both are applicable only to dry-active waste (DAW). A significant cost from decommissioning operations is from disposal of solidified liquid wastes, for the reference laboratories, and contaminated soil, for the reference sites. Making an additional effort in planning decommissioning operations and selecting decommissioning technology that minimizes this non-volume-reducible waste could result in significant savings in disposal costs.

8.3 REFERENCES

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

APPENDIX A

DETAILS OF DECOMMISSIONING OF FACILITY COMPONENTS

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DETAILS OF DECOMMISSIONING OF FACILITY COMPONENTS

This appendix provides manpower and cost details for the DECON of facility components by the options of 1) decontamination of the component to unrestricted release levels or 2) disassembly and packaging of the component and disposal at a shallow-land burial ground. Descriptions of facilities and some facility components (e.g., fume hoods, glove boxes, and a small hot cell) are given in Appendix A of NUREG/CR-1754.[1]

The facility components for which decommissioning details are given, and the DECON options evaluated for each component, are shown in Table A.1.

The following key bases and assumptions are used for estimating manpower requirements and costs:

1. To determine the total time required to decommission a facility component, an estimate is made of the time required for efficient performance of the work by a postulated work crew. This is then increased by 50% to provide for preparation and set-up time, rest periods, etc., (ancillary time).

2. One important factor that affects time and manpower estimates for decontamination of a component is the amount of residual contamination that must be removed from the surface. Residual surface contamination levels on facility components are taken from the facility descriptions of Section 7 of NUREG/CR-1754.[1] Allowable contamination levels for unrestricted release are based on the NRC guidelines for the decontamination of facilities and equipment prior to release for unrestricted use.[2]

3. An individual decontamination step, such as steam-cleaning, spraying and rinsing, mopping, scrubbing, etc., is assumed to reduce the level of surface contamination on a component by one or two orders of magnitude. This is an average value based on experience and is used as a guide for estimating the time required to decontaminate a component to release levels.

4. Several small equipment items, such as wet-dry vacuum cleaners, power scrubbers, and steam generators, are used for decontaminating facility components. Because an equipment item is only used for a few days, it is not reasonable to charge its entire cost to the decommissioning of one component. To estimate equipment costs, a 1-year equipment lifetime is assumed and a charge of x/250 of the cost of the item is made, where x is the number of days required to decontaminate the component.

5. Radiation survey equipment and equipment for the analysis of wipe samples are assumed to be readily available and not chargeable to decommissioning because such equipment is in routine use during the operation of a facility.

6. All radioactive wastes from the decommissioning of facility components are shipped by truck a distance of 800 km to a shallow-land burial ground. A truck distance of 350 km is assumed for shipments of waste to the centrally located supercompaction facility. Solidified liquid wastes are assumed to go straight to the disposal site while dry solid waste and sectioned metal waste are assumed to go first to the supercompactor facility and then to the disposal site. Radioactive wastes from the decontamination option include solidified decontamination liquids, protective clothing, and cleaning supplies from decontamination operations. Radioactive wastes from the packaging and disposal option include the facility component. Transportation charges are based on the fraction of a truckload required to transport the wastes. It is assumed that one truckload consists of one hundred-twenty 208-ℓ steel drums or 30 m^3 of plywood boxes containing compacted or incinerated waste. Only 80 drums of supercompacted waste are assumed to be transported per truckload, due to weight limitations.

7. Because supercompaction, incineration, transportation, and waste disposal operations are contracted activities, manpower costs for each of these operations are included in the total costs for each.

8. The base-case scenario for determining the requirements and costs of packaging and disposal of contaminated facility components assumes that large components such as fume hoods and glove boxes are shipped intact with a minimum of sectioning. Volume-reduction procedures such as compaction and incineration are not used. To provide a basis for cost comparisons, a second scenario is evaluated that assumes sectioning of the component, compaction, and supercompaction of appropriate wastes. A third scenario is evaluated that assumes sectioning of the component, compaction, and incineration of appropriate wastes. Sectioning and compaction are estimated to reduce the waste volume by a factor of 5. Supercompaction is assumed to reduce the post-compacted waste volume by a factor of 2 and post-sectioned metal waste by a factor of 2.5. Incineration is assumed to reduce the post-compacted waste by a factor of 10.

9. All costs are in January 1988 dollars.

10. Cost estimates are based on unit costs for manpower, equipment, supplies, and waste management that are given in Appendix D.

For ease in evaluating time and manpower requirements of the decontamination option and the packaging and disposal option, each option is divided into a series of tasks or steps. The steps in the decontamination option are:

- remove equipment and material and perform initial radiation survey
- decontaminate component
- monitor for compliance with release limits
- reclean hot spots and monitor
- dispose of radioactive wastes.

The steps in the packaging and disposal option are:

- remove equipment and material and perform initial radiation survey
- remove loose contamination and fix residual contamination
- disconnect service lines and ductwork and prepare component for packaging
- package component
- ship packaged component to shallow-land burial ground.

A.1 FUME HOODS

Estimated costs for decommissioning a radiochemical fume hood by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated hood at an authorized disposal site are shown in Table A.2. Total costs include manpower, equipment and supplies, and waste management costs. Costs for the packaging and disposal options are shown for the case in which the hood is packaged without sectioning and for the cases in which the hood is sectioned, compactible waste is compacted, followed by supercompaction or incineration of appropriate wastes to reduce the volume of radioactive material shipped to a shallow-land burial ground.

Time and manpower requirements for the DECON of a fume hood are shown in Table A.3. Tables A.2 and A.3 are based on a fume hood with exterior dimensions of 1.5 m wide by 0.9 m deep by 2.1 m high, for a total volume of 2.835 m^3.

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination in the fume hoods from residual levels to unrestricted release levels. These contamination levels and the decontamination procedures postulated to reduce the contamination to these levels have not changed since publication of NUREG/CR-1754[1] and can be found in Section E.1 of that document. A decontamination step that reduces the surface contamination by a factor of about 100 is assumed to require 3 hours for completion for hoods contaminated with ^{3}H or ^{14}C. For hoods contaminated with ^{125}I or ^{137}Cs, a single decontamination step is assumed to reduce surface contamination by a factor of 50. For hoods contaminated with ^{241}Am, a single decontamination step is assumed to reduce surface contamination by a factor of 50 and to require 6 hours for completion. A work crew consisting of a foreman and two technicians is postulated to perform the work.

For the packaging and disposal option, the manpower requirements shown in Table A.3 include only those needed to prepare and package the hood for shipment to the shallow-land burial ground. Craftsmen (an electrician and a pipefitter) are added to the work crew on a temporary basis to disconnect services and prepare the hood for packaging.

Material costs for the decontamination option are assumed to include the costs of replacement filters. Waste management costs for this option include the costs of packaging, transportation, and disposal of the decontamination liquids and cleaning supplies used to clean the hoods to unrestricted release levels. Decontamination wastes are packaged in 208-ℓ steel drums and are postulated to include three drums of solid waste (including filters) and two drums of solidified liquid waste.

Waste management costs for the packaging and disposal option include the costs of disposal of the hood and of the roughing and HEPA filters and 1 m of contaminated ventilation ductwork attached to the hood. The hood and associated items are wrapped in plastic and packaged for shipment in a plastic-lined plywood box. Decontamination wastes for this option include one 208-ℓ drum of solid waste and one drum of solidified liquid waste.

Unit cost factors for a fume hood are provided in Table A.4. The cost factors for manpower and equipment and supplies are given in $\$/m^3$ of the component being decommissioned, while volume reduction, packaging, transportation, and disposal cost factors are given in $\$/m^3$ of original waste volume. The original waste volume unit factors are given in m^3 of waste per m^3 of the component being decommissioned.

TABLE A.1. DECON Options for Facility Components

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hood	x[a]	x
Glove Box	x	x
Small Hot Cell	x	x
Laboratory Workbench	x	x
Sinks and Drains	x	x
Ventilation Ductwork		x
Building Surfaces[b]	x	

(a) An "x" indicates that the facility component can be decommissioned by the indicated option.
(b) Some contaminated material, such as floor tiles or concrete chipped from walls, might be packaged and shipped for disposal.

TABLE A.2. Estimated Costs for DECON of a Fume Hood[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower	1.67	1.44	1.67	1.67	2.88
Equipment & Supplies	1.82	1.82	1.82	1.82	1.82
Waste Management					
Packaging	0.18	0.27	0.27	0.27	0.27
Transportation	0.06	0.06	0.06	0.06	0.06
Disposal	1.10	1.10	1.10	1.10	1.10
Subtotals	4.81	4.69	4.92	4.92	6.13
25% Contingency	1.20	1.17	1.23	1.22	1.53
Totals	6.0	5.9	6.2	6.2	7.7
Packaging & Disposal w/o Volume Reduction					
Manpower	1.60	1.60	1.60	1.60	2.17
Equipment & Supplies	1.30	1.30	1.30	1.30	1.30
Waste Management					
Packaging	0.41	0.41	0.41	0.41	0.41
Transportation	0.18	0.18	0.18	0.18	0.18
Disposal	4.09	4.09	4.09	4.09	4.09
Subtotals	7.58	7.58	7.58	7.58	8.15
25% Contingency	1.90	1.90	1.90	1.90	2.04
Totals	9.5	9.5	9.5	9.5	10.2

(contd)

TABLE A.2. (contd)

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[(b)]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction and Supercompaction					
Manpower	2.70	2.70	2.70	2.70	3.25
Equipment & Supplies	1.45	1.45	1.45	1.45	1.45
Waste Management					
Supercompaction	0.23	0.23	0.23	0.23	0.23
Packaging	0.17	0.17	0.17	0.17	0.17
Transportation	0.06	0.06	0.06	0.06	0.06
Disposal	0.55	0.55	0.55	0.55	0.55
Subtotals	5.16	5.16	5.16	5.16	5.71
25% Contingency	1.29	1.29	1.29	1.29	1.43
Totals	6.5	6.5	6.5	6.5	7.1
Packaging & Disposal w/Compaction and Incineration					
Manpower	2.70	2.70	2.70	2.70	3.25
Equipment & supplies	1.45	1.45	1.45	1.45	1.45
Waste Management					
Incineration	0.34	0.34	0.34	0.34	0.34
Packaging	0.14	0.14	0.14	0.14	0.14
Transportation	0.04	0.04	0.04	0.04	0.04
Disposal	0.95	0.95	0.95	0.95	0.95
Subtotals	5.62	5.62	5.62	5.62	6.17
25% Contingency	1.41	1.41	1.41	1.41	1.54
Totals	7.0	7.0	7.0	7.0	7.7

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.

TABLE A.3. Details of Estimated Time and Manpower Requirements for DECON of a Fume Hood

DECON Option	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
	^{3}H		^{14}C		^{125}I		^{137}Cs		^{241}Am	
	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days
Decontamination										
Remove Equipment & Survey Component	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75
Decontaminate	1.00	3.00	0.75	2.25	1.00	3.00	1.00	3.00	2.00	6.00
Monitor	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75
Reclean Hot Spots & Monitor	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.75	2.25
Subtotals	2.00	6.00	1.75	5.25	2.00	6.00	2.00	6.00	3.25	9.75
50% Ancillary Time	1.00	3.00	0.88	2.64	1.00	3.00	1.00	3.00	1.63	4.89
Totals	3.0	9.0	2.6	7.9	3.0	9.0	3.0	9.0	4.9	14.6
Packaging & Disposal w/o Volume Reduction										
Remove Equipment & Survey Component	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75
Fix Contamination	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	1.00	3.00
Disconnect Services & Prepare for Packaging	0.38	1.90	0.38	1.90	0.38	1.90	0.38	1.90	0.50	2.50
Package Component	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	1.63	5.65	1.63	5.65	1.63	5.65	1.63	5.65	2.25	7.75
50% Ancillary Time	0.82	2.83	0.82	2.83	0.83	2.82	0.82	2.83	1.12	3.87
Totals	2.5	8.5	2.5	8.5	2.5	8.5	2.5	8.5	3.4	11.6

(contd)

TABLE A.3. (contd)

DECON Option	^{3}H Time (days)	^{3}H Man-days	^{14}C Time (days)	^{14}C Man-days	^{125}I Time (days)	^{125}I Man-days	^{137}Cs Time (days)	^{137}Cs Man-days	^{241}Am Time (days)	^{241}Am Man-days
	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
Packaging & Disposal w/Compaction and Supercompaction										
Remove Equipment & Survey Component	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75
Fix Contamination	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	1.00	3.00
Disconnect Services	0.38	1.90	0.38	1.90	0.38	1.90	0.38	1.90	0.50	2.50
Section Component	1.00	4.00	1.00	4.00	1.00	4.00	1.00	4.00	1.00	4.00
Packaging	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	2.63	9.65	2.63	9.65	2.63	9.65	2.63	9.65	3.25	11.75
50% Ancillary Time	1.32	4.83	1.32	4.83	1.32	4.83	1.32	4.83	1.68	5.88
Totals	4.0	14.5	4.0	14.5	4.0	14.5	4.0	14.5	4.9	17.6
Packaging & Disposal w/Compaction and Incineration										
Remove Equipment & Survey Component	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75
Fix Contamination	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	1.00	3.00
Disconnect Services	0.38	1.90	0.38	1.90	0.38	1.90	0.38	1.90	0.50	2.50
Section Component	1.00	4.00	1.00	4.00	1.00	4.00	1.00	4.00	1.00	4.00
Packaging	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	2.63	9.65	2.63	9.65	2.63	9.65	2.63	9.65	3.25	11.75
50% Ancillary Time	1.32	4.83	1.32	4.83	1.32	4.83	1.32	4.83	1.68	5.88
Totals	4.0	14.5	4.0	14.5	4.0	14.5	4.0	14.5	4.9	17.6

TABLE A.4. Estimated Unit Factors for DECON of a Fume Hood[a]

Cost Item	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower ($K/m^3 component)	0.59	0.50	0.59	0.59	1.02
Equipment & Supplies ($K/m^3 component)	0.64	0.64	0.64	0.64	0.64
Waste Volume (m^3 waste/m^3 component)	0.37	0.37	0.37	0.37	0.37
Packaging ($K/m^3 waste)	0.18	0.26	0.26	0.26	0.26
Transportation ($K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
Disposal ($K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/o Volume Reduction					
Manpower ($K/m^3 component)	0.57	0.57	0.57	0.57	0.76
Equipment & Supplies ($K/m^3 component)	0.46	0.46	0.46	0.46	0.46
Waste Volume (m^3 waste/m^3 component)	1.38	1.38	1.38	1.38	1.38
Packaging ($K/m^3 waste)	0.10	0.10	0.10	0.10	0.10
Transportation ($K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
Disposal ($K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/Compaction & Supercompaction					
Manpower ($K/m^3 component)	0.95	0.95	0.95	0.95	1.14
Equipment & Supplies ($K/m^3 component)	0.51	0.51	0.51	0.51	0.51
Waste Volume (m^3 waste/m^3 component)	1.38	1.38	1.38	1.38	1.38
Supercompaction ($K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
Packaging ($K/m^3 waste)	0.04	0.04	0.04	0.04	0.04
Transportation ($K/m^3 waste)	0.02	0.02	0.02	0.02	0.02
Disposal ($K/m^3 waste)	0.14	0.14	0.14	0.14	0.14
Packaging & Disposal w/Compaction & Incineration					
Manpower ($K/m^3 component)	0.95	0.95	0.95	0.95	1.14
Equipment & Supplies ($K/m^3 component)	0.51	0.51	0.51	0.51	0.51
Waste Volume (m^3 waste/m^3 component)	1.38	1.38	1.38	1.38	1.38
Incineration ($K/m^3 waste)	0.09	0.09	0.09	0.09	0.09
Packaging ($K/m^3 waste)	0.04	0.04	0.04	0.04	0.04
Transportation ($K/m^3 waste)	0.01	0.01	0.01	0.01	0.01
Disposal ($K/m^3 waste)	0.24	0.24	0.24	0.24	0.24

(a) Costs are in January 1988 dollars.

A.2 GLOVE BOXES

Estimated costs for decommissioning a glove box by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated hood at an authorized disposal site are shown in Table A.5. Total costs include manpower, equipment and supplies, and waste management costs. Costs for the packaging and disposal options are shown for the case in which the glove box is packaged without sectioning and for the cases in which the glove box is sectioned, compactible waste is compacted, followed by supercompaction or incineration to reduce the volume of radioactive material shipped to a shallow-land burial ground.

Time and manpower requirements for the DECON of a glove box are shown in Table A.6. Tables A.5 and A.6 are based on a glove box with exterior dimensions of 0.9 m wide by 0.6 m deep by 0.6 m high, for a total volume of 0.324 m^3.

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination in the glove boxes from residual levels to unrestricted release levels. These contamination levels and the decontamination procedures postulated to reduce the contamination to these levels have not changed since publication of NUREG/CR-1754[1] and can be found in Section E.2 of that document. A decontamination step that reduces the surface contamination by a factor of about 100 is assumed to require 2 hours for completion for glove boxes contaminated with ^{3}H or ^{14}C. For glove boxes contaminated with ^{125}I, a single decontamination stop is assumed to reduce surface contamination by a factor of 50. For glove boxes contaminated with ^{241}Am, a single decontamination step is assumed to reduce surface contamination by about a factor of 50 and to require 4 hours for completion. Recleaning of hot spots is assumed to require twice as much time for a glove box contaminated with ^{241}Am as is required for other glove boxes. A work crew consisting of a foreman and one technician is assumed to perform the work. A pair of replacement gloves for the glove box is estimated to cost $90.

For the packaging and disposal option, the manpower requirements shown in Table A.6 are those needed to prepare and package the glove box for shipment. An electrician and a pipefitter are added to the work crew on a temporary basis to disconnect services and assist in preparing the glove box.

Material costs for the decontamination option are assumed to include the costs of replacement filters and glove box gloves. Waste management costs for this option include the costs of packaging, transportation, and disposal of the decontamination liquids and cleaning supplies used to clean the glove boxes to unrestricted release levels. Decontamination wastes include three 208-ℓ drums of solid waste (including contaminated filters and glove box gloves) and one drum of solidified liquid waste.

Waste management costs for the packaging and disposal options include the costs of disposal of the glove box and of the roughing and HEPA filters and 1 m of contaminated ventilation ductwork attached to the box. The glove box and associated items are wrapped in plastic and packaged for shipment in a plastic-lined plywood box. Decontamination wastes for this option include one 208-ℓ drum of solid waste and one drum of solidified liquid waste.

Unit cost factors for a glove box are provided in Table A.7. The cost factors for manpower and equipment and supplies are given in $\$/m^3$ of the component being decommissioned, while volume reduction, packaging, transportation, and disposal cost factors are given in $\$/m^3$ of original waste volume. The original waste volume unit factors are given in m^3 of waste per m^3 of the component being decommissioned.

TABLE A.5. Estimated Costs for DECON of a Glove Box[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower	1.00	0.73	1.00	--[c]	2.00
Equipment & Supplies	1.45	1.45	1.45	--	1.45
Waste Management					
Packaging	0.14	0.18	0.18	--	0.18
Transportation	0.05	0.05	0.05	--	0.05
Disposal	0.88	0.88	0.88		0.88
Subtotals	3.52	3.29	3.56	--	4.56
25% Contingency	0.88	0.82	0.89	--	1.14
Totals	4.4	4.1	4.5	--	5.7
Packaging & Disposal w/o Volume Reduction					
Manpower	1.01	1.01	1.01	--[c]	1.40
Equipment & Supplies	1.02	1.02	1.02	--	1.02
Waste Management					
Packaging	0.19	0.19	0.19	--	0.19
Transportation	0.05	0.05	0.05	--	0.05
Disposal	0.96	0.96	0.96	--	0.96
Subtotals	3.23	3.23	3.23	--	3.62
25% Contingency	0.81	0.81	0.81	--	0.91
Totals	4.0	4.0	4.0	--	4.5

(contd)

TABLE A.5. (contd)

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction and Supercompaction					
Manpower	1.40	1.40	1.40	--[c]	2.01
Equipment & supplies	1.17	1.17	1.17	--	1.17
Waste Management					
Supercompaction	0.04	0.04	0.04	--	0.04
Packaging	0.12	0.12	0.12	--	0.12
Transportation	0.02	0.02	0.02	--	0.02
Disposal	0.28	0.28	0.28	--	0.28
Subtotals	3.03	3.03	3.03	--	3.64
25% Contingency	0.76	0.76	0.76	--	0.91
Totals	3.8	3.8	3.8	--	4.6
Packaging & Disposal w/Compaction and Incineration					
Manpower	1.40	1.40	1.40	--[c]	2.01
Equipment & Supplies	1.17	1.17	1.17	--	1.17
Waste Management					
Incineration	0.17	0.17	0.17	--	0.17
Packaging	0.10	0.10	0.10	--	0.10
Transportation	0.02	0.02	0.02	--	0.02
Disposal	0.32	0.32	0.32	--	0.32
Subtotals	3.18	3.18	3.18	--	3.79
25% Contingency	0.80	0.80	0.80	--	0.95
Totals	4.0	4.0	4.0	--	4.7

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.
(c) There are no glove boxes in the reference ^{137}Cs laboratory facility.

TABLE A.6. Details of Estimated Time and Manpower Requirements for DECON of a Glove Box

	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
	^{3}H		^{14}C		^{125}I		^{137}Cs		^{241}Am	
DECON Option	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days
Decontamination										
Remove Equipment & Survey Component	0.25	0.50	0.25	0.50	0.25	0.50	--[a]	--[a]	0.25	0.50
Decontaminate	1.00	2.00	0.50	1.00	1.00	2.00	--	--	2.50	5.00
Monitor	0.25	0.50	0.25	0.50	0.25	0.50	--	--	0.25	0.50
Reclean Hot Spots & Monitor	0.25	0.50	0.25	0.50	0.25	0.50	--	--	0.50	1.00
Subtotals	1.75	3.50	1.25	2.50	1.75	3.50	--	--	3.50	7.00
50% Ancillary Time	0.88	1.75	0.62	1.25	0.88	1.75	--	--	1.75	3.50
Totals	2.6	5.2	1.9	3.8	2.6	5.2	--	--	5.2	10.5
Packaging & Disposal w/o Volume Reduction										
Remove Equipment & Survey Component	0.25	0.50	0.25	0.50	0.25	0.50	--[a]	--[a]	0.25	0.50
Fix Contamination	0.25	0.50	0.25	0.50	0.25	0.50	--	--	0.50	1.00
Disconnect Services & Prepare for Packaging	0.25	1.00	0.25	1.00	0.25	1.00	--	--	0.50	2.00
Package Component	0.50	1.50	0.50	1.50	0.50	1.50	--	--	0.50	1.50
Subtotals	1.25	3.50	1.25	3.50	1.25	3.50	--	--	1.75	5.00
50% Ancillary Time	0.63	1.75	0.63	1.75	0.63	1.75	--	--	0.88	2.50
Totals	1.9	5.2	1.9	5.2	1.9	5.2	--	--	2.6	7.5

(contd)

TABLE A.6. (contd)

DECON Option	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
	^{3}H		^{14}C		^{125}I		^{137}Cs		^{241}Am	
	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days
Packaging & Disposal w/Compaction and Supercompaction										
Remove Equipment & Survey Component	0.25	0.50	0.25	0.50	0.25	0.50	--(a)	--(a)	0.25	0.50
Fix Contamination	0.25	0.50	0.25	0.50	0.25	0.50	--	--	0.50	1.00
Disconnect Services	0.25	1.00	0.25	1.00	0.25	1.00	--	--	0.50	2.00
Section Component	0.50	1.50	0.50	1.50	0.50	1.50	--	--	0.75	2.25
Packaging	0.50	1.50	0.50	1.50	0.50	1.50	--	--	0.50	1.50
Subtotals	1.75	5.00	1.75	5.00	1.75	5.00	--	--	2.50	7.25
50% Ancillary Time	0.88	2.50	0.88	2.50	0.88	2.50	--	--	1.25	3.62
Totals	2.6	7.5	2.6	7.5	2.6	7.5	--	--	3.8	10.9
Packaging & Disposal w/Compaction and Incineration										
Remove Equipment & Survey Component	0.25	0.50	0.25	0.50	0.25	0.50	--(a)	--(a)	0.25	0.50
Fix Contamination	0.25	0.50	0.25	0.50	0.25	0.50	--	--	0.50	1.00
Disconnect Services	0.25	1.00	0.25	1.00	0.25	1.00	--	--	0.50	2.00
Section Component	0.50	1.50	0.50	1.50	0.50	1.50	--	--	0.75	2.25
Packaging	0.50	1.50	0.50	1.50	0.50	1.50	--	--	0.50	1.50
Subtotals	1.75	5.00	1.75	5.00	1.75	5.00	--	--	2.50	7.25
50% Ancillary Time	0.88	2.50	0.88	2.50	0.88	2.50	--	--	1.25	3.62
Totals	2.6	7.5	2.6	7.5	2.6	7.5	--	--	3.8	10.9

(a) There are no glove boxes in the Reference ^{137}Cs laboratory facility.

TABLE A.7. Estimated Unit Factors for DECON of a Glove Box[a]

Cost Item	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
Decontamination					
Manpower ($K/m^3 component)	3.08	2.26	3.08	--[b]	6.17
Equipment & Supplies ($K/m^3 component)	4.48	4.48	4.48	--	4.48
Waste Volume (m^3 waste/m^3 component)	2.57	2.57	2.57	--	2.57
Packaging ($K/m^3 waste)	0.17	0.22	0.22	--	0.22
Transportation ($K/m^3 waste)	0.06	0.06	0.06	--	0.06
Disposal ($K/m^3 waste)	1.05	1.05	1.05	--	1.05
Packaging & Disposal w/o Volume-Reduction					
Manpower ($K/m^3 component)	3.11	3.11	3.11	--[b]	4.33
Equipment & Supplies ($K/m^3 component)	3.15	3.15	3.15	--	3.15
Waste Volume (m^3 waste/m^3 component)	2.83	2.83	2.83	--	2.83
Packaging ($K/m^3 waste)	0.21	0.21	0.21	--	0.21
Transportation ($K/m^3 waste)	0.05	0.05	0.05	--	0.05
Disposal ($K/m^3 waste)	1.05	1.05	1.05	--	1.05
Packaging & Disposal w/Compaction & Supercompaction					
Manpower ($K/m^3 component)	4.33	4.33	4.33	--[b]	6.20
Equipment & Supplies ($K/m^3 component)	3.61	3.61	3.61	--	3.61
Waste Volume (m^3 waste/m^3 component)	2.83	2.83	2.83	--	2.83
Supercompaction ($K/m^3 waste)	0.05	0.05	0.05	--	0.05
Packaging ($K/m^3 waste)	0.13	0.13	0.13	--	0.13
Transportation ($K/m^3 waste)	0.02	0.02	0.02	--	0.02
Disposal ($K/m^3 waste)	0.31	0.31	0.31	--	0.31
Packaging & Disposal w/Compaction & Incineration					
Manpower ($K/m^3 component)	4.33	4.33	4.33	--[b]	6.20
Equipment & Supplies ($K/m^3 component)	3.61	3.61	3.61	--	3.61
Waste Volume (m^3 waste/m^3 component)	2.83	2.83	2.83	--	2.83
Incineration ($K/m^3 waste)	0.18	0.18	0.18	--	0.18
Packaging ($K/m^3 waste)	0.11	0.11	0.11	--	0.11
Transportation ($K/m^3 waste)	0.02	0.02	0.02	--	0.02
Disposal ($K/m^3 waste)	0.35	0.35	0.35	--	0.35

(a) Costs are in January 1988 dollars.
(b) There are no glove boxes in the reference ^{137}Cs laboratory facility.

A.3 SMALL HOT CELL

Estimated costs for decommissioning a small hot cell by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated cell at an authorized disposal site are shown in Table A.8. The hot cell is described in Section A.5.3 of NUREG/CR-1754.(1) Total costs of decommissioning include manpower, equipment and supplies, and waste management costs. Costs for the packaging and disposal option are shown for the case in which there is no lead salvage and for the cases in which 65% of the lead bricks are reclaimed and sold for salvage. Credit for lead salvage is based on a value of $1.25 per kilogram of lead.

The only reference laboratory that contains a hot cell is the laboratory for the manufacture of ^{137}Cs sealed sources described in Section 7.1.4 of NUREG/CR-1754.(1) Cesium-137 contamination on inside surfaces of the cell is estimated to range from 10^{10} to 10^{12} d/m/100 cm^2. The allowable contamination level for unrestricted release, based on the NRC guidelines for the decontamination of facilities and equipment prior to release for unrestricted use,(2) is 10^3 d/m/100 cm^2.

Time and manpower requirements for the decontamination of the hot cell to unrestricted release levels or for packaging and disposal of the contaminated cell are shown in Table A.9. Tables A.8 and A.9 are based on a hot cell that is a 1.2-m cube (inside dimensions) with a 0.1-m wall thickness, for a total volume of 2.744 m^3.

For the decontamination option, a work crew consisting of a foreman and two technicians is assumed to perform the work. Postulated decontamination procedures include the following:

- dry vacuum
- sweep
- wet wipe
- spray
- wash
- scrub hot spots.

Decontamination is performed remotely, using master-slave manipulators, until residual contamination levels are sufficiently lowered to permit contact procedures. For this option, it is assumed that the cell liner has been effective in preventing the contamination of all but a few of the lead bricks. If most of the bricks are contaminated, 2 or 3 additional days may be required to inspect and decontaminate the bricks, resulting in an additional manpower cost of about $1,600. Contaminated bricks are cleaned by scrubbing, using a commercial decontaminate, or by soaking in hydrochloric acid solution, followed by a water rinse.

For the packaging and disposal option, the manpower requirements shown in Table A.9 are those needed to disassemble and package the hot cell components for shipment to a shallow-land burial ground. An electrician and a pipefitter are added to the basic crew to disconnect services. A lift-truck operator is added to the crew to assist in moving plywood boxes filled with lead bricks. Three days (9 man-days) are required to inspect and decontaminate the brick for the case where the bricks are to be salvaged.

Waste management costs for the decontamination option include the costs of packaging and disposal of the decontamination liquids and cleaning supplies used to clean the small hot cell to unrestricted release levels. This decontamination waste is packaged in five 208-ℓ steel drums.

Unit cost factors for a hot cell are provided in Table A.10. The cost factors for manpower, equipment and supplies, and lead salvage credit are given in $\$/m^3$ of the component being decommissioned, while volume reduction, packaging, transportation, and disposal cost factors are given in $\$/m^3$ of original waste volume. The original waste volume unit factors are given in m^3 of waste per m^3 of the component being decommissioned.

TABLE A.8. Estimated Costs for DECON of a Small Hot Cell

	$ thousands				
Cost Item	Decontamination	Packaging & Disposal w/o Volume Reduction w/o Lead Salvage	Packaging & Disposal w/o Volume Reduction w/Lead Salvage	Packaging & Disposal w/ Compaction and Supercompaction w/Lead Salvage	Packaging & Disposal w/ Compaction and Incineration w/ Lead Salvage
Manpower	2.95	2.35	4.70	5.21	5.21
Equipment & Supplies	2.52	2.11	2.27	2.41	2.41
Waste Management					
Supercompaction	--	--	--	0.04	--
Incineration	--	--	--	--	0.34
Packaging	0.27	0.98	0.58	0.49	0.47
Transportation	0.06	0.11	0.09	0.07	0.06
Disposal	1.10	2.51	1.92	1.33	1.32
Subtotals	6.90	8.06	9.56	9.55	9.81
25% Contingency	1.73	2.02	2.39	2.39	2.[illegible]5
Totals	8.6	10.1	12.0	11.9	12.3
Credit for Lead Salvage			9.3	9.3	9.3

(a) Costs are in January 1988 dollars.

TABLE A.9. Details of Estimated Time and Manpower Requirements for DECON of a Small Hot Cell

DECON Option	Time (days)	Man-days
Decontamination Option		
Remove Equipment & Survey Component	0.50	1.50
Decontaminate	2.00	6.00
Monitor	0.50	1.50
Reclean Hot Spots & Monitor	0.50	1.50
Subtotals	3.50	10.50
50% Ancillary Time	1.75	5.25
Totals	5.3	15.8
Packaging & Disposal Option w/o Volume Reduction w/o Lead Salvage		
Remove Equipment & Survey Component	0.50	1.50
Fix Contamination	0.50	1.50
Disconnect Services & Prepare for Packaging	0.25	1.25
Package Component	1.00	4.00
Subtotals	2.25	8.25
50% Ancillary Time	1.13	4.13
Totals	3.4	12.4
Packaging & Disposal Option w/o Volume Reduction w/Lead Salvage		
Remove Equipment & Survey Component	0.50	1.50
Decontaminate and/or Fix Contamination	1.00	3.00
Disconnect Services & Prepare for Packaging	0.25	1.25
Survey & Decontaminate Lead Bricks	3.00	9.00
Package Contaminated Material	0.50	2.00
Subtotals	5.25	16.75
50% Ancillary Time	2.62	8.38
Totals	7.9	25.1

(contd)

TABLE A.9. (contd)

DECON Option	Time (days)	Man-days
Packaging & Disposal Option w/Compaction and Super-compaction w/Lead Salvage		
Remove Equipment & Survey Component	0.50	1.50
Decontaminate and/or Fix Contamination	1.00	3.00
Disconnect Services	0.25	1.25
Section Component	0.50	2.00
Survey & Decontaminate Lead Bricks	3.00	9.00
Package Contaminated Material	0.50	2.00
Subtotals	5.75	18.75
50% Ancillary Time	2.87	9.37
Totals	8.6	28.1
Packaging & Disposal Option w/Compaction and Incineration w/Lead Salvage		
Remove Equipment & Survey Component	0.50	1.50
Decontaminate and/or Fix Contamination	1.00	3.00
Disconnect Services	0.25	1.25
Section Component	0.50	2.00
Survey & Decontaminate Lead Bricks	3.00	9.00
Package Contaminated Material	0.50	2.00
Subtotals	5.75	18.75
50% Ancillary Time	2.87	9.37
Totals	8.6	28.1

TABLE A.10. Estimated Unit Factors for DECON of a Small Hot Cell[(a)]

Cost Item	Decontamination	Packaging & Disposal w/o Volume Reduction w/o Lead Salvage	Packaging & Disposal w/o Volume Reduction w/Lead Salvage	Packaging & Disposal w/ Compaction and Supercompaction w/Lead Salvage	Packaging & Disposal w/ Compaction and Incineration w/ Lead Salvage
Manpower ($\$K/m^3$ component)	1.07	0.85	1.71	1.90	1.90
Equipment & Supplies ($\$K/m^3$ component)	0.92	0.77	0.83	0.88	0.88
Waste Volume (m^3 waste/m^3 component)	0.38	0.38	0.38	0.38	0.38
Supercompaction ($\$K/m^3$ waste)	--	--	--	0.02	--
Incineration ($\$K/m^3$ waste)	--	--	--	--	0.18
Packaging ($\$K/m^3$ waste)	0.26	0.41	0.32	0.27	0.25
Transportation ($\$K/m^3$ waste)	0.05	0.05	0.05	0.04	0.03
Disposal ($\$K/m^3$ waste)	1.05	1.05	1.05	0.72	0.72
Credit for Lead Salvage ($\$K/m^3$ component)			3.41	3.41	3.41

(a) All costs are in January 1988 dollars.

A.4 LABORATORY WORKBENCHES

Estimated costs for decommissioning a laboratory workbench by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated workbench are shown in Table A.11. Total costs include manpower, equipment and supplies, and waste management costs. The workbench is assumed to be 0.9 m high, 0.75 m wide, and 4.6 m long.

Time and manpower requirements for the DECON of a workbench are shown in Table A.12. Tables A.11 and A.12 are based on a laboratory workbench that is 0.9 m high, 0.75 m wide, and 4.6 m long.

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination on the bench top and other surfaces from residual levels to unrestricted release levels. These contamination levels and the decontamination procedures postulated to reduce the contamination to these levels have not changed since publication of NUREG/CR-1754[1] and can be found is Section E.4 of that document. Decontamination is performed by a work crew consisting of one foreman and one technician.

Cleaning supplies and contaminated liquids from the decontamination option are packaged for disposal in two 208-ℓ steel drums (one for cleaning supplies and one for solidified liquids).

For the packaging and disposal options, the manpower needed to prepare and package the bench for shipment to a shallow-land burial ground is shown in Table A.12. An electrician and a pipefitter are temporarily added to the work crew to disconnect services. A second technician is added to the work crew to assist in packaging the bench. The bench is cut into two sections, each 2.3 m long, for ease of packaging. It is then packaged in two large plywood boxes.

Unit cost factors for a laboratory bench are provided in Table A.13. The cost factors for labor and equipment and supplies are given in \$/m (linear length) of the component being decommissioned, while volume reduction, packaging, transportation, and disposal cost factors are given in $\$/m^3$ of original waste volume. The original waste volume unit factors are given in m^3 of waste per linear length (m) of the component being decommissioned.

TABLE A.11. Estimated Costs for DECON of a Laboratory Workbench[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower	0.42	0.42	0.42	0.42	0.42
Equipment & Supplies	0.65	0.65	0.65	0.65	0.65
Waste Management					
Packaging	0.08	0.12	0.12	0.12	0.12
Transportation	0.02	0.02	0.02	0.02	0.02
Disposal	0.44	0.44	0.44	0.44	0.44
Subtotals	1.61	1.65	1.65	1.65	1.65
25% Contingency	0.40	0.41	0.41	0.41	0.41
Totals	2.0	2.1	2.1	2.1	2.1
Packaging & Disposal w/o Volume Reduction					
Manpower	0.78	0.78	0.78	0.78	0.78
Equipment & Supplies	0.59	0.59	0.59	0.59	0.59
Waste Management					
Packaging	0.41	0.41	0.41	0.41	0.41
Transportation	0.23	0.23	0.23	0.23	0.23
Disposal	5.22	5.22	5.22	5.22	5.22
Subtotals	7.23	7.23	7.23	7.23	7.23
25% Contingency	1.81	1.81	1.81	1.81	1.81
Totals	9.0	9.0	9.0	9.0	9.0

(contd)

TABLE A.11. (contd)

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope(b)				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction & Supercompaction					
Manpower	1.17	1.17	1.17	1.17	1.17
Equipment & Supplies	0.60	0.60	0.60	0.60	0.60
Waste Management					
Supercompaction	0.30	0.30	0.30	0.30	0.30
Packaging	0.13	0.13	0.13	0.13	0.13
Transportation	0.06	0.06	0.06	0.06	0.06
Disposal	1.48	1.48	1.48	1.48	1.48
Subtotals	3.74	3.74	3.74	3.74	3.74
25% Contingency	0.94	0.94	0.94	0.94	0.94
Totals	4.7	4.7	4.7	4.7	4.7

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.

TABLE A.12. Details of Estimated Time and Manpower Requirements for DECON of a Laboratory Workbench

DECON Option	^{3}H Time (days)	^{3}H Man-days	^{14}C Time (days)	^{14}C Man-days	^{125}I Time (days)	^{125}I Man-days	^{137}Cs Time (days)	^{137}Cs Man-days	^{241}Am Time (days)	^{241}Am Man-days
	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
Decontamination										
Remove Equipment & Survey Component	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25
Decontaminate	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50
Monitor	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25
Reclean Hot Spots & Monitor	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50
Subtotals	0.75	1.50	0.75	1.50	0.75	1.50	0.75	1.50	0.75	1.50
50% Ancillary Time	0.38	0.75	0.38	0.75	0.38	0.75	0.38	0.75	0.38	0.75
Totals	1.1	2.3	1.1	2.3	1.1	2.3	1.1	2.3	1.1	2.3
Packaging & Disposal w/o Volume Reduction										
Remove Equipment & Survey Component	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25
Fix Contamination	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50
Disconnect Services & Prepare for Packaging	0.13	0.50	0.13	0.50	0.13	0.50	0.13	0.50	0.13	0.50
Package Component	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	1.00	2.75	1.00	2.75	1.00	2.75	1.00	2.75	1.00	2.75
50% Ancillary Time	0.50	1.38	0.50	1.38	0.50	1.38	0.50	1.38	0.50	1.38
Totals	1.5	4.1	1.5	4.1	1.5	4.1	1.5	4.1	1.5	4.1

(contd)

TABLE A.12. (contd)

DECON Option	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope: ^{3}H Time (days)	^{3}H Man-days	^{14}C Time (days)	^{14}C Man-days	^{125}I Time (days)	^{125}I Man-days	^{137}Cs Time (days)	^{137}Cs Man-days	^{241}Am Time (days)	^{241}Am Man-days
Packaging & Disposal w/Compaction and Supercompaction										
Remove Equipment Survey Component	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25	0.13	0.25
Fix Contamination	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50	0.25	0.50
Disconnect Services	0.13	0.50	0.13	0.50	0.13	0.50	0.13	0.50	0.13	0.50
Section Component	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Package Component	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	1.50	4.25	1.50	4.25	1.50	4.25	1.50	4.25	1.50	4.25
50% Ancillary Time	0.75	2.12	0.75	2.12	0.75	2.12	0.75	2.12	0.75	2.12
Totals	2.2	6.4	2.2	6.4	2.2	6.4	2.2	6.4	2.2	6.4

TABLE A.13. Estimated Unit Factors for DECON of a Workbench[a]

Cost Item	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower ($K/m component)	0.09	0.09	0.09	0.09	0.09
Equipment & Supplies ($K/m component)	0.14	0.14	0.14	0.14	0.14
Waste Volume (m^3 waste/m component)	0.09	0.09	0.09	0.09	0.09
Packaging ($K/m^3 waste)	0.18	0.29	0.29	0.29	0.29
Transportation ($K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
Disposal ($K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/o Volume Reduction					
Manpower ($K/m component)	0.18	0.18	0.18	0.18	0.18
Equipment & Supplies ($K/m component)	0.13	0.13	0.13	0.13	0.13
Waste Volume (m^3 waste/m component)	1.09	1.09	1.09	1.09	1.09
Packaging ($K/m^3 waste)	0.08	0.08	0.08	0.08	0.08
Transportation ($K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
Disposal ($K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/Compaction & Supercompaction					
Manpower ($K/m component)	0.26	0.26	0.26	0.26	0.26
Equipment & Supplies ($K/m component)	0.13	0.13	0.13	0.13	0.13
Waste Volume (m^3 waste/m^3 component)	1.09	1.09	1.09	1.09	1.09
Supercompaction ($K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
Packaging ($K/m^3 waste)	0.03	0.03	0.03	0.03	0.03
Transportation ($K/m^3 waste)	0.01	0.01	0.01	0.01	0.01
Disposal ($K/m^3 waste)	0.30	0.30	0.30	0.30	0.30

(a) Costs are in January 1988 dollars.

A.5 SINKS AND DRAINS

Estimated costs for decommissioning sinks and drains by the DECON options of 1) decontamination to unrestricted release levels or 2) packaging and disposal of the contaminated sinks and associated piping at an authorized disposal site are shown in Table A.14. Total costs include manpower, equipment and supplies, and waste management costs.

Sinks are located in the reference laboratories for the preparation of ^{14}C- or ^{125}I-labeled compounds and in the laboratory for the manufacture of ^{137}Cs sealed sources. The sinks are used for personal cleanliness and for washing or rinsing noncontaminated glassware or glassware that has previously been decontaminated. Contaminated liquids are not purposely discharged to the sanitary sewer via these sinks. Hence, they are anticipated to have low levels of radioactive contamination.

Time and manpower requirements for the DECON of a sink and the associated piping are shown in Table A.15. Tables A.14 and A.15 are based on a sink, a trap, and a 0.12-m diameter, 10-m-long steel drain pipe.

For the decontamination option, time and manpower requirements are based on reducing the levels of contamination from residual levels to unrestricted release levels. These contamination levels and the decontamination procedures postulated to reduce the contamination to these levels have not changes since publication of NUREG/CR-1754[1] and can be found in Section E.5 of that document. A work crew consisting of a foreman and one technician is postulated to perform the work.

For the packaging and disposal option, the manpower needed to disconnect and package the sink and associated piping is shown in Table A.15. A pipefitter is temporarily added to the work crew to disconnect the sink and cut pipe. A second technician is added to the work crew to assist in packaging the contaminated components.

For the decontamination option, a single 208-ℓ drum of waste from cleaning operations is shipped to the shallow-land burial ground. For the packaging and disposal option, the contaminated waste that is packaged and shipped to the disposal site includes the sink, the trap, and the steel drain pipe.

Unit cost factors for a sink and drain line are provided in Table A.16. The cost factors for labor and equipment and supplies are given in \$/m (linear length) of the drain line being decommissioned, while volume reduction, packaging, transportation, and disposal cost factors are given in $\$/m^3$ of original waste volume. The original waste volume unit factors are given in m^3 of waste per linear length (m) of the component being decommissioned.

TABLE A.14. Estimated Costs for DECON of a Sink and Drain[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisctope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower	--[b]	0.46	0.46	0.46	--[c]
Equipment & Supplies	--	0.34	0.34	0.34	--
Waste Management					
Packaging	--	0.03	0.03	0.03	--
Transportation	--	0.01	0.01	0.01	--
Disposal	--	0.22	0.22	0.22	--
Subtotals	--	1.06	1.06	1.06	--
25% Contingency	--	0.27	0.27	0.27	--
Totals	--	1.3	1.3	1.3	--
Packaging & Disposal w/o Volume-Reduction					
Manpower	--[c]	0.71	0.71	0.71	--[c]
Equipment & Supplies	--	0.51	0.51	0.51	--
Waste Management					
Packaging	--	0.08	0.08	0.08	--
Transportation	--	0.02	0.02	0.02	--
Disposal	--	0.52	0.52	0.52	--
Subtotals	--	1.84	1.84	1.84	--
25% Contingency	--	0.46	0.46	0.46	--
Totals	--	2.3	2.3	2.3	--

(contd)

TABLE A.14. (contd)

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope(b) ^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction & Supercompaction					
Manpower	--(c)	0.92	0.92	0.92	--(c)
Equipment & Supplies	--	0.52	0.52	0.52	--
Waste Management					
Supercompaction	--	0.03	0.03	0.03	--
Packaging	--	0.01	0.01	0.01	--
Transportation	--	0.01	0.01	0.01	--
Disposal	--	0.04	0.04	0.04	--
Subtotals	--	1.53	1.53	1.53	--
25% Contingency	--	0.38	0.38	0.38	--
Totals	--	1.9	1.9	1.9	--

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.
(c) There are no sinks in the reference ^{3}H and ^{241}Am laboratory facilities.

TABLE A.15. Details of Estimated Time and Manpower Requirements for DECON of Sinks and Drains

DECON Option	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope: ^{3}H Time (days)	^{3}H Man-days	^{14}C Time (days)	^{14}C Man-days	^{125}I Time (days)	^{125}I Man-days	^{137}Cs Time (days)	^{137}Cs Man-days	^{241}Am Time (days)	^{241}Am Man-days
Decontamination										
Remove Equipment & Survey Component	--[(a)]	--[(a)]	--	--	--	--	--	--	--[(a)]	--[(a)]
Decontaminate	--	--	0.50	1.00	0.50	1.00	0.50	1.00	--	--
Monitor	--	--	0.13	0.26	0.13	0.26	0.13	0.26	--	--
Reclean Hot Spots & Monitor	--	--	0.13	0.26	0.13	0.26	0.13	0.26	--	--
Subtotals	--	--	0.76	1.52	0.76	1.52	0.76	1.52	--	--
50% Ancillary Time	--	--	0.38	0.76	0.38	0.76	0.38	0.76	--	--
Totals	--	--	1.2	2.3	1.2	2.3	1.2	2.3	--	--
Packaging & Disposal w/o Volume Reduction										
Remove Equipment & Survey Component	--[(a)]	--[(a)]	--	--	--	--	--	--	--[(a)]	--[(a)]
Fix Contamination	--	--	0.13	0.25	0.13	0.25	0.13	0.25	--	--
Disconnect Services & Prepare for Packaging	--	--	0.50	1.50	0.50	1.50	0.50	1.50	--	--
Package Component	--	--	0.25	0.75	0.25	0.75	0.25	0.75	--	--
Subtotals	--	--	0.88	2.50	0.88	2.50	0.88	2.50	--	--
50% Ancillary Time	--	--	0.44	1.25	0.44	1.25	0.44	1.25	--	--
Totals	--	--	1.3	3.8	1.3	3.8	1.3	3.8	--	--

(contd)

TABLE A.15. (contd)

Requirements for DECON of a Component Contaminated by the Indicated Radioisotope

DECON Option	^{3}H Time (days)	^{3}H Man-days	^{14}C Time (days)	^{14}C Man-days	^{125}I Time (days)	^{125}I Man-days	^{137}Cs Time (days)	^{137}Cs Man-days	^{241}Am Time (days)	^{241}Am Man-days
Packaging & Disposal w/Compaction & Supercompaction										
Remove Equipment & Survey Component	--(a)	--(a)	--	--	--	--	--	--	--(a)	--(a)
Fix Contamination	--	--	0.13	0.25	0.13	0.25	0.13	0.25	--	--
Disconnect Services	--	--	0.50	1.50	0.50	1.50	0.50	1.50	--	--
Section Component	--	--	0.25	0.75	0.25	0.75	0.25	0.75	--	--
Package Component	--	--	0.25	0.75	0.25	0.75	0.25	0.75	--	--
Subtotals	--	--	1.13	3.25	1.13	3.25	1.13	3.25	--	--
50% Ancillary Time	--	--	0.56	1.62	0.56	1.62	0.56	1.62	--	--
Totals	--	--	1.7	4.9	1.7	4.9	1.7	4.9	--	--

(a) There are no sinks or drains in the reference ^{3}H or ^{241}Am laboratory facilities.

TABLE A.16. Estimated Unit Factors for DECON of a Sink and Drain Line[a]

Cost Item	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower ($K/m component)	--[b]	0.05	0.05	0.05	--[b]
Equipment & Supplies ($K/m component)	--	0.03	0.03	0.03	--
Waste Volume (m^3 waste/m component)	--	0.02	0.02	0.02	--
Packaging ($K/$m^3$ waste)	--	0.15	0.15	0.15	--
Transportation ($K/$m^3$ waste)	--	0.05	0.05	0.05	--
Disposal ($K/$m^3$ waste)	--	1.05	1.05	1.05	--
Packaging & Disposal w/o Volume-Reduction					
Manpower ($K/m component)	--[b]	0.07	0.07	0.07	--[b]
Equipment & Supplies ($K/m component)	--	0.05	0.05	0.05	--
Waste Volume (m^3 waste/m component)	--	0.05	0.05	0.05	--
Packaging ($K/$m^3$ waste)	--	0.15	0.15	0.15	--
Transportation ($K/$m^3$ waste)	--	0.05	0.05	0.05	--
Disposal ($K/$m^3$ waste)	--	1.05	1.05	1.05	--
Packaging & Disposal w/Compaction & Supercompaction					
Manpower ($K/m component)	--[b]	0.09	0.09	0.09	--[b]
Equipment & Supplies ($K/m component)	--	0.05	0.05	0.05	--
Waste Volume (m^3 waste/m component)	--	0.05	0.05	0.05	--
Supercompaction ($K/$m^3$ waste)	--	0.06	0.06	0.06	--
Packaging ($K/$m^3$ waste)	--	0.03	0.03	0.03	--
Transportation ($K/$m^3$ waste)	--	0.01	0.01	0.01	--
Disposal ($K/$m^3$ waste)	--	0.09	0.09	0.09	--

(a) Costs are in January 1988 dollars.
(b) There are no sinks in the reference ^{3}H and ^{241}Am laboratory facilities.

A.6 VENTILATION DUCTWORK

Dirt and grime that accumulates on inside surfaces of ventilation ductwork makes decontamination very difficult. Therefore, the usual practice when decommissioning a laboratory where radioactive materials have been processed is to package the ductwork for disposal at a shallow-land burial ground. Estimated costs for this DECON option are shown in Table A.17. The estimates are based on the packaging and disposal of 20 m of 0.20-m-diameter sheet metal ductwork. Cost estimates are made for the case in which the ductwork is packaged without compaction and for the cases in which the ductwork is compacted before being packaged for shipment.

Time and manpower requirements for the disassembly and packaging of the ductwork are shown in Table A.18. Tables A.17 and A.18 are based on a 0.20-m-diameter, 20-m-long sheet metal ductwork and a 20-m-long, 0.25-m by 0.60-m rectangular sheet metal ductwork, for a total ductwork length of 40 m. Levels for radioactive contamination on inside surfaces of the ductwork are given in Section E.6 of NUREG/CR-1754.[1]

A work crew that includes a foreman, a technician, and a sheet metal worker are postulated to section the ductwork and wrap each section in plastic. For the packaging step, a foreman and two technicians are required. For packaging without compaction, the ductwork is cut into 2-m-long sections. Smaller sections, each 1 m in length, are required if the ductwork is to be compacted prior to packaging. To estimate the time requirements for cutting the ductwork, it is postulated that each cut requires approximately 20 minutes.

Unit cost factors for ductwork are provided in Table A.19. The cost factors for labor and equipment and supplies are given in \$/m (linear length) of the ductwork being decommissioned, while volume reduction, packaging, transportation, and disposal cost factors are given in $\$/m^3$ of original waste volume. The original waste volume unit factors are given in m^3 of waste per linear length (m) of the component being decommissioned.

TABLE A.17. Estimated Costs for DECON of Ventilation Ductwork[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/o Volume Reduction					
Manpower	1.86	1.86	1.86	1.86	2.27
Equipment & Supplies	1.14	1.14	1.14	1.14	1.14
Waste Management					
Packaging	0.54	0.54	0.54	0.54	0.54
Transportation	0.25	0.25	0.25	0.25	0.25
Disposal	5.66	5.66	5.66	5.66	5.66
Subtotals	9.45	9.45	9.45	9.45	9.86
25% Contingency	2.36	2.36	2.36	2.36	2.47
Totals	11.8	11.8	11.8	11.8	12.3
Packaging & Disposal w/Compaction & Supercompaction					
Manpower	2.53	2.53	2.53	2.53	3.32
Equipment & Supplies	1.33	1.33	1.33	1.33	1.33
Waste Management					
Supercompaction	0.33	0.33	0.33	0.33	0.33
Packaging	0.16	0.16	0.16	0.16	0.16
Transportation	0.07	0.07	0.07	0.07	0.07
Disposal	0.48	0.48	0.48	0.48	0.48
Subtotals	4.90	4.90	4.90	4.90	5.69
25% Contingency	1.23	1.23	1.23	1.23	1.42
Totals	6.1	6.1	6.1	6.1	7.1

(contd)

TABLE A.17. (contd)

Cost Item	Costs ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[a]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction & Incineration					
Manpower	2.53	2.53	2.53	2.53	3.32
Equipment & Supplies	1.33	1.33	1.33	1.33	1.33
Waste Management					
Incineration	0.44	0.44	0.44	0.44	0.44
Packaging	0.10	0.10	0.10	0.10	0.10
Transportation	0.05	0.05	0.05	0.05	0.05
Disposal	1.04	1.04	1.04	1.04	1.04
Subtotals	5.49	5.49	5.49	5.49	6.28
25% Contingency	1.37	1.37	1.37	1.37	1.57
Totals	6.9	6.9	6.9	6.9	7.9

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.

TABLE A.18. Details of Estimated Time and Manpower Requirements for DECON of Ventilation Ductwork

	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
	^{3}H		^{14}C		^{125}I		^{137}Cs		^{241}Am	
DECON Option	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days
Packaging & Disposal w/o Volume-Reduction										
Survey Ductwork	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00
Fix Contamination	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00
Section Ductwork	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00	1.50	4.50
Package Ductwork	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	2.50	6.50	2.50	6.50	2.50	6.50	2.50	6.50	3.00	8.00
50% Ancillary Time	1.25	3.25	1.25	3.25	1.25	3.25	1.25	3.25	1.50	4.00
Totals	3.8	9.8	3.8	9.8	3.8	9.8	3.8	9.8	4.5	12.0
Packaging & Disposal w/ Compaction & Supercompaction										
Survey Ductwork	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00
Fix Contamination	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00
Section Ductwork	1.50	4.50	1.50	4.50	1.50	4.50	1.50	4.50	2.00	6.00
Compaction	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.75	2.25
Package Ductwork	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	3.50	9.50	3.50	9.50	3.50	9.50	3.50	9.50	4.25	11.75
50% Ancillary Time	1.75	4.75	1.75	4.75	1.75	4.75	1.75	4.75	2.13	5.88
Totals	5.2	14.2	5.2	14.2	5.2	14.2	5.2	14.2	6.4	17.6

(contd)

TABLE A.18. (contd)

DECON Option	^{3}H Time (days)	^{3}H Man-days	^{14}C Time (days)	^{14}C Man-days	^{125}I Time (days)	^{125}I Man-days	^{137}Cs Time (days)	^{137}Cs Man-days	^{241}Am Time (days)	^{241}Am Man-days
	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
Packaging & Disposal w/ Compaction & Incineration										
Survey Ductwork	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00
Fix Contamination	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00	0.50	1.00
Section Ductwork	1.50	4.50	1.50	4.50	1.50	4.50	1.50	4.50	2.00	6.00
Compaction	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.75	2.25
Package Ductwork	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Subtotals	3.50	9.50	3.50	9.50	3.50	9.50	3.50	9.50	4.25	11.75
50% Ancillary Time	1.75	4.75	1.75	4.75	1.75	4.75	1.75	4.75	2.13	5.88
Totals	5.2	14.2	5.2	14.2	5.2	14.2	5.2	14.2	6.4	17.6

TABLE A.19. Estimated Unit Factors for DECON of a Ventilation Ductwork[a]

Cost Item	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/o Volume Reduction					
Manpower ($K/m component)	0.05	0.05	0.05	0.05	0.06
Equipment & Supplies ($K/m component)	0.03	0.03	0.03	0.03	0.03
Waste Volume (m^3 waste/m component)	0.14	0.14	0.14	0.14	0.14
Packaging ($K/$m^3$ waste)	0.10	0.10	0.10	0.10	0.10
Transportation ($K/$m^3$ waste)	0.05	0.05	0.05	0.05	0.05
Disposal ($K/$m^3$ waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/Compaction & Supercompaction					
Manpower ($K/m component)	0.06	0.06	0.06	0.06	0.08
Equipment & Supplies ($K/m component)	0.03	0.03	0.03	0.03	0.03
Waste Volume (m^3 waste/m component)	0.14	0.14	0.14	0.14	0.14
Supercompaction ($K/$m^3$ waste)	0.06	0.06	0.06	0.06	0.06
Packaging ($K/$m^3$ waste)	0.03	0.03	0.03	0.03	0.03
Transportation ($K/$m^3$ waste)	0.01	0.01	0.01	0.01	0.01
Disposal ($K/$m^3$ waste)	0.09	0.09	0.09	0.09	0.09
Packaging & Disposal w/Compaction & Incineration					
Manpower ($K/m component)	0.06	0.06	0.06	0.06	0.08
Equipment & Supplies ($K/m component)	0.03	0.03	0.03	0.03	0.03
Waste Volume (m^3 waste/m component)	0.14	0.14	0.14	0.14	0.14
Incineration ($K/$m^3$ waste)	0.08	0.08	0.08	0.08	0.08
Packaging ($K/$m^3$ waste)	0.02	0.02	0.02	0.02	0.02
Transportation ($K/$m^3$ waste)	0.01	0.01	0.01	0.01	0.01
Disposal ($K/$m^3$ waste)	0.19	0.19	0.19	0.19	0.19

(a) Costs are in January 1988 dollars.

A.7 BUILDING SURFACES

Building surfaces include walls and floors. Decontamination to unrestricted release levels is the DECON option evaluated for these surfaces. Some contaminated material, such as floor tiles or concrete chipped from walls, might be packaged and shipped to a shallow-land burial ground.

The reference laboratories assumed for these decommissioning cost evaluations measure 6 m by 10 m, with walls 3 m high. This translates into a total wall area of 96 m^2 and a total floor area of 60 m^2. Building materials used in individual laboratories are specified in the laboratory descriptions of Section 7.1 of NUREG/CR-1754.[1]

A.7.1 Walls

Estimated costs for decontamination of the walls of the reference laboratories to unrestricted release levels are shown in Table A.20. Total costs include manpower, equipment and supplies, and waste management costs.

Time and manpower requirements for wall decontamination are shown in Table A.21. These requirements are based on reducing the levels of contamination from residual levels to unrestricted release levels. These contamination levels and the decontamination procedures postulated to reduce the contamination to these levels have not changed since publication of NUREG/CR-1754[1] and can be found in Section E.7.1 of that document.

The decontamination work crew includes a foreman and two technicians. Decontamination of walls by steam cleaning is estimated to require less time than decontamination by washing and scrubbing. Surfaces covered with epoxy or acrylic paint require less recleaning of hot spots than do surfaces covered with latex enamel paint.

Wastes generated during decontamination operations include eight drums of solid waste (rags, brushes, contaminated clothing, etc.) and 16 drums of solidified liquid waste. Liquid wastes from steam cleaning operations are solidified with cement and packaged in 208-ℓ drums. Therefore, waste packaging costs for operations that utilize organic decontaminates are greater than those for operations that utilize steam cleaning.

Liquid wastes from cleaning operations that use organic decontamination solutions are adsorbed on diatomaceous earth or some other adsorbent contained in 113-ℓ drums. The 113-ℓ drums are then overpacked in 208-ℓ drums. Therefore, waste packaging costs for operations that utilize organic decontaminates are greater than those for operations that use steam cleaning.

Unit cost factors for walls are provided in Table A.22. The cost factors for labor and equipment and supplies are given in $\$/m^2$ (area) of the walls being decontaminated, while packaging, transportation, and disposal cost factors are given in $/m^3 of original waste volume. The original waste volume unit factors are given in m^3 of waste per unit area (m^2) of the walls being decontaminated.

A.7.2 Floors

Estimated costs for decontamination of the floors of the reference laboratories to unrestricted release levels are shown in Table A.23. Total costs include manpower, equipment and supplies, and waste management costs.

Time and manpower requirements for floor decontamination are shown in Table A.24. These requirements are based on reducing the levels of contamination from residual levels to unrestricted release levels. These contamination levels and the decontamination procedures postulated to reduce the contamination to these levels have not changed since publication of NUREG/CR-1754[1] and can be found in Section E.7.2 of that document.

The decontamination work crew includes a foreman and two technicians. With the exception of the floor in the ^{241}Am laboratory, all of the floors are covered with asphalt tile. The floor in the ^{241}Am laboratory is covered with linoleum with heat-treated seams. Because the linoleum is free from cracks, it is easier to decontaminate and requires less recleaning than do the asphalt tile floors.

Waste generated during decontamination operations include four drums of solid waste and eight drums of solidified liquids.

Unit cost factors for floors are provided in Table A.25. The cost factors for labor and equipment and supplies are given in $/m^2 (area) of the floor being decontaminated, while packaging, transportation, and disposal cost factors are given in $/m^3 of original waste volume. The original waste volume unit factors are given in m^3 of waste per unit area (m^2) of the floor being decontaminated.

TABLE A.20. Estimated Costs for DECON of Walls[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radioisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower	5.44	5.44	5.83	6.22	5.83
Equipment & Supplies	3.65	3.65	4.11	4.11	4.11
Waste Management					
Packaging	0.96	0.96	1.65	1.65	1.65
Transportation	0.27	0.27	0.27	0.27	0.27
Disposal	5.27	5.27	5.27	5.27	5.27
Subtotals	15.59	15.59	17.13	17.52	17.13
25% Contingency	3.90	3.90	4.28	4.38	4.28
Totals	19.5	19.5	21.4	21.9	21.4

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.

TABLE A.21. Details of Estimated Time and Manpower Requirements for DECON of Walls

	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
	^{3}H		^{14}C		^{125}I		^{137}Cs		^{241}Am	
DECON Option	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days
Decontamination										
Initial Survey	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Decontaminate	3.00	9.00	3.00	9.00	4.00	12.00	4.00	12.00	4.00	12.00
Monitor	1.50	4.50	1.50	4.50	1.50	4.50	1.50	4.50	1.50	4.50
Reclean Hot Spots & Monitor	1.50	4.50	1.50	4.50	1.00	3.00	1.50	4.50	1.00	3.00
Subtotals	6.50	19.50	6.50	19.50	7.00	21.00	7.50	22.50	7.00	21.00
50% Ancillary Time	3.25	9.75	3.25	9.75	3.50	10.50	3.75	11.25	3.50	10.50
Totals	9.8	29.2	9.8	29.2	10.5	31.5	11.2	33.8	10.5	31.5

TABLE A.22. Estimated Unit Factors for DECON of Walls[(a)]

Cost Item	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower ($K/m^3 component)	0.06	0.06	0.06	0.06	0.06
Equipment & Supplies ($K/m^3 component)	0.04	0.04	0.04	0.04	0.04
Packaging ($K/m^3 waste)	0.19	0.19	0.33	0.33	0.33
Transportation ($K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
Disposal ($K/m^3 waste)	1.05	1.05	1.05	1.05	1.05

(a) Costs are January 1988 dollars.

TABLE A.23. Estimated Costs for DECON of Floors[a]

Cost Item	Cost ($ thousands) for DECON of a Component Contaminated by the Indicated Radicisotope[b]				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower	1.88	1.88	1.88	1.88	1.67
Equipment & Supplies	1.54	1.54	1.54	1.54	1.54
Waste Management					
Packaging	0.82	0.82	0.82	0.82	0.82
Transportation	0.14	0.14	0.14	0.14	0.14
Disposal	2.63	2.63	2.63	2.63	2.63
Subtotals	7.01	7.01	7.01	7.01	6.80
25% Contingency	1.75	1.75	1.75	1.75	1.70
Totals	8.8	8.8	8.8	8.8	8.5

(a) Costs are in January 1988 dollars.
(b) Number of figures shown is for computational accuracy only.

TABLE A.24. Details of Estimated Time and Manpower Requirements for DECON of Floors

	Requirements for DECON of a Component Contaminated by the Indicated Radioisotope									
	^{3}H		^{14}C		^{125}I		^{137}Cs		^{241}Am	
DECON Option	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days	Time (days)	Man-days
Decontamination										
Remove Equipment & Survey Component	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75	0.25	0.75
Decontaminate	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00
Monitor	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50
Reclean Hot Spots & Monitor	0.50	1.50	0.50	1.50	0.50	1.50	0.50	1.50	0.25	0.75
Subtotals	2.25	6.75	2.25	6.75	2.25	6.75	2.25	6.75	2.00	6.00
50% Ancillary Time	1.13	3.38	1.13	3.38	1.13	3.38	1.13	3.38	1.00	3.00
Totals	3.4	10.1	3.4	10.1	3.4	10.1	3.4	10.1	3.0	9.00

TABLE A.25. Estimated Unit Factors for DECON of Floors[a]

Cost Item	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
Manpower ($K/m^3 component)	0.03	0.03	0.03	0.03	0.03
Equipment & Supplies ($K/m^3 component)	0.03	0.03	0.03	0.03	0.03
Waste Volume (m^3 waste/m^3 component)	0.04	0.04	0.04	0.04	0.04
Packaging ($K/m^3 waste)	0.33	0.33	0.33	0.33	0.33
Transportation ($K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
Disposal ($K/m^3 waste)	1.05	1.05	1.05	1.05	1.05

(a) Costs are in January 1988 dollars.

REFERENCES

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

2. Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material, U.S. Nuclear Regulatory Commission, Washington, D.C., November 1976.

APPENDIX B

DETAILS OF DECOMMISSIONING OF REFERENCE FACILITIES

APPENDIX B

DETAILS OF DECOMMISSIONING OF REFERENCE FACILITIES

This appendix provides manpower, waste management, and costs details for the decommissioning of materials licensee laboratory facilities by the DECON alternative. The six reference laboratories for which data are given are described in Section 7 of NUREG/CR-1754.[1] Estimates of decommissioning requirements and costs for these example facilities are based on manpower and cost data for facility components presented in Appendix A.

Appendix A lists some key bases and assumptions used for estimating the requirements and costs of decommissioning facility components. These same bases and assumptions are used in estimating the requirements and costs of decommissioning the example laboratory facilities.

Estimates of manpower requirements and costs for both the planning and preparation phase and the actual decommissioning phase of facility decommissioning are given in this appendix. Planning and preparation activities are described in Section D.2 of NUREG/CR-1754.[1] These activities include the preparation of documentation for regulatory agencies, an initial radiation survey of the facility, and the development of detailed work plans.

Decommissioning of the reference laboratories is assumed to be performed by a work crew consisting of a foreman and three technicians, assisted by a health physicist. Craftsmen (electricians, pipefitter, etc.) are added to this crew on a part-time basis to perform specific tasks. The members of the work crew are recruited from the staff of the facility owner. Manpower costs are postulated to include the salary of a supervisor on a half-time basis.

Removal of contamination that has penetrated to the interior of structural walls or beneath the primary surfacing on floors is not included in these generic analyses because the effort and cost of removal in these instances is very situation-specific. However, a number of methods for removal of such materials are described in Appendix B of NUREG/CR-1754.[1]

The final decommissioning activity is a comprehensive radiological survey to document levels of radioactivity remaining in the facility after DECON procedures are completed and to verify that these levels are less than those specified for unrestricted release. The procedures and instrumentation for performing this radiological survey are described in Section C.2 of NUREG/CR-1754.[1]

Two scenarios are presented for each type of laboratory decommissioned: 1) a scenario assuming minimal use of volume reduction of the low-level waste before shipment to the disposal site, and 2) a scenario assuming that the hardware is sectioned and that the trash is compacted before being shipped to a centrally located supercompactor facility. After supercompaction, the waste is sent on to the disposal site. Solidified liquids are not assumed to be volume reduced.

B.1 DETAILS OF DECOMMISSIONING THE REFERENCE LABORATORY FOR THE MANUFACTURE OF ^{3}H-LABELED COMPOUNDS

The reference laboratory for the manufacture of ^{3}H-labeled compounds is described in Section 7.1.1 of NUREG/CR-1754.[1] The DECON options postulated for the components and building surfaces of this laboratory are shown in Table B.1 along with a brief description of each component. These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the laboratory.

Three of the fume hoods are postulated to be decontaminated to unrestricted release levels. The two remaining hoods are postulated to have high levels of difficult-to-remove residual contamination and are cleaned to remove loose or lightly held contamination and then packaged for disposal at a shallow-land burial ground. Three of the glove boxes are cleaned to unrestricted release levels and the three remaining glove boxes are packaged for disposal. Laboratory benches and other components such as the refrigerators, the freezer, and the storage cabinets are cleaned to unrestricted release levels. Ventilation ductwork is sectioned and packaged for disposal. All of the HEPA and roughing filters and the fiberboard ceiling panels are packaged for disposal. The walls and the floor are decontaminated to unrestricted release levels. (Floor tiles that cannot be easily decontaminated are removed and replaced with new tiles.) Since the contamination is from tritium, steam cleaning techniques are used to decontaminate facility components and building surfaces.

Details of estimated manpower requirements and costs for DECON of the reference ^{3}H laboratory are shown in Table B.2 for the two alternative scenarios. Manpower costs for planning and preparation are estimated to account for about 24 to 26% of the total decommissioning manpower costs. Manpower costs for the final radiation survey are estimated to account for about 7 to 8% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference ^{3}H laboratory are shown in Table B.3 for the two alternative scenarios. In the no-volume-reduction scenario, a total volume of 44.2 m^{3} of contaminated components, equipment, and cleaning supplies is postulated to be packaged in 16 plywood boxes and in one hundred thirty-two 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. The total waste management cost, including containers, transportation, and disposal, is estimated to be about $68,700. In estimating the requirements and costs of waste management, it is assumed that components intended for shallow-land burial are packaged with a minimum of sectioning (i.e., cutting) or compaction. This approach minimizes the time and cost of packaging operations, but maximizes the volume of radioactive waste shipped to the shallow-land burial ground.

The use of volume reduction reduces the total volume of waste to be disposed of to 19.9 m^3, packaged in ninety-five 208-ℓ drums. The total waste management cost is estimated to be about $40,700.

TABLE B.1. DECON Options for Facility Components in the Reference Laboratory for the Manufacture of ^{3}H-Labeled Compounds(a)

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hoods(b)	x	x
Glove Boxes(c)	x	x
Laboratory Benches(d)	x	
Other Components		
Freezer (1)	x	
Refrigerators (2)	x	
Storage Cabinets (2)	x	
Filters		x
Ventilation Ductwork(e)		x
Ceiling(f)		x
Walls (132 m^2)	x	
Floor (120 m^2)	x	

(a) An "x" indicates that the facility component is decommissioned by the indicated option.
(b) Three hoods are cleaned to unrestricted release levels. The other two hoods are packaged for disposal. Each hood is assumed to be a reference hood of 2.835 m^3.
(c) Three glove boxes are cleaned to unrestricted release levels. The other three glove boxes are packaged for disposal. Each box is assumed to be a reference box of 0.324 m^3.
(d) 20 linear meters of laboratory workbenches are assumed.
(e) 40 linear meters of ventilation ductwork are assumed.
(f) Fiberboard ceiling panels are packaged for disposal.

TABLE B.2. Details of Estimated Manpower Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{3}H-Labeled Compounds

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foremen	Craftsmen	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[b]
DECON w/o Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	5	--	5	--	10	--	--	15	2.73
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	30	12.5	30	--	15		12.5	70	14.19
Decommissioning									
Fume Hoods	9	4.5	9	2	4.5	27	--	47	8.92
Glove Boxes	8	4	8	2	4	24	--	42	7.97
Laboratory Benches	1	0.5	1	--	0.5	3	--	5	0.95
Ductwork	2	1	2	2	1	6	--	12	2.26
Other Components	1	0.5	1	--	0.5	3	--	5	0.95
Ceiling	1	0.5	1	--	0.5	3	--	5	0.95
Walls	10	5	10	--	5	30	--	50	9.52
Floor	4	2	4	--	2	12	--	20	3.81
Subtotals	36	18	36	6	18	108	--	186	35.33
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	4.11
25% Cost Contingency	--	--	--	--	--	--	--	--	13.41
Totals	71	33	71	6	43	108	18	279	67.0

(contd)

TABLE B.2. (contd)

Operation	Time (days)(a)	Worker Man-Days: Supervisor	Foremen	Craftsmen	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)(b)
DECON w/ Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	5	--	5	--	10	--	--	15	2.73
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	30	12.5	30	--	15	--	12.5	70	14.19
Decommissioning									
Fume Hoods	11	5.5	11	2	5.5	33	--	57	10.83
Glove Boxes	9.5	5	9.5	2	5	28.5	--	50	9.51
Laboratory Benches	1	0.5	1	--	0.5	3	--	5	0.95
Ductwork	3.5	2	3.5	2	2	10.5	--	20	3.80
Other Components	1	0.5	1	--	0.5	3	--	5	0.95
Ceiling	1	0.5	1	--	0.5	3	--	5	0.95
Walls	10	5	10	--	5	30	--	50	9.52
Floor	4	2	4	--	2	12	--	20	3.81
Subtotals	41	21	41	6	21	12.3	--	212	40.32
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	4.11
25% Contingency	--	--	--	--	--	--	--	--	14.66
Totals	76	36	76	6	46	123	18	305	73.3

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.

TABLE B.3. Details of Waste Management Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^3H-Labeled Compounds

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Compaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Supercompaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Burial Cost[a] ($)	Waste Management Cost[a] ($)
DECON w/o Volume Reduction											
Components & Equipment	Plywood Box	11	11.5	--	943	524	--	--	--	12,017	13,484
Ventilation Ductwork	Plywood Box	5	5.0	--	410	228	--	--	--	5,225	5,863
HEPA & Roughing Filters	Steel Drum 208-ℓ	2	0.42	--	64	23	--	--	--	439	526
Solidified Decontamination Liquids	Steel Drum 208-ℓ	78[b]	16.38	--	3,432	889	--	--	--	17,117	21,438
Trash	Steel Drum 208-ℓ	52	10.92	--	1,664	592	--	--	--	11,411	13,667
Cost Subtotals				--	6,513	2,256	--	--	--	46,209	54,978
25% Contingency											13,744
Totals		16 Boxes 132 Drums	44.2								68,700
DECON w/Volume Reduction											
Components & Equipment	Plywood Box	5	2.5	--	205	69	--	--	--	--	274
Ventilation Ductwork	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	7	--	--	--	--	39
Solidified Decontamination Liquids	Steel Drum 208-ℓ	78[b]	16.38	--	--	--	--	3,432	889	17,117	21,438
Trash	Steel Drum 208-ℓ	11	[illegible]	3,936	352	76	--	--	--	--	4,364
Supercompacted Waste	Steel Drum 208-ℓ	--	--	--	--	--	1,800	544	290	3,695	6,329
Cost Subtotals				3,936	671	180	1,800	3,969	1,179	20,812	32,554
25% Contingency											8,139
Totals		7 Boxes 90 Drums	22.4				17 Drums				40,700

(a) Costs are in January 1988 dollars. Number of significant figures shown is for computational accuracy only.
(b) All drums contain aqueous waste.

B.2 DETAILS OF DECOMMISSIONING THE REFERENCE LABORATORY FOR THE MANUFACTURE OF ^{14}C-LABELED COMPOUNDS

The reference laboratory for the manufacture of ^{14}C-labeled compounds is described in Section 7.1.2 of NUREG/CR-1754.[1] The DECON options postulated for the contaminated components and building surfaces of this laboratory are shown in Table B.4 along with a brief description of each component. These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the laboratory.

Three of the fume hoods are postulated to be decontaminated to unrestricted release levels. The remaining hood is cleaned to remove loose or lightly held contamination and then packaged for disposal at a shallow-land burial ground. Three of the glove boxes are cleaned to unrestricted release levels and the remaining glove box is packaged for disposal. Laboratory benches and other components such as the refrigerators, the freezer, and the storage cabinets are cleaned to unrestricted release levels. The sink is cleaned to an unrestricted release level, but the contaminated drain line is sectioned and packaged for disposal. All of the HEPA and roughing filters and the fiberboard ceiling panels are packaged for disposal. The walls and floor are decontaminated to unrestricted release levels. (Floor tiles that cannot be easily decontaminated are removed and replaced with new tiles.) The walls of the laboratory are steam cleaned. The laboratory floor and the surfaces of contaminated components are scrubbed with a decontaminating solution.

Details of estimated manpower requirements and costs for DECON of the reference ^{14}C laboratory are shown in Table B.5 for the two alternative scenarios. Manpower costs for planning and preparation are estimated to account for about 28 to 30% of the total decommissioning manpower costs. Manpower costs for the final radiation survey are estimated to account for about 9% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference ^{14}C laboratory are shown in Table B.6 for the two alternative scenarios. In the no-volume-reduction scenario, a total volume of 33.9 m^3 of contaminated components, equipment, and cleaning supplies is postulated to be packaged in 10 plywood boxes and in one hundred-fourteen 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. The drummed waste includes 29 drums containing organic liquids adsorbed on diatomaceous earth and packaged in 113-ℓ drums before being overpacked in 208-ℓ drums. (See Section D.3 of Appendix D of NUREG/CR-1754 for a description of the method of treating and packaging liquid wastes.) The total waste management cost, including containers, transportation, and disposal, is estimated to be about $54,700.

The use of volume reduction reduces the total volume of waste to be disposed of to 16.2 m^3, packaged in seventy-eighty 208-ℓ drums. The total waste management cost is estimated to be about $34,700.

TABLE B.4. DECON Options for Facility Components in the Reference Laboratory for the Manufacture of ^{14}C-Labeled Compounds[a]

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hoods(b)	x	x
Glove Boxes[c]	x	x
Laboratory Benches[d]	x	
Other Components		
Freezer (1)	x	
Refrigerators (2)	x	
Storage Cabinets (2)	x	
Sink and Drain[e]		x
Filters		x
Ventilation Ductwork[f]		x
Ceiling[g]		x
Walls (108 m^2)	x	
Floor (80 m^2)	x	

(a) An "x" indicates that the facility component is decommissioned by the indicated option.
(b) Three hoods are cleaned to unrestricted release levels. The other hood is packaged for disposal. Each hood is assumed to be a reference hood of 2.835 m^3.
(c) Three glove boxes are cleaned to unrestricted release levels. The other glove box is packaged for disposal. Each box is assumed to be a reference box of 0.324 m^3.
(d) 15 linear meters of laboratory workbenches are assumed.
(e) The sink is cleaned to unrestricted release levels. The drain line is dismantled and packaged for disposal. The drain line is 10 m long.
(f) 40 linear meters of ventilation ductwork are assumed.
(g) Fiberboard ceiling panels are packaged for disposal.

TABLE B.5. Details of Estimated Manpower Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{14}C-Labeled Compounds

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Crafts	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[b]
DECON w/o Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	3.5	--	3.5	--	7	--	--	10.5	1.91
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	28.5	12.5	28.5	--	12	--	12.5	65.5	13.37
Decommissioning									
Fume Hoods	7	3.5	7	1	3.5	21	--	36	6.84
Glove Boxes	5	2.5	5	0.5	2.5	15	--	25.5	4.60
Laboratory Benches	1	0.5	1	--	0.5	3	--	5	0.95
Sink and Drain Line	0.5	0.25	0.5	0.5	0.25	1.5	--	3	0.57
Ductwork	2	1	2	2	1	6	--	12	2.26
Other Components	1	0.5	1	--	0.5	3	--	5	0.95
Ceiling	1	0.5	1	--	0.5	3	--	5	0.95
Walls	8	4	8	--	4	24	--	40	7.61
Floor	3	1.5	3	--	1.5	9	--	15	2.85
Subtotals	28.5	14.25	28.5	4	14.25	85.5	--	146.5	27.58
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	4.11
25% Cost Contingency	--	--	--	--	--	--		--	11.27
Totals	62	29	62	4	36	86	18	235	56.3

(contd)

TABLE B.5. (contd)

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[b]
DECON w/ Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	3.5	--	3.5	--	7	--	--	10.5	1.91
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	28.5	12.5	28.5	--	12	--	12.5	65.5	13.37
Decommissioning									
Fume Hoods	8	4	8	1	4	24	--	41	7.79
Glove Boxes	5.5	3	5.5	0.5	3	16.5	--	28.5	5.19
Laboratory Benches	1	0.5	1	--	0.5	3	--	5	0.95
Sink and Drain Line	0.5	0.25	0.5	0.5	0.25	1.5	--	3	0.57
Ductwork	3.5	2	3.5	2	2	10.5	--	20	3.80
Other Components	1	0.5	1	--	0.5	3	--	5	0.95
Ceiling	1	0.5	1	--	0.5	3	--	5	0.95
Walls	8	4	8	--	4	24	--	40	7.61
Floor	3	1.5	3	--	1.5	9	--	15	2.85
Subtotals	31.5	16.25	31.5	4	16.25	94.5	--	162.5	30.66
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	4.11
25% Cost Contingency	--	--	--	--	--	--	--	--	12.04
Totals	65	31	65	4	38	95	18	61	60.2

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.

TABLE B.6. Details of Waste Management Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{14}C-Labeled Compounds

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Compaction Cost(a) ($)	Disposable Container Cost(a) ($)	Transportation Cost(a) ($)	Supercompaction Cost(a) ($)	Disposable Container Cost(a) ($)	Transportation Cost(a) ($)	Burial Cost(a) ($)	Waste Management Cost(a) ($)
DECON w/o Volume Reduction											
Components & Equipment	Plywood Box	6	6.0	--	492	273	--	--	--	6,270	7,035
Ventilation Ductwork	Plywood Box	4	4.0	--	328	182	--	--	--	4,180	4,690
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	11	--	--	--	219	262
Solidified Decontamination Liquids	Steel Drum 208-ℓ	67(b)	14.07	--	4,195	763	--	--	--	14,703	19,661
Trash	Steel Drum 208-ℓ	46	9.65	--	1,472	524	--	--	--	10,095	12,091
Cost Subtotals				--	6,519	1,753	--	--	--	35,467	43,739
25% Contingency											10,935
Totals		10 Boxes 114 Drums	33.9								54,700
DECON w/Volume Reduction											
Components & Equipment	Plywood Box	3	1.5	--	123	41	--	--	--	--	164
Ventilation Ductwork	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	7	--	--	--	--	39
Solidified Decontamination Liquids	Steel Drum 208-ℓ	67(b)	14.07	--	--	--	--	4,195	763	14,703	19,661
Trash	Steel Drum 208-ℓ	10	2.08	3,024	320	69	--	--	--	--	3,413
Supercompacted Waste	Steel Drum 208-ℓ	--	--	--	--	--	1,437	352	188	2,391	4,368
Cost Subtotals				3,024	557	145	1,437	4,547	951	17,094	27,755
25% Contingency											6,839
Totals		5 Boxes 78 Drums	18.7				11 Drums				34,700

(a) Costs are in January 1988 dollars. Number of significant figures shown is for computational accuracy only.
(b) 38 drums of aqueous waste plus 29 drums of organic waste.

B.3 DETAILS OF DECOMMISSIONING THE REFERENCE LABORATORY FOR THE MANUFACTURE OF ^{125}I-LABELED COMPOUNDS

The reference laboratory for the manufacture of ^{125}I-labeled compounds is described in Section 7.1.3 of NUREG/CR-1754.[1] The DECON options postulated for the contaminated components and building surfaces of this laboratory are shown in Table B.7 along with a brief description of each component. These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the laboratory.

The four glove boxes located inside fume hoods in the reference laboratory are packaged and shipped to a shallow-land burial ground for disposal. The fume hoods are then decontaminated to unrestricted release levels. Laboratory benches and other components such as the refrigerator, the storage cabinet, and the shelves are cleaned to unrestricted release levels. The sink is cleaned to an unrestricted release level, and the contaminated drain line is sectioned and packaged for disposal. Ventilation ductwork is sectioned and packaged for disposal. Filters are packaged for disposal. The ceiling, walls, and floor are decontaminated to unrestricted release levels. (Floor tiles that cannot be easily decontaminated are removed and replaced with new tiles.)

Details of estimated manpower requirements and costs for DECON of the reference ^{125}I laboratory are shown in Table B.8 for the two alternative scenarios. Manpower costs for planning and preparation are estimated to account for about 28 to 30% of the total decommissioning manpower costs. Manpower costs for the final radiation survey are estimated to account for about 5 to 6% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference ^{125}I laboratory are shown in Table B.9 for the two alternative scenarios. In the no-volume-reduction scenario, a total volume of 22.4 m^3 of contaminated components, equipment, and cleaning supplies is postulated to be packaged in nine plywood boxes and in seventy-eight 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. The glove boxes are assumed to be packaged without being sectioned. All of the decontamination liquids are organic liquids that are adsorbed on diatomaceous earth, packaged in 113-ℓ drums and overpacked in 208-ℓ drums. The total waste management cost, including containers, transportation, and disposal, is estimated to be about $37,400.

The use of volume reduction reduces the total volume of waste to be disposed of to 10.8 m^3, packaged in fifty-two 208-ℓ drums. The total waste management cost is estimated to be about $26,100.

TABLE B.7. DECON Options for Facility Components in the Reference Laboratory for the Manufacture of ^{125}I-Labeled Compounds[(a)]

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hoods[(b)]	x	
Glove Boxes[(c)]		x
Laboratory Benches[(d)]	x	
Other Components		
Refrigerators (1)	x	
Storage Cabinets (1)	x	
Shelves (1)	x	
Sink and Drain[(e)]	x	x
Filters		x
Ventilation Ductwork[(f)]		x
Ceiling	x	
Walls (84 m^2)	x	
Floor (48 m^2)	x	

(a) An "x" indicates that the facility component is decommissioned by the indicated option.
(b) There are four hoods at 2.835 m^3 each.
(c) There are four specially designed glove boxes, each being 1.2 m wide, by 0.6 m deep, by 0.6 m high, for a total volume of 0.432 m^3.
(d) There are 8 linear meters of laboratory workbenches.
(e) The sink is cleaned to unrestricted release levels. The drain line is dismantled and packaged for disposal. The drain line is 10 m long.
(f) There are 40 linear meters of ventilation ductwork.

TABLE B.8. Details of Estimated Manpower Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{125}I-Labeled Compounds

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs[b] ($ thousands)
DECON w/o Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	3.5	--	3.5	--	7	--	--	10.5	1.91
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	28.5	12.5	28.5	--	12	--	12.5	65.5	13.37
Decommissioning									
Fume Hoods	8	4	8	--	4	24	--	40	7.61
Glove Boxes	5	2.5	5	2	2.5	15	--	27	5.12
Laboratory Benches	0.5	0.25	0.5	--	0.25	1.5	--	2.5	0.47
Sink and Drain Line	0.5	0.25	0.5	0.5	0.25	1.5	--	3	0.57
Ductwork	2	1	2	2	1	6	--	12	2.26
Other Components	1	0.5	1	--	0.5	3	--	5	0.95
Ceiling	3	1.5	3	--	1.5	9	--	15	2.85
Walls	7	3.5	7	--	3.5	21	--	35	6.66
Floor	2	1	2	--	1	6	--	10	1.91
Subtotals	29	14.5	29	4.5	14.5	87	--	149.5	28.40
Final Radiological Survey	3	1.5	3	--	6	--	3	13.5	2.46
25% Cost Contingency	--	--	--	--	--	--	--	--	11.06
Totals	61	28	61	5	33	87	16	230	55.3

(contd)

TABLE B.8. (contd)

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[b]
DECON w/ Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	3.5	--	3.5	--	7	--	--	10.5	1.91
Develop Work Plan	10	5	10	--	5	--	5	23	5.08
Subtotals	28.5	12.5	28.5	--	12	--	12.5	65.5	13.37
Decommissioning									
Fume Hoods	8	4	8	--	4	24	--	40	7.61
Glove Boxes	7	3.5	7	2	3.5	21	--	37	7.01
Laboratory Benches	0.5	0.25	0.5	--	0.25	1.5	--	2.5	0.47
Sink and Drain Line	0.5	0.25	0.5	0.5	0.25	1.5	--	3	0.57
Ductwork	3.5	2	3.5	2	2	10.5	--	20	3.80
Other Components	1	0.5	1	--	0.5	3	--	5	0.95
Ceiling	3	1.5	3	--	1.5	9	--	15	2.85
Walls	7	3.5	7	--	3.5	21	--	35	6.66
Floor	2	1	2	--	1	6	--	10	1.91
Subtotals	32.5	16.5	32.5	4.5	16.5	97.5	--	167.5	31.83
Final Radiological Survey	3	1.5	3	--	6	--	3	13.5	2.46
25% Cost Contingency	--	--	--	--	--	--	--	--	11.92
Totals	65	30	65	5	35	98	16	247	59.6

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.

TABLE B.9. Details of Waste Management Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{125}I-Labeled Compounds

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Compaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Supercompaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Burial Cost[a] ($)	Waste Management Cost[a] ($)
DECON w/o Volume Reduction											
Components & Equipment	Plywood Box	6	3.0	--	246	137	--	--	--	3,135	3,518
Ventilation Ductwork	Plywood Box	3	3.0	--	246	137	--	--	--	3,135	3,518
HEPA & Roughing Filters	Steel Drum 208-ℓ	3	0.63	--	96	34	--	--	--	658	788
Solidified Decontamination Liquids	Steel Drum 208-ℓ	44[b]	9.24	--	3,828	501	--	--	--	9,656	13,985
Trash	Steel Drum 208-ℓ	31	6.51	--	992	353	--	--	--	6,803	8,148
Cost Subtotals				--	5,408	1,162	--	--	--	23,387	29,957
25% Contingency											7,489
Totals		9 Boxes 78 Drums	22.4								37,400
DECON w/Volume Reduction											
Components & Equipment	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
Ventilation Ductwork	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	7	--	--	--	--	39
Solidified Decontamination Liquids	Steel Drum 208-ℓ	44[b]	9.24	--	--	--	--	3,828	501	9,656	13,985
Trash	Steel Drum	7	1.46	3,120	224	48	--	--	--	--	3,392
Supercompacted Waste	Steel Drum 208-ℓ	--	--				1,100	256	137	1,739	3,232
Cost Subtotals				3,120	420	111	1,100	4,084	638	11,395	20,868
25% Contingency											5,217
Totals		4 Boxes 52 Drums	12.9				8 Drums				26,100

(a) Costs are in January 1988 dollars. Number of significant figures shown is for computational accuracy only.
(b) All drums contain organic waste.

B.4 DETAILS OF DECOMMISSIONING THE REFERENCE LABORATORY FOR THE MANUFACTURE OF ^{137}CS SEALED SOURCES

The reference laboratory for the manufacture of ^{137}Cs sealed sources is described in Section 7.1.4 of NUREG/CR-1754.[1] The DECON options postulated for the contaminated components and building surfaces of this laboratory are shown in Table B.10 along with a brief description of each component. These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the laboratory.

The fume hoods are postulated to be decontaminated to unrestricted release levels. The hot cells are disassembled and the lead-glass windows and contaminated cell liners are packaged for disposal by shallow-land burial. The lead bricks are monitored and 65% of the bricks are decontaminated and sold for salvage. The remaining bricks are packaged for disposal. Laboratory benches are cleaned to unrestricted release levels. The sink is cleaned to an unrestricted release level, and the contaminated drain line is sectioned and packaged for disposal. Ventilation ductwork is sectioned and packaged for disposal. HEPA and roughing filters are packaged for disposal. The ceiling, walls, and floor are decontaminated to unrestricted release levels. (Floor tiles that cannot be easily decontaminated are removed and replaced with new tiles.)

Details of estimated manpower requirements and costs for DECON of the reference ^{137}Cs laboratory are shown in Table B.11 for the two alternative scenarios. Manpower costs for planning and preparation are estimated to account for about 28 to 29% of the total decommissioning manpower costs. Manpower costs for the final radiation survey are estimated to account for about 5 to 6% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference ^{137}Cs laboratory are shown in Table B.12 for the two alternative scenarios. In the no-volume-reduction scenario, a total volume of 19.8 m^3 of contaminated components, equipment, and cleaning supplies is postulated to be packaged in 26 plywood boxes and in sixty-one 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. All of the decontamination liquids are organic liquids that are adsorbed on diatomaceous earth and packaged in 113-ℓ drums before being overpacked in 208-ℓ drums. The total waste management cost, including containers, transportation, and disposal, is estimated to be about $14,600.

The use of volume reduction reduces the total volume of waste to be disposed of to 8.7 m^3, packaged in forty-two 208-ℓ drums. The total waste management cost is estimated to be about $6,200.

TABLE B.10. DECON Options for Facility Components in the Reference Laboratory for the Manufacture of ^{137}Cs Sealed Sources[a]

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hoods[b]	x	
Hot Cells[c]	x	x
Laboratory Benches[d]	x	
Sink and Drain[e]	x	x
Filters		x
Ventilation Ductwork[f]		x
Ceiling	x	
Walls (84 m^2)	x	
Floor (48 m^2)	x	

(a) An "x" indicates that the facility component is decommissioned by the indicated option.
(b) There are two fume hoods at 2.835 m^3 each.
(c) There are two hot cells at 1.728 m^3 each. 65% of the lead bricks are reclaimed and sold for salvage. The remaining bricks are packaged for disposal. The manipulator and the cell liners are packaged for disposal.
(d) There are 4 linear meters of workbenches.
(e) The sink is cleaned to unrestricted release levels. The drain line is dismantled and packaged for disposal. The drain line is 10 m long.
(f) There are 40 linear meters of ventilation ductwork.

TABLE B.11. Detail of Estimated Manpower Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{137}Cs Sealed Sources

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs[b] ($ thousands)
DECON w/o Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	2.5	--	2.5	--	5	--	--	7.5	1.36
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	27.5	12.5	27.5	--	10	--	12.5	62.5	12.82
Decommissioning									
Fume Hoods	4	2	4	--	2	12	--	20	3.81
Hot Cells	9	4.5	9	2	4.5	27	--	47	8.92
Laboratory Benches	0.5	0.25	0.5	--	0.25	1.5	--	2.5	0.47
Sink and Drain Line	0.5	0.25	0.5	0.5	0.25	1.5	--	3	0.57
Ductwork	2	1	2	2	1	6	--	12	2.26
Ceiling	3	1.5	3	--	1.5	9	--	15	2.85
Walls	8	4	8	--	4	24	--	40	7.61
Floor	2	1	2	--	1	6	--	10	1.91
Subtotals	29	14.5	29	4.5	14.5	87	--	149.5	28.40
Final Radiological Survey	3	1.5	3	--	6	--	3	13.5	2.46
25% Cost Contingency	--	--	--	--	--	--	--	--	10.92
Totals	60	28	60	5	30	87	16	226	54.6

(contd)

TABLE B.11. (contd)

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs[b] ($ thousands)
DECON w/ Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	2.5	--	2.5	--	5	--	--	7.5	1.36
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	27.5	12.5	27.5	--	10	--	12.5	62.5	12.82
Decommissioning									
Fume Hoods	4	2	4	--	2	12	--	20	3.81
Hot Cells	9	4.5	9	2	4.5	27	--	47	8.92
Laboratory Benches	0.5	0.25	0.5	--	0.25	1.5	--	2.5	0.47
Sink and Drain Line	0.5	0.25	0.5	0.5	0.25	1.5	--	3	0.57
Ductwork	3.5	2	3.5	2	2	10.5	--	20	3.80
Ceiling	3	1.5	3	--	1.5	9	--	15	2.85
Walls	8	4	8	--	4	24	--	40	7.61
Floor	2	1	3	--	1	6	--	10	1.91
Subtotals	30.5	15.5	30.5	4.5	15.5	91.5	--	157.5	29.94
Final Radiological Survey	3	1.5	3	--	6	--	3	13.5	2.46
25% Cost Contingency	--	--	--	--	--	--	--	--	11.31
Totals	61	29	61	5	31	92	16	234	56.5

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.

TABLE B.12. Details of Waste Management Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{137}Cs Sealed Sources

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Compaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Supercompaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Burial Cost[a] ($)	Waste Management Cost[a] ($)
DECON w/o Volume Reduction											
Components & Equipment	Plywood Box	22	3.0	--	632[b]	137	--	--	--	3,135	3,904
Ventilation Ductwork	Plywood Box	4	4.0	--	328	182	--	--	--	4,180	4,690
HEPA & Roughing Filters	Steel Drum 208-ℓ	2	0.42	--	64	23	--	--	--	439	526
Solidified Decontamination Liquids	Steel Drum 208-ℓ	36[e]	7.56	--	3,132	410	--	--	--	7,900	11,442
Trash	Steel Drum 208-ℓ	23	4.83	--	736	262	--	--	--	5,047	6,045
Cost Subtotals				--	4,892	1,014	--	--	--	20,701	26,607
25% Contingency											6,652
Totals		26 Boxes 61 Drums	19.8								33,300
Credit for Lead Salvage[d]											18,700
DECON w/Volume Reduction											
Components & Equipment	Plywood Box	21	2.5	--	41	14	--	550[b]	91	2,090	2,786
Ventilation Ductwork	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	7	--	--	--	--	39
Solidified Decontamination Liquids	Steel Drum 208-ℓ	36[c]	7.56	--	--	--	--	3,132	410	7,900	11,442
Trash	Steel Drum 208-ℓ	5	1.04	2,929	160	34	--	--	--	--	3,123
Supercompacted Waste	Steel Drum 208-ℓ	--	--	--	--	--	824	192	68	1,304	2,388
Cost Subtotals				2,929	315	83	824	3,874	569	11,294	19,888
25% Contingency											4,977
Totals		23 Boxes 42 Drums	12.3				6 Drums				24,860
Credit for Lead Salvage[d]											18,700

(a) Costs are in January 1988 dollars. Number of significant figures shown is for computational accuracy only.
(b) Twenty containers with a total volume of 2 m^3 are small boxes specially made to contain lead bricks and steel plate. These boxes are assumed to cost $27.50 each.
(c) All drums contain organic waste.
(d) A total of 11,500 kg of lead per hot cell, 65% of which has a salvage value of $1.25 per kg credit for lead salvage.

B.5 DETAILS OF DECOMMISSIONING THE REFERENCE LABORATORY FOR THE MANUFACTURE OF ^{241}AM SEALED SOURCES

The reference laboratory for the manufacture of ^{241}Am sealed sources is described in Section 7.1.5 of NUREG/CR-1754.(1) The DECON options postulated for the contaminated components and building surfaces of this laboratory are shown in Table B.13 along with a brief description of each component. These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the laboratory.

The locations of fume hoods and glove boxes in the reference ^{241}Am laboratory are shown schematically in Section 7.1.5 of NUREG/CR-1754.(1) The fume hoods and the glove box in the low-level alpha lab are postulated to be decontaminated to unrestricted release levels. The glove boxes and transfer tunnels in the high-level alpha lab are decontaminated to remove loose or lightly held contamination and to reduce total transuranic contamination to acceptable levels for shallow-land burial of these components. These glove boxes and transfer tunnels are then packaged and shipped to a shallow-land burial site for disposal. Laboratory benches are decontaminated to unrestricted release levels. Ventilation ductwork is sectioned and packaged for disposal. HEPA and roughing filters are packaged for disposal. The ceiling, walls, and floor of the laboratory are decontaminated to unrestricted release levels.

Details of estimated manpower requirements and cost for DECON of the reference ^{241}Am laboratory are shown in Table B.14 for the two alternative scenarios. Manpower costs for planning and preparation are estimated to account for about 20 to 22% of the total decommissioning manpower costs. Manpower costs for the final radiation survey are estimated to account for about 6% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference ^{241}Am laboratory are shown in Table B.15 for the two alternative scenarios. In the no-volume-reduction scenario, a total volume of 31.2 m^3 of contaminated components, equipment, and cleaning supplies is postulated to be packaged in 15 plywood boxes and in one hundred-one 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. All of the decontamination liquids are organic liquids that are adsorbed on diatomaceous earth and packaged in 113-ℓ drums before being overpacked in 208-ℓ drums. The total waste management cost, including containers, transportation, and disposal, is estimated to be about \$52,000.

The use of volume reduction reduces the total volume of waste to be disposed of to 14.4 m^3, packaged in sixty-nine 208-ℓ drums. The total waste management cost is estimated to be about \$35,100.

TABLE B.13. DECON Options for Facility Components in the Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources[a]

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hoods[b]	x	
Glove Boxes[c]	x	x
Laboratory Benches[d]	x	
Other Components		
Transfer Tunnels[e]		x
Filters		x
Ventilation Ductwork[f]		x
Ceiling	x	
Walls (96 m^2)	x	
Floor (63 m^2)	x	

(a) An "x" indicates that the facility component is decommissioned by the indicated option.
(b) There are two hoods at 2.835 m^3 each.
(c) One glove box is cleaned to unrestricted release levels. The remaining six glove boxes are decontaminated to acceptance levels for shallow-land burial and are then packaged for disposal. Each glove box is 1.2 m wide, by 0.6 m high, for a total volume of 0.432 m^3.
(d) There are 2 linear meters of laboratory workbenches.
(e) Transfer tunnels are decontaminated to acceptance levels for shallow-land burial and are then packaged for disposal.
(f) There are 40 linear meters of ventilation ductwork.

TABLE B.14. Details of Estimated Manpower Requirements and Costs for DECON of the Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs[b] ($ thousands)
DECON w/o Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Preform Radiological Survey	4.5	--	4.5	--	9	--	--	13.5	2.45
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	29.5	12.5	29.5	--	14	--	12.5	65.5	13.91
Decommissioning									
Fume Hoods	7	3.5	7	--	3.5	21	--	35	6.66
Glove Boxes	15	7.5	15	10	7.5	45	--	85	16.36
Laboratory Benches	0.5	0.25	0.5	--	0.25	1.5	--	2.5	0.47
Ductwork	2	1	2	2	1	6	--	12	2.26
Other Components	2	1	2	--	1	6	--	10	1.91
Ceiling	6	3	6	--	3	18	--	30	5.71
Walls	12	6	12	--	6	36	--	60	11.42
Floor	2	1	2	--	1	6	--	10	1.91
Subtotals	46.5	23.25	46.5	12	23.25	139.5	--	244.5	46.70
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	4.11
25% Cost Contingency	--	--	--	--	--	--	--	--	16.18
Totals	81	38	81	12	47	140	18	336	80.9

(contd)

TABLE B.14. (contd)

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs[b] ($ thousands)
DECON w/ Volume-Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	4.5	--	4.5	--	9	--	--	13.5	2.45
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	29.5	12.5	29.5	--	14	--	12.5	68.5	13.91
Decommissioning									
Fume Hoods	7	3.5	7	--	3.5	21	--	35	6.66
Glove Boxes	18	9	18	10	9	54	--	100	18.90
Laboratory Benches	0.5	0.25	0.5	--	0.25	1.5	--	2.5	0.47
Ductwork	3.5	2	3.5	2	2	10.5	--	20	3.80
Other Components	2	1	2	--	1	6	--	10	1.91
Ceiling	6	3	6	--	3	18	--	30	5.71
Walls	12	6	12	--	6	36	--	60	11.42
Floor	2	1	2	--	1	6	--	10	1.91
Subtotals	51	25.75	51	12	25.75	153	--	267.5	50.78
Final Radiological Survey	5	2.5	5	--	10	--	5	22.5	4.11
25% Cost Contingency	--	--	--	--	--	--	--	--	17.20
Totals	86	41	86	12	50	153	18	359	86.0

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.

TABLE B.15. Details of Waste Management Requirements and Costs of DECON of the Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Compaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Supercompaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Burial Cost[a] ($)	Waste Management Cost[a] ($)
DECON w/o Volume Reduction											
Components & Equipment	Plywood Box	10	5.0	--	410	228	--	--	--	5,225	5,863
Ventilation Ductwork	Plywood Box	5	5.0	--	410	228	--	--	--	5,225	5,863
HEPA & Roughing Filters	Steel Drum 208-ℓ	3	0.63	--	96	34	--	--	--	658	788
Solidified Decontamination Liquids	Steel Drum 208-ℓ	60[b]	12.60	--	5,220	684	--	--	--	13,167	19,071
Trash	Steel Drum 208-ℓ	38	7.98	--	1,216	433	--	--	--	8,339	9,988
Cost Subtotals				--	7,352	1,607	--	--	--	32,614	41,573
25% Contingency											10,393
Totals		15 Boxes 101 Drums	31.2								52,000
DECON w/Volume Reduction											
Components & Equipment	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
Ventilation Ductwork	Plywood Box	2	1.0	--	82	28	--	--	--	--	110
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	7	--	--	--	--	39
Solidified Decontamination Liquids	Steel Drum 208-ℓ	60[b]	12.60	--	--	--	--	5,220	684	13,167	19,071
Trash	Steel Drum 208-ℓ	8	1.66	4,896	256	55	--	--	--	--	5,207
Supercompacted Waste	Steel Drum 208-ℓ	--	--	--	--	--	1,162	288	154	1,956	3,560
Cost Subtotals	--	--	--	4,896	452	118	1,162	5,508	838	15,123	28,097
25% Contingency											7,024
Totals		4 Boxes 69 Drums	16.5								35,100

(a) Costs are in January 1988 dollars. Number of significant figures shown is for computational accuracy only.
(b) All drums contain organic waste.

B.6 DETAILS OF DECOMMISSIONING THE REFERENCE INSTITUTIONAL USER LABORATORY

The reference institutional user laboratory is described in Section 7.2 of NUREG/CR-1754.(1) The DECON options postulated for the contaminated components and building surfaces of this laboratory are shown in Table B.16 along with a brief description of each component. These DECON options provide a basis for estimating the manpower and waste management requirements and costs of decommissioning the reference institutional user laboratory.

Four of the fume hoods are postulated to be decontaminated to unrestricted release levels. The remaining hood is cleaned to remove loose or lightly held contamination and then packaged for disposal at a shallow-land burial ground. The glove box is decontaminated to an unrestricted release level. Laboratory benches and other components such as the refrigerator and the lead storage vault are decontaminated to unrestricted release levels. The animal cage is packaged for disposal at a shallow-land burial ground. Sinks are cleaned to unrestricted release levels; drain lines are packaged for disposal. Filters and ventilation ductwork are packaged for disposal. Fiberboard ceiling panels are packaged for disposal. The walls and floor are decontaminated to unrestricted release levels. The walls of the laboratory are steam cleaned. The laboratory floor and the surfaces of contaminated components are scrubbed with a decontaminating solution. (Floor tiles that cannot be easily decontaminated are removed and replaced with new tiles.)

Details of estimated manpower requirements and costs for DECON of the reference institutional user laboratory are shown in Table B.17 for the two alternative scenarios. Manpower costs for planning and preparation are estimated to account for about 26 to 27% of the total decommissioning manpower costs. The final radiation survey includes a survey of the equipment room, rest room, office, counting room, and building corridors, as well as of those areas with known contamination that have been previously decontaminated. Manpower costs for this final survey are estimated to account for about 12 to 13% of the total manpower costs.

Details of estimated waste management requirements and costs for DECON of the reference institutional user laboratory are shown in Table B.18 for the two alternative scenarios. In the no-volume-reduction scenario, a total volume of 34.2 m^3 of contaminated components, equipment, and cleaning supplies is postulated to be packaged in 13 plywood boxes and in one hundred-eight 208-ℓ steel drums and to be shipped to a shallow-land burial site for disposal. The total waste management cost, including containers, transportation, and disposal, is estimated to be about $54,100.

The use of volume reduction reduces the total volume of waste to be disposed of to 15.6 m^3, packaged in seventy-five 208-ℓ drums. The total waste management cost is estimated to be about $33,300.

TABLE B.16. DECON Options for Facility Components in the Reference Institutional User Laboratory[(a)]

Facility Component	DECON Option: Clean to Unrestricted Release Levels	DECON Option: Dismantle and Package for Disposal
Fume Hoods[(b)]	x	x
Glove Boxes[(c)]	x	
Laboratory Benches[(d)]	x	
Other Components		
Refrigerator (1)	x	
Lead Vault (1)	x	
Animal Cage (1)		x
Sink and Drain[(e)]	x	x
Filters		x
Ventilation Ductwork[(f)]		x
Ceiling[(g)]		x
Walls (360 m^2)	x	
Floor (176 m^2)	x	

(a) An "x" indicates that the facility component is decommissioned by the indicated option.
(b) Four hoods are cleaned to unrestricted release levels. One hood is packaged for disposal. Each hood occupies 2.835 m^3.
(c) There is one glove box at 0.324 m^3.
(d) There are 30 linear meters of laboratory workbenches.
(e) Sinks are cleaned to unrestricted release levels. Drain lines are dismantled and packaged for disposal. There are five sinks, each with a 10-m-long drain line.
(f) There are 40 linear meters of ventilation ductwork.
(g) Fiberboard ceiling panels are packaged for disposal.

TABLE B.17. Details of Estimated Manpower Requirements and Costs for DECON of the Reference Institutional User Laboratory

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[b]
DECON w/o Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	5	--	5	--	10	--	--	15	2.73
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	30	12.5	30	--	15	--	12.5	70	14.19
Decommissioning									
Fume Hoods	10	5	10	1	5	30	--	51	9.69
Glove Boxes	2	1	2	--	1	6	--	10	1.91
Laboratory Benches	1	0.5	1	--	0.5	3	--	5	0.95
Sink and Drain Line	1	0.5	1	1	0.5	3	--	6	1.13
Ductwork	2	1	2	2	1	6	--	12	2.26
Other Components	2	1	2	--	1	6	--	10	1.91
Ceiling	1	0.5	1	--	0.5	3	--	5	0.95
Walls	10	5	10	--	5	30	--	50	9.52
Floor	3	1.5	3	--	1.5	9	--	15	2.85
Subtotals	32	16	32	4	16	96	--	164	31.17
Final Radiological Survey	8	4	8	--	16	--	8	36	6.58
25% Cost Contingency	--	--	--	--	--	--	--	--	12.99
Totals	70	32	70	4	47	96	21	270	64.9

(contd)

TABLE B.17. (contd)

Operation	Time (days)[a]	Worker Man-Days: Supervisor	Foreman	Craftsman	H. P. Technician	Technician	Secretary	Total Man-Days	Manpower Costs ($ thousands)[b]
DECON w/ Volume Reduction									
Planning & Preparation									
Prepare Documentation	15	7.5	15	--	--	--	7.5	30	6.38
Perform Radiological Survey	5	--	5	--	10	--	--	15	2.73
Develop Work Plan	10	5	10	--	5	--	5	25	5.08
Subtotals	30	12.5	30	--	15	--	12.5	70	14.19
Decommissioning									
Fume Hoods	11	5.5	11	1	5.5	33	--	56	10.65
Glove Boxes	2	1	2	--	1	6	--	10	1.91
Laboratory Benches	1	0.5	1	--	0.5	3	--	5	0.95
Sink and Drain Line	1	0.5	1	1	0.5	3	--	6	1.13
Ductwork	3.5	2	3.5	2	2	10.5	--	20	3.80
Other Components	2	1	2	--	1	6	--	10	1.91
Ceiling	1	0.5	1	--	0.5	3	--	5	0.95
Walls	10	5	10	--	5	30	--	50	9.52
Floor	3	1.5	3	--	1.5	9	--	15	2.85
Subtotals	34.5	17.5	34.5	4	17.5	103.5	--	177	33.67
Final Radiological Survey	8	4	8	--	16	--	8	36	6.58
25% Cost Contingency	--	--	--	--	--	--	--	--	13.61
Totals	73	34	73	4	49	104	21	283	68.1

(a) 50% ancillary time is included in estimates of decommissioning times.
(b) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.

TABLE B.18. Details of Waste Management Requirements and Costs for DECON of the Reference Institutional User Laboratory

Waste Category	Container Type	Number of Containers	Shipping Volume (m^3)	Compaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Supercompaction Cost[a] ($)	Disposable Container Cost[a] ($)	Transportation Cost[a] ($)	Burial Cost[a] ($)	Waste Management Cost[a] ($)
DECON w/o Volume Reduction											
Components & Equipment	Plywood Box	8	6.5	--	533	296	--	--	--	6,793	7,622
Ventilation Ductwork	Plywood Box	5	5.0	--	410	228	--	--	--	5,225	5,863
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	11	--	--	--	217	260
Solidified Decontamination Liquids	Steel Drum 208-ℓ	65[b]	13.66	--	3,720	740	--	--	--	14,128	18,588
Trash	Steel Drum 208-ℓ	42	8.82	--	1,344	478	--	--	--	9,129	10,951
Cost Subtotals				--	6,039	1,753	--	--	--	35,492	43,284
25% Contingency											10,821
Totals		13 Boxes 108 Drums	34.2								54,100
DECON w/Volume Reduction											
Components & Equipment	Plywood Box	3	1.5	--	123	41	--	--	--	--	164
Ventilation Ductwork	Plywood	2	1.0	--	82	28	--	--	--	--	110
HEPA & Roughing Filters	Steel Drum 208-ℓ	1	0.21	--	32	7	--	--	--	--	39
Solidified Decontamination Liquids	Steel Drum 208-ℓ	65[b]	13.56	--	--	--	--	3,720	740	14,128	18,588
Trash	Steel Drum 208-ℓ	9	1.87	3,312	288	93	--	--	--	--	3,693
Supercompacted Waste	Steel Drum 208-ℓ	--	--	--	--	--	1,374	320	171	2,174	4,039
Cost Subtotals				3,312	525	169	1,374	4,040	911	16,302	26,633
25% Contingency											6,658
Totals		5 Boxes 75 Drums	18.2								33,300

(a) Costs are in January 1988 dollars. Number of significant figures shown is for computational accuracy only.
(b) 48 drums of aqueous waste plus 20 drums of organic waste.

B.7 REFERENCES

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

APPENDIX C

DETAILS OF DECOMMISSIONING OF REFERENCE SITES

APPENDIX C

DETAILS OF DECOMMISSIONING OF REFERENCE SITES

This appendix provides details to support the description of the decommissioning of sites presented in Chapter 7. The reference sites include 1) a site with a contaminated underground waste line and hold-up tank, 2) a site with a contaminated ground surface, and 3) a tailings pile/evaporation pond containing uranium and thorium residues. The reference sites are described in Section 7.3 of NUREG/CR-1754.[1]

The decommissioning alternatives for contaminated sites are 1) site stabilization followed by long-term care and 2) removal of the contaminated material to an approved shallow-land burial ground. Details of the technology and costs of these two alternatives are given in another report on the technology, safety, and costs of decommissioning a low-level waste burial ground.[2] For convenience of reference, brief descriptions of several site stabilization options are given in Section G.1 of NUREG/CR-1754.[1]

The following key bases and assumptions are used for estimating manpower requirements and costs:

1. The decommissioning of a site is performed by a contractor hired by the owner/operator of the site. Separate contractors might be hired for the site survey and for the actual decommissioning operations. (In some instances, the owner/operator would perform his own site survey.) The impact on decommissioning costs of utilizing contractors is discussed in Section D.1 of NUREG/CR-1754.[1]

2. To determine the total time required to decommission a radioactively contaminated site, an estimate is made of the time required for efficient performance of the work by a postulated work crew. This time estimate is then increased by 50% to provide for preparation and set-up time, rest periods, etc. (ancillary time).

3. All radioactive wastes from the decommissioning of contaminated sites are shipped by truck a distance of 800 km to a shallow-land burial ground.

4. Transportation and waste disposal operations are subcontracted activities. The manpower costs for the transportation and disposal of radioactive material are included in the total costs of these items.

5. Decommissioning includes the backfilling of a site from which wastes have been exhumed and the restoration of the decommissioned site by

grading the site and/or planting grass or other appropriate vegetative cover. Costs of backfilling and site restoration are included in the costs of decommissioning.

6. If a site is to be released for unrestricted public use, the final decommissioning activity is a site survey to verify that residual levels of radioactivity are below unrestricted release limits. Costs of this final radiation survey are included in the estimated costs of decommissioning.

7. All costs are in January 1988 dollars.

For ease in evaluating time and manpower requirements for the decommissioning of sites, each decommissioning alternative is divided into a sequence of tasks or steps. For the site stabilization alternative, the steps are:

- planning and preparation (including initial site survey)
- mobilization/demobilization
- site stabilization
- revegetation.

For the removal alternative, the steps are:

- planning and preparation (including initial site survey)
- mobilization/demobilization
- remove overburden
- exhume and package contaminated material
- transport and dispose of contaminated material at a shallow-land burial ground
- backfill and restore site
- termination site survey.

C.1 DETAILS OF DECOMMISSIONING A CONTAMINATED UNDERGROUND DRAIN LINE

Time and manpower requirements and total costs for the exhumation and disposal of a contaminated drain line, hold-up tank, and soil are presented in this section. The reference site is described in Section 7.3.1 of NUREG/CR-1754.(1) Procedures for decommissioning a drain line and hold-up tank are given in Section G.2.1 of that same document.

Details of estimated time and manpower requirements for removing a contaminated drain line and hold-up tank are presented in Table C.1. The radiological survey that precedes site decommissioning is performed by a work crew consisting of a foreman and two health physics technicians from the site owner's organization. A foreman and an equipment operator are required during excavation of the trench. Exhumation and packaging of a 20-m-long, 0.1-m-diameter drain line, a 1.5-m-diameter, 2-m-high cylindrical hold-up tank, and contaminated soil are performed by a crew that includes a foreman, an equipment operator, a pipefitter, and two technicians. A health physics technician is present during excavation and exhumation operations to make radiological measurements. An equipment operator and a technician backfill and grade the site after exhumation operations are completed. The final site survey is performed by a foreman and two health physics technicians.

Costs details for removing a contaminated drain line and hold-up tank are presented in Table C.2. The total cost of decommissioning the site is estimated to be about $69,200. A contractor's fee is included in the total cost as described in Section D.1 of NUREG/CR-1754.[1] It is assumed that soil samples are sent to a commercial laboratory for analysis. Waste management costs are based on a requirement for 7 m^3 of plastic-lined plywood boxes to contain the exhumed material and contaminated soil.

Only about 13% of the total decommissioning costs are due to disposal charges, with most of this due to disposal of the hold-up tank. Volume reduction of the hold-up tank via sectioning and supercompaction was not analyzed because of the lack of any significant savings potential.

Unit cost factors for the removal of a contaminated drain line and hold-up tank are given in Table C.3. The cost factors for manpower, equipment, and materials are given in $/$m^3$ (rectangular volume occupied by both the tank and drain line combined). These unit cost factors are also a function of the depth at which the drain line is buried, hence the H term. The soil analysis cost factor is given in $/m (linear length) of the drain line while the package, transportation, and disposal cost factors are given in $/$m^3$ of waste volume. The waste volume unit factor is given in m^3 of waste volume generated per rectangular volume of the tank and drain line combined.

TABLE C.1. Details of Estimated Time and Manpower Requirements for the Removal of a Contaminated Drain Line and Hold-Up Tank

Operator	Time (Days)[a]	Worker Man-Days: Supervisor[b]	Foreman	Equipment Operator	Craftsman	Health Physics Technician	Technician	Total Man-days	Manpower Costs ($ thousands)[c,d]
Planning and Preparation	5	5	5	--	--	4	--	14	3.51
Mobilization/ Demobilization	2	1	2	2	--	--	2	7	2.04
Remove Overburden	1.5	0.75	1.5	1.5	--	1.5	--	5.25	1.42
Exhume and Package Drain Line	3	1.5	3	3	3	3	6	19.5	5.01
Exhume and Package Hold-Up Tank	2.5	1.25	2.5	2.5	2.5	2.5	5	16.25	4.17
Backfill and Restore Site	1	0.5	--	1	--	--	1	2.5	0.72
Final Site Survey	2	1	2	--	--	4	--	7	1.44
Totals	17	11	16	10	5.5	15	14	71.5	18.31

(a) 50% ancillary time is included in estimate.
(b) Charged half-time to project.
(c) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.
(d) 25% contingency not included.

TABLE C.2. Cost Details for the Removal of a Contaminated Drain Line and Hold-up Tank

Cost Item	Cost ($ thousands)[a]
Manpower	18.31
Equipment	16.50
Materials	2.82
Soil Analyses	6.40
Contractor's Fee[b]	3.07
Waste Management	
Packaging	0.70
Transportation	0.32
Disposal	7.32
Subtotal	55.44
25% Contingency	13.86
Total	69.3

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for manpower, equipment, materials, and packaging.

TABLE C.3. Estimated Unit Factors for Removal of a Contaminated Drain Line and Hold-Up Tank[a]

Cost Item	Unit Factor[a]
Manpower ($K/m^3 of tank and pipe)	3.23 + 0.29H
Equipment ($K/m^3 of tank and pipe)	2.90 + 0.26H
Materials ($K/m^3 of tank and pipe)	0.50 + 0.05H
Soil Analysis ($K/m of pipe length)	0.32
Waste Volume (m^3 waste/m^3 of tank and pipe)	1.40
Packaging ($K/m^3 waste)	0.10
Transportation ($K/m^3 waste)	0.0[illegible]
Disposal ($K/m^3 waste)	1.05

(a) Costs are in January 1988 dollars.
(b) H is the depth at which the drain line is buried.

C.2 DETAILS OF DECOMMISSIONING A CONTAMINATED GROUND SURFACE

Time and manpower requirements and total costs for the removal of contaminated soil from a reference site are evaluated in this section. The reference site is described in Section 7.3.2 of NUREG/CR-1754.[1] It is assumed to be contaminated with radioactive residue from uranium processing operations that was trucked to the site from another location, dumped on the site, and used as fill material. Procedures for removing contaminated ground surface are given in Section G.3.1 of NUREG/CR-1754.[1]

Details of estimated time and manpower requirements for removing a contaminated ground surface are presented in Table C.4. Radiological surveys are performed by a work crew consisting of a foreman and three health physics technicians from the site owner's organization. The contractor's work crew for removal of approximately 1000 m^3 of contaminated soil includes a foreman, two equipment operators, and two laborers. This crew is assisted by a health physics technician. Backfilling and grading of the site (after soil removal operations are completed) is accomplished by a work crew that includes a foreman, two equipment operators, and a laborer.

Cost details for removing a contaminated ground surface are presented in Table C.5. The total cost of decommissioning the site is estimated to be about $1,829,000.

Approximately 7% of the total decommissioning cost is related to the initial and final site surveys. More than 70% of the cost of site surveys is associated with the analysis of soil samples. If adequate records exist, or if visual inspection of the site permits an area of contaminated soil to be located with reasonable accuracy, it may be possible to reduce the number of soil samples collected for analysis. For example, if samples are collected from the centers of 20-m by 20-m survey blocks instead of from the 10-m by 10-m blocks used as a basis for the cost estimates of Table C.4, the number of soil samples and the cost of sample analyses would decrease by a factor of 4.

Most of the cost of soil removal (approximately 89% of total) is related to the packaging, transportation, and disposal of the exhumed material. Packaging costs could be substantially reduced if the soil were transported to the shallow-land burial ground in plastic-lined dump trucks instead of being packaged in plywood boxes. Transportation charges are not significantly affected by the type of vehicle used to transport the soil, but are affected by the distance from the contaminated site to the burial ground. Disposal costs are not significantly affected by alternative modes of packaging or transport since these costs are directly proportional to the volume of soil requiring removal.

Disposal costs account for about 73% of the total decommissioning cost. No savings through volume reduction is possible since soil in not compactible or combustible.

Unit cost factors for the removal of contaminated ground surface are given in Table C.6. The cost factors for manpower, equipment, materials, and soil analysis are given in $\$/m^2$ (area) of the site. The packaging, transportation, and disposal cost factors are given in $\$/m^3$ of waste volume. The waste volume unit factor is given in m^3 of waste volume generated per area (m^2) of the site.

TABLE C.4. Details of Estimated Time and Manpower Requirements for the Removal of a Contaminated Ground Surface

Operator	Time (Days)[a]	Worker Man-Days: Supervisor[b]	Foreman	Equipment Operator	Health Physics Technician	Truck Driver	Laborer	Total Man-days	Manpower Costs ($ thousands)[c,d]
Planning and Preparation	20	20	20	--	30	--	--	70	16.36
Mobilization/ Demobilization	2	1	2	4	--	--	4	11	3.11
Exhume and Package Contaminated Soil	12	6	12	24	12	--	24	78	20.67
Backfill and Restore Site	3	1.5	3	6	--	8	3	21.5	5.86
Final Site Survey	5	2.5	5	--	15	--	--	22.5	4.44
Totals	42	31	42	34	57	8	31	203	50.44

(a) 50% ancillary time is included in estimates.
(b) Charged half-time to project.
(c) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.
(d) 25% contingency not included.

TABLE C.5. Cost Details for the Removal of Contaminated Ground Surface

Cost Item	Cost ($ thousands)[a]
Manpower	50.44
Equipment	38.40
Materials	19.20
Soil Analyses	76.80
Contractor's Fee[b]	16.17
Waste Management	
Packaging	94.14
Transportation	102.53
Disposal	1065.90
Subtotal	1463.58
25% Contingency	365.90
Total	1829.5

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for manpower, equipment, materials, and packaging.

TABLE C.6. Estimated Unit Factors for Removal of Contaminated Ground Surface[(a)]

Cost Item	Unit Factor
Manpower ($K/m^2 of site)	0.005
Equipment ($K/m^2 of site)	0.004
Materials ($K/m^2 of site)	0.002
Soil Analysis ($K/m^2 of site)	0.008
Waste Volume (m^3 waste/m^2 site)	0.100
Packaging ($K/m^3 waste)	0.094
Transportation ($K/m^3 waste)	0.103
Disposal ($K/m^3 waste)	1.066

(a) Costs are in January 1988 dollars.

C.3 DETAILS OF DECOMMISSIONING A TAILINGS PILE/EVAPORATION POND

Time and manpower requirements and total costs for decommissioning a tailings pile/evaporation pond by the alternatives of 1) stabilization or 2) removal are evaluated in this section. Annual requirements and costs of long-term care following stabilization are also evaluated.

The tailings pile/evaporation pond is described in Section 7.3.3 of NUREG/CR-1754.(1) It is actually a settling pond that contains the residue from ore refinery operations in which tin slag is processed for the recovery of niobium and tantalum. The residue from these operations contains 0.2 wt% U_3O_8 and 0.5 wt% ThO_2. The pond measures 100 m long by 50 m wide by 5 m deep with a 2.5 to 1 slope on each side. It contains 16,400 m^3 of glassy residue weighing 4.1×10^7 kg.

Procedures for decommissioning the pile/pond by the two alternatives are given in Section G.4.1 of NUREG/CR-1754.(1)

Details of estimated time and manpower requirements for decommissioning the pile/pond are presented in Table C.7. Cost details are presented in Table C.8.

C.3.1 Site Stabilization Alternative

The asphalt for the hard cover over the tailings pile/evaporation pond is delivered to the site in tanker trucks. It is then transferred to a self-propelled soil stabilizer for application to the surface of the pile/pond. The asphalt is applied at an assumed rate of 50 ℓ/m^2. Two days are required to complete this operation, which is performed by a work crew consisting of a foreman, two equipment operators, and two laborers.

The soil used as backfill over the hard cover is hauled to the site in 10-m^3 dump trucks. Approximately 5,600 m^3 of soil is required. After the soil is in place, it is graded to the specified contours and compacted with a roller. Six days are required to complete this operation, which is performed by a work crew that includes a foreman, two equipment operators, eight truck drivers, and two laborers.

After the soil cover over the pile/pond is compacted and contours are established, the area is planted with grass. Two equipment operators and two laborers perform this operation.

The total cost of site stabilization is estimated to be about $334,000. About half of this cost is for the asphalt and the soil used to establish the cover over the tailings pile.

The total annual cost of long-term care is estimated to be about $11,000. Manpower costs represent almost 60% of this cost.

Unit cost factors for the site stabilization and annual long-term care of a tailings pile are given in Table C.9. All of the cost factors (manpower, equipment, materials, and soil analysis) are given in $\$/m^2$ (area) occupied by the tailings pile.

C.3.2 Removal Alternative

Two work crews, working at opposite ends of the pile/pond, are employed to remove and package the residue from the pile/pond. Each crew includes three equipment operators and three laborers. A foreman supervises the work, and a health physics technician assists the crews. Bulldozers and front-end loaders are used to break up the residue and load it into 1.2-m by 1.2-m by 2.4-m (3.4-m^3) plastic-lined plywood boxes for shipment to the shallow-land burial ground. Approximately 5,700 boxes are required for the 19,000 m^3 of tailings residue and contaminated soil removed from the site. The boxes are shipped by truck to the burial ground. Shipments are weight-limited, and are restricted to four boxes per flat-bed trailer. Therefore, 1442 shipments must be made to decommission the site.

After the contaminated material is removed, soil is brought from off-site in 20-m^3-capacity scraper-haulers to fill the hole. The site is then graded and seeded with grass.

Approximately 114 work days (23 weeks) are required to remove the contaminated material and restore the site.

The total cost of the removal option is estimated to be about $31 million. Most of this cost (approximately 81%) is associated with the disposal of the exhumed material. The waste management cost could be reduced by about $1.6 million if the contaminated material was transported to the shallow-land burial ground in plastic-lined 10-m^3-capacity dump trucks instead of being packaged in plywood boxes. No savings through volume reduction is possible since soil in not compactible or combustible.

Unit cost factors for the removal of a tailings pile are given in Table C.10. The cost factors for manpower, equipment, materials, and soil analysis are given in $\$/m^3$ (volume) of the tailings pile. The packaging, transportation, and disposal cost factors are given in $\$/m^3$ of waste volume. The waste volume unit factor is given in m^3 of waste volume generated per m^3 of tailings pile.

TABLE C.7. Details of Estimated Time and Manpower Requirements for Decommissioning a Tailings Pile/Evaporation Pond

Operation	Time (Days)[a]	Worker Man-Days: Supervisor[b]	Foreman	Equipment Operator	Truck Driver	Health Physics Technician	Laborer	Secretary	Total Man-days	Manpower Costs[c,d] ($ thousands)
Site Stabilization Option										
Planning and Preparation	20	20	20	--	--	10	--	20	70	15.71
Mobilize/Demobilize	2	1	2	4	--	--	4	--	11	3.1[illegible]
Placement of Asphalt Layer	2	1	2	4	--	2	4	--	13	3.44
Placement of Soil Cover	6	3	6	12	40	2	12	--	75	19.20
Revegetation	2	1	--	2	--	--	2	--	5	1.43
Totals	32	26	30	22	40	14	22	20	174	42.89
Long-Term Care (Annual Values)										
Administration	2	2	--	--	--	--	--	2	4	0.84
Site Maintenance	3	--	3	3	--	--	3	--	9	1.80
Environmental Surveillance	1	--	--	--	--	2	--	--	2	0.33
Vegetation Management	4	--	4	--	--	--	8	--	12	2.22
Totals	10	2	7	3	--	2	11	2	27	5.19
Removal Option										
Planning and Preparation	20	20	20	--	--	10	--	20	70	15.71
Mobilize/Demobilize	4	2	4	24	--	--	24	--	54	14.86
Exhume and Package Tailings	90	45	90	540	--	90	540	--	1,305	349.16
Backfill and Restore Site	20	10	20	40	100	--	40	--	210	54.96
Final Site Survey	5	3	5	--	--	10	--	--	18	3.79
Totals	139	80	139	604	100	110	604	20	1,657	438.48

(a) 50% ancillary time is included in estimates.
(b) Charged half-time to project.
(c) Costs are in January 1988 dollars. Number of cost figures shown is for computational accuracy only.
(d) 25% contingency not included.

TABLE C.8. Cost Details for Decommissioning a Tailings Pile/Evaporation Pond

Cost Item	Cost ($ thousands)[a] Site Stabilization	Long-Term Care (Annual Costs)	Pile Removal
Manpower	42.9	5.2	438.5
Equipment	36.7	1.6	163.6
Materials	160.4	0.8	127.0
Soil Analyses	7.9	1.6	11.1
Contractor's Fee[b]	19.2	--	201.5
Waste Management			
Packaging	--	--	1,790.2
Transportation	--	--	1,998.6
Disposal	--	--	20,269.9
Subtotal	267.1	9.1	25,000.4
25% Contingency	66.8	2.3	6,250.1
Total	334	11	31,250

(a) Costs are in January 1988 dollars. Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for manpower, equipment, materials, and packaging.

TABLE C.9. Estimated Unit Factors for Site Stabilization and Long-Term Care of a Tailings Pile/Evaporation Pond[a]

Cost Item	Site Stabilization	Long-Term Care (Annual Costs)
Manpower ($\$K/m^2$ of pond)	0.0086	0.0010
Equipment ($\$K/m^2$ of pond)	0.0073	0.0003
Materials ($\$K/m^2$ of pond)	0.0321	0.0002
Soil Analysis ($\$K/m^2$ of pond)	0.0016	0.0003

(a) Costs are in January 1988 dollars.

TABLE C.10. Estimated Unit Factors for Removal of a Tailings Pile/Evaporation Pond[a]

Cost Item	Unit Factor
Manpower ($K/m^3 of pile)	0.0267
Equipment ($K/m^3 of pile)	0.0100
Materials ($K/m^3 of pile)	0.0077
Soil Analysis ($K/m^3 of pile)	0.0007
Waste Volume (m^3 waste/m^3 of pile)	1.1585
Packaging ($K/m^3 of waste)	0.0942
Transportation ($K/m^3 of waste)	0.1052
Disposal ($K/m^3 of waste)	1.0668

(a) Costs are in January 1988 dollars.

C.4 REFERENCES

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

2. E. S. Murphy and G. M. Holter. 1980. Technology, Safety, and Costs of Decommissioning a Reference Low-Level Waste Burial Ground, NUREG/CR-0570, Vols. 1 and 2, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

APPENDIX D

COST ESTIMATING BASES

APPENDIX D

COST ESTIMATING BASES

The cost information presented in this study is based on unit cost data given in this appendix. Categories for which cost data are given include: manpower, waste management (i.e., shipping container, transportation, and waste disposal costs), and special equipment and supplies. The data are all given in January 1988 prices.

D.1 MANPOWER COSTS

Salary data for the various decommissioning staff members are listed in Table D.1. The 1978 data base is adjusted by a factor of 1.59 for all categories of labor based on the Handy-Whitman Index, to account for escalation between 1978 and 1988.[1]

Decommissioning of laboratories is assumed to be performed by employees of the owner/operator of the facility. Decommissioning of sites is assumed to be performed by a contractor hired by the site owner. Overhead rates applied to staff labor are expected to be significantly higher for the decommissioning contractor than they are for the site owner/operator. These higher overhead rates for a contractor apply because of the larger ratio of supervisory and support personnel to direct labor that usually exists in contractor organizations and because of travel and living expenses associated with having personnel in the field rather than in an office. In Table D.1, an overhead rate of 50% is applied to direct staff labor for owner/operator personnel and an overhead rate of 110% is applied to direct staff labor for contractor personnel.

The salary data in Table D.1 are given on an annual basis. To obtain a daily rate, the annual salary is divided by 250.

TABLE D.1. Decommissioning Staff Salary Data[a]

Position	Basic Annual Salary ($)	Owner/Operator's Staff Assumed Overhead Rate ($)	Owner/Operator's Staff Annual Charge-Out Rate ($)	Contractor's Staff Assumed Overhead Rate ($)	Contractor's Staff Annual Charge-Out Rate ($)	Reference
Supervisor	42 300	70	71 900	110	88 900	2
Foreman	35 900	50	53 900	110	75 400	4
Equipment Operator	35 900	50	53 900	110	75 400	(b)
Craftsman	29 500	50	44 300	110	62 000	4
Technician	28 400	50	42 600	110	59 600	3
Health Physics Technician	27 600	50	41 300	110	57 900	4
Truck Driver	28 400	50	42 600	110	59 600	(b)
Laborer	28 400	50	42 600	110	59 600	3
Secretary	22 100	50	33 200	110	46 500	(b)

(a) Adjusted to January 1988.
(b) Study estimate.

D.2 WASTE MANAGEMENT COSTS

The radioactive wastes from decommissioning the two types of materials facilities considered in this study are as follows:

- from laboratories: contaminated equipment (hoods, glove boxes, exhaust filters and ducting, etc.), contaminated structural materials (floor coverings, chipped concrete, etc.), contaminated decommissioning materials (rags, mops, sweeping compound, non-reuseable anti-contamination clothing, etc.), contaminated decontamination solutions, and contaminated soils

- from sites: contaminated equipment (drain lines, hold-up tanks, etc.), contaminated tailings, and contaminated soils.

Waste management includes the packaging of contaminated materials, transportation of the packaged waste to an approved disposal site, and disposal of the waste. The costs of waste management are discussed in the following subsections.

D.2.1 Shipping Container Costs

Shipping container requirements for decommissioning wastes from materials facilities are discussed in Section D.3 of NUREG/CR-1754.[5] Unit costs of shipping containers and packing materials are given Table D.2.

D.2.2 Transportation Costs

Transport of radioactive waste materials from a non-fuel-cycle nuclear facility to an approved disposal site or a centrally located supercompactor facility is assumed to be accomplished by truck. The distance from the facility to the disposal site or from the supercompactor facility to the disposal site is assumed to be 800 km. The distance from the facility to the supercompactor facility is assumed to be 350 km. A rate schedule for truck shipments of legal size and weight is shown in Table D.3. This table, which forms the basis for transportation costs in this study, is reproduced from the published rates of a carrier licensed to transport radioactive materials.[6]

The gross vehicle weight (GVW) for normal shipments by truck (i.e., the legal weight) is assumed to be less than 21.77 Mg. The maximum allowed commodity weight without special equipment and special permission, for most states, is about 33.11 Mg. Overweight charges by states vary widely.[6] For this study, the maximum allowed GVW and the overweight charges for the state of Washington are assumed to apply. These overweight charges are shown in Table D.4. An additional surcharge of $0.13 per km is imposed by the carrier for shipments with commodity weights greater than 21.77 Mg. Shipments with commodity weights in excess of 33.11 Mg require special equipment and special permission. Carrier charges for these shipments would have to be determined on a case-by-case basis.

The GVW of an unloaded exclusive-use van or tractor-trailer is assumed to be 14.52 Mg. Therefore the payload per shipment in an exclusive-use van is 21.77 Mg legal weight. Any vehicle exceeding 36.29 Mg GVW is considered to be overweight.

The base transportation costs assumed in this study for truck shipments are summarized in Table D.5.

To assure rapid turnaround on waste shipments requiring use of a Type B overpack, a second driver is assumed to be required, at an additional cost of $0.093 per kilometer.

D.2.3 Waste Disposal Costs

A basic assumption of this study is that all radioactive wastes from the decommissioning of non-fuel-cycle nuclear facilities are disposed of by burial at a shallow-land burial ground. The burial costs are based on a January 1988 price list from U.S. Ecology, Inc., which operates burial sites at Richland, Washington, and Beatty, Nevada, and from Chem-Nuclear Systems, Inc., which operates a burial site at Barnwell, South Carolina.[7,8] Disposal charges as a function of dose rate at the container surface, container weight, and curie content are shown in Tables D.6 and D.7.

A basic cost of $\$1045/m^3$ is assumed for shallow-land burial at the Richland site.

TABLE D.2. Unit Costs of Shipping Containers and Packaging Materials

Item	Estimated Unit Cost ($)
208-ℓ steel drum	23 each
113-ℓ steel drum	22 each
Reinforced plywood box	82/m^3
Polyethylene liner for steel drum	9 each
Cement (42.6-kg bag)	6/bag
Diatomaceous earth (45.4-kg bag)	12/bag
Cask rental for high activity beta-gamma waste (Type B cask)	1 500/day

TABLE D.3. Transportation Rates for Legal-Size and -Weight Shipments (effective January 19, 1988)

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TRI-STATE MOTOR TRANSIT CO.

ITEM NO. 3000 | SECTION II - MILEAGE COMMODITY RATES (Cont.)

MILEAGE COMMODITY RATES

COMMODITY: Radioactive Waste (low level) and empty containers therefor moving to or from points of loading, unloading or storage. (For rates on non-radioactive hazardous waste, see Tri-State Motor Transit Co. Tariff ICC TSMT 4033.)

BETWEEN: All points in the United States, except Alaska and Hawaii, as published in Scope of Operating Rights published herein.

▲RATES IN CENTS PER MILE

One Way Mileage (Not Over)	Column 1	Column 2	Column 3	One Way Mileage (Not Over)	Column 1	Column 2	Column 3
100	499	525	358	750	183	222	151
125	459	487	332	800	175	215	151
150	420	448	306	850	174	214	151
175	384	412	284	900	172	212	151
200	332	364	260	950	169	209	151
225	314	349	247	1000	165	205	151
250	301	334	230	1100	165	204	151
275	287	322	216	1200	165	201	151
300	275	308	206	1300	165	199	151
325	267	302	194	1400	165	198	151
350	259	295	188	1500	165	197	151
375	249	284	181	1600	165	195	151
400	237	273	175	1700	165	194	151
425	230	267	172	1800	165	193	151
450	219	257	167	1900	165	192	151
475	214	251	164	2000	165	191	151
500	206	244	161	2100	165	190	151
550	201	239	158	2200	165	188	151
600	196	235	151	2300	165	187	151
650	190	228	151	2400	165	186	151
700	187	224	151	2500 & Beyond	165	184	151

NOTES:

(1) Rates apply on legal size and weight shipments per vehicle used only. Overweight shipments not exceeding a gross vehicle weight of 85,000 pounds shall be subject to an additional charge of $0.21 per mile for each mile traveled in a state or states requiring overweight permits, in addition to all other applicable charges. For rates on shipments exceeding 85,000 pounds gross vehicle weight, see Section II, Item 2000 application.

(2) Column 1 rates applicable to one-way shipments having a destination East of the Mississippi River.

(3) Column 2 rates applicable to one-way shipments having a destination West of the Mississippi River.

(CONTINUED)

The provisions published herein will not, if effective, have an effect on the quality of the human environment.

For explanation of reference marks and abbreviations, see Item 110.

ISSUED: July 31, 1987 | **EFFECTIVE:** August 13, 1987

Issued by: George Cain, Vice-President, Traffic; P. O. Box 113, Joplin, MO 64802

4007A-47 87

TABLE D.3. (contd)

ITEM NO. 3000 (Cont.) — SECTION II - MILEAGE COMMODITY RATES (Cont.)

NOTES: (Continued)

(4) Subject to restriction. Column 3 rates apply only to continuous excursion moves in which a subsequent shipment is made available to carrier within 24 hours after arrival at point of loading or unloading. Only one stop in transit allowed under Column 3 rates. RESTRICTION: Column 3 rates will not apply in connection with shipments moving under Item 520 deadhead of special equipment application.

(5) Minimum charge per trip to be computed on basis of 100 one-way miles.
(C)

(6) When temperature controlled van trailers or shielded van trailers are required, the rate shall be based on the round trip miles from point of origin to destination and return to point of origin. Column 3 rates shall apply unless trailer is not released to carrier within 24 hours after arrival at point of unloading in which case the inbound loaded movement and subsequent empty move shall be subject to the applicable Column 1 or Column 2 rates. When temperature control trailer is provided, a second driver is assigned and the charges in Item 530 will apply.

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The provisions published herein will not, if effective, have an effect on the quality of the human environment.

For explanation of reference marks and abbreviations, see Item 110.

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TABLE D.4. Additional Charges when the Commodity Weight Exceeds 21.77 Mg, Based on Rates for the State of Washington[a,b]

Weight (Mg)	Charge ($/km)
21.77 to 25.85	0.062
25.86 to 28.57	0.124
28.58 to 31.29	0.186
31.30 to 34.01[c]	0.280
34.02 to 36.73[c]	0.466
36.74 to 39.45[c]	0.621
39.46 to 42.18[c]	0.932
42.19 to 44.90[c]	1.087
Greater than 44.90[c]	1.243

(a) A flat charge of $25.00 is levied in addition to the charges shown in the table.
(b) From Reference 6.
(c) Normally require special equipment/permission.

TABLE D.5. Transportation Costs for Truck Shipments

Status	Payload (Mg)	GVW (Mg)	Cost ($)
Legal[a]	21.77	36.29	1213
Legal[b]	21.77	36.29	759
Overweight[a]	24.04	38.55	1367
Overweight[b]	24.04	38.55	826

(a) A one-way, 800-km shipment (destination west of the Mississippi River) with a single driver is assumed.
(b) A one-way, 350-km shipment (destination west of the Mississippi River) with a single driver is assumed.

TABLE D.6. Schedule of Disposal Charges for Shallow-Land Burial at the Richland, Washington, Site[a]

I - Disposal Charges for Solid Low-Level Radioactive Waste in Packages 0.34 m^3 each or less

R/hr at Container Surface	Charge ($/$m^3$)
0.00 - 0.20	1 045
0.201 - 1.00	1 098
1.01 - 2.00	1 139
2.01 - 5.00	1 183
5.01 - 10.00	1 298
10.01 - 20.00	1 412
20.01 - 40.00	1 589
Over 40.00	By Request

II - Disposal Charges for Solid Low-Level Radioactive Waste Disposable Liners Removed from Shield (greater than 0.34 m^3 each)

R/hr at Container Surface	Surcharge Per Liner ($)	Disposal Charge ($/$m^3$)
0.00 - 0.20	No Charge	1 045
0.201 - 1.00	193.50	1 045
1.01 - 2.00	441.00	1 045
2.01 - 5.00	747.00	1 045
5.01 - 10.00	1 192.50	1 045
10.01 - 20.00	1 566.00	1 045
20.01 - 40.00	1 791.00	1 045
Over 40.00	By Request	By Request

III - Surcharge for Curies (per Load) for Solid Low-Level Radioactive Waste

Ci/Load	Surcharge
Less than 100	No Charge
101 - 300	$1 569.00 + $0.21/ci
Greater than 300	By Request

IV - Disposal Charges for Other Low-Level Radioactive Wastes

Waste Stream	Charge ($/$m^3$)
Aqueous Liquids in Vials, Less than 50 ml Each	1 290
Aqueous Liquids, Absorbed	1 045
Biological Waste, Animal Carcasses	1 111

V - Cask Handling Fee: $550 each

(a) From Reference 7.

TABLE D.7. Schedule of Disposal Charges for Shallow-Land Burial at the Barnwell, South Carolina, Site[(a)]

I - Base Disposal Charges for Low-Level Radioactive Waste

Waste Stream	Disposal Charge ($/m^3)
Standard Waste	1 247
Biological Waste	1 305

II - Weight Surcharges for Low-Level Radioactive Waste

Weight of Container (kg)	Surcharge/ Container ($)
0 - 453.6	No Charge
453.7 - 2 268.0	405
2 268.1 - 4 536.0	710
4 536.1 - 9 072.0	1 010
9 072.1 - 13 608.0	1 310
13 608.1 - 18 144.0	1 915
18 144.1 - 22 680.0	2 520
Greater than 22 680.0	By Request

III - Curie Surcharges for Shielded Shipments of Low-Level Radioactive Waste

Ci/Shipment	Surcharge/Shipment ($)
0 - 5	2 500
>5 - 15	2 820
>15 - 25	3 750
>25 - 50	5 650
>50 - 75	6 900
>75 - 100	9 350
>100 - 150	11 200
>150 - 250	15 000
>250 - 500	18 800
>500 - 1 000	22 500
>1 000 - 5 000	30 000
>5 000	By Request

IV - Curie Surcharges for Non-Shielded Shipments Containing Tritium and Carbon-14

Ci/Shipment	Surcharges/Shipment ($)
0 - 100	No Charge
Greater than 100	By Request

V - Cask Handling Fee: $1000 each
Miscellaneous Surcharges: 2.4% of total cost

(a) From Reference 8.

D.3 COSTS OF SPECIAL EQUIPMENT AND SUPPLIES

The equipment and supply needs for the decommissioning of laboratories and sites are sufficiently different as to require separate treatment.

The costs of special equipment and supplies for decommissioning a laboratory are presented in Table D.8. Only those items that are postulated for use in decommissioning and that represent a significant or special expense are listed. Radiation survey equipment and equipment for the analysis of wipe samples is not listed in the table. This equipment is assumed to be readily available and not chargeable to decommissioning because of its use during the operational phase of the laboratory.

Decommissioning of sites is assumed to be performed by a contractor hired by the site owner. Unit charges for equipment owned by the decommissioning contractor are shown in Table D.9. The monthly charges shown in the table are calculated on the basis of 6% of the capital cost of equipment and include allowances for equipment depreciation, maintenance and operating expenses (e.g., fuel, lubrication, etc.), decontamination following use, and return on investment. They do not include the operator's wage. Weekly charges are estimated to be approximately one-third of the monthly charges.

Unit costs for supplies and materials and for soils analyses associated with decommissioning a rare-metals refinery tailings pile are listed in Table D.10. The 1978 data base for Tables D.8 and D.9 is adjusted by factors determined from the Producer Price Indexes to account for escalation between 1978 and 1988.[9] The data for the Table D.10 is generated from the Building Construction Cost Data for 1988 and phone conversations with vendors.[10]

TABLE D.8. Unit Costs of Special Equipment and Supplies for Decommissioning a Nuclear Materials Processing and Use Laboratory

Item	Estimated Unit Cost ($)[a]
Equipment	
Steam Cleaner	1 900
Wet/Dry Vacuum	2 900
Powered Floor Scrubber	500
Oxyacetylene Torch	2 100
Nibbler 1 600	
Ratcheting Pipe Cutter	80
Reciprocating Saw	300
Waste Compactor	24 000
Centrally Located Super Compactor (per m^3)	300
Mobile Incinerator (per m^3)	4 200
Paint Sprayer	800
Supplies	
Anti-Contamination Clothing (per person per week)	90
Decontamination Solution (per 208-ℓ drum)	650
HEPA Filter (24 x 24 x 11-1/2in)	250
Roughing Filter (24 x 24 x 11-1/2in)	125
Paint (per liter)	4.5
EDTA (per kilogram)	3.1
Oxalic Acid (per kilogram)	1.6
Citric Acid (per kilogram)	1.6
Polyethylene Sheet (per m^2)	1.75

(a) Adjusted to January 1988 prices.

TABLE D.9. Charges for Contractor Equipment for Decommissioning of Sites[a,b]

Item	Estimated Weekly Charge ($)	Estimated Monthly Charge ($)
Tractor, farm type	700	2 100
Grader, self-propelled	950	2 850
Roller, sheepsfoot, self-propelled	1 800	5 400
Front loader (2-m^3-capacity)	1 400	4 200
Backhoe (2-m^3-capacity)	3 750	11 250
Bulldozer	1 650	4 950
Soil stabilizer, self-propelled	6 450	19 350
Scraper-hauler (20-m^3-capacity)	2 600	7 800
Dump truck (10-m^3-capacity)	1 250	3 750
Lift truck (10-Mg-capacity)	700	2 100
Crane, boom-type (10-Mg-capacity)	1 600	4 800
Light-duty drilling rig	4 150	12 450
Disc-harrow, tractor-drawn	250	750
Seeder, tractor-drawn	300	900

(a) Includes equipment depreciation, operating expenses (fuel, lubrication, etc.), decontamination following use, and return on investment. Does not include operator's wage.

(b) Adjusted to January 1988 prices.

TABLE D.10. Unit Costs of Supplies, Materials, and Soil Analyses for Decommissioning a Rare-Metals Refinery Tailings Pile

Item	Unit	Estimated Unit Cost[a] ($)
Backfill (topsoil)	m^3	13[b]
Backfill (common borrow)	m^3	4.0[b]
Gravel (graded)	m^3	4.5[b]
Asphalt emulsion	ℓ	0.3
Seed	kg	4.1
Fertilizer	kg	0.3
Straw	bale	2.1
Anti-contamination clothing	per person per week	90
PVC pipe (0.15-m-diameter)	m	20
Chain-link fencing (1.8-m-wide)	m	30
Soil analysis	each	160
Cutie Pie detector	each	1000
G-M probe	each	200
Gamma Scintillation probe (3" x 3" crystal)	each	1400
Ratemeter (log-lin.)	each	1200
Phoswhich detector (5" diameter)	each	9000

(a) Adjusted to January 1988 prices.
(b) Cost shown does not include delivery to site.

).4 REFERENCES

1. Handy-Whitman Index of Public Utility Construction Costs, Bulletin No. 127, Section B-1, March 31, 1988.

2. U.S. Department of Labor, Bureau of Labor Statistics, March 1975.

3. R. S. Godfrey, ed., Building Construction Cost Data-1975, R. S. Means Co., Inc., Duxbury, Massachusetts, 1975.

4. Hanford Atomic Metal Trades Council Pay Scales, Richland, Washington, 1975.

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

6. ICC TSMT 4007-A, Naming Specific Truckload Commodity Rates--Also Mileage Truckload Commodity Rates Applying on Radioactive Materials, Related Articles Classified or Declared Sensitive by the U.S. Government, and Empty Radioactive Material Containers From, To, Between All Points and Places in the United States Except Alaska and Hawaii, Tri-State Motor Transit Co., Joplin, Missouri, January 1988.

7. U.S. Ecology, Washington Nuclear Center Schedule of Charges for Radioactive Waste Disposal at the Richland, Washington, Site, January 1988.

8. Barnwell Low-Level Radioactive Waste Management Facility Schedule of Charges for Radioactive Waste Disposal at the Barnwell, South Carolina Site, January 1988.

9. Producer Price Indexes, U.S. Department of Labor, Bureau of Labor Statistics, September 1987.

10. W. D. Mahoney, ed., Building Construction Cost Data-1988, R. S. Means Co., Inc., Kingston, Massachusetts, 1988.

APPENDIX E

PROCEDURE FOR DEVELOPING A COST ESTIMATE

APPENDIX E

PROCEDURE FOR DEVELOPING A COST ESTIMATE

This appendix provides a procedure and the necessary data for quickly and easily developing cost estimates for decommissioning individual laboratory components and entire laboratories. While unique unit cost factors have not been calculated for dealing with large industrial equipment that might be present in some facilities, the factors provided herein are believed to be adequate for use in developing first-order cost estimates for the decommissioning of such large items as well as for the specific laboratory components considered in this report. The purpose of this procedure is to provide a means for NRC staff to generate their own cost estimate for a given facility, to compare against a licensee's submittal.

E.1 INDIVIDUAL FACILITY COMPONENTS

The procedure for generating a cost estimate to decommission individual laboratory components is given in Table E.1. The only parameter that needs to be provided by the analyst using the procedure is DIM_PAR, mentioned in the first step of the procedure. The value of this parameter is either the total volume (m^3) of the component (fume hood, glove box, and hot cell), or the total linear length (m) of the component (workbench, drain line, and ductwork), or the total surface area (m^2) of the component (walls and floors). All of the unit factor data needed in steps 2-8 are provided in Tables E.2 through E.9, summarized from Appendix A, for the different facility components.

Table E.10 demonstrates use of the procedure by estimating the cost to decommission a fume hood contaminated with ^3H via the decontamination option. The total volume (DIM_PAR) of the fume hood is assumed to be 2.835 m^3, the same as the reference fume hood utilized in this study.

E.2 ENTIRE FACILITIES

The procedure for generating a cost estimate to decommission an entire laboratory is given in Table E.11. The basic methodology of this procedure is to utilize the procedure given in Table E.1 to calculate the cost to decommission each of the major individual components present in the laboratory. Each of the individual costs (i.e., manpower, equipment and supplies, etc.) are then summed together to generate subtotals for each. The subtotal for equipment and supplies is revised to account for the improved utilization possible from decommissioning several components as opposed to just one component. The subtotal for manpower costs is revised to account for the planning and preparation that occurs before decommissioning operations begin and to account for the final radiation survey that is performed after decommissioning operations end. Finally, all of the subtotals costs are summed together and then increased to reflect a contingency factor.

Table E.12 demonstrates use of the procedure by estimating the cost to decommission the reference laboratory for the manufacture of ^{3}H-labeled compounds.

E.3 ENTIRE SITES

The procedure for generating a cost estimate to decommission an element of an industrial field site is given in Table E.13. This procedure allows for exhuming of a tank and associated piping, removal of contaminated ground surface, and either the site stabilization and long-term care of a tailings pile or complete removal of the pile. Table E.14 summarizes the unit cost data from Appendix C that is needed in this procedure. An example of the use of this procedure to estimate the cost to remove a tailings pile from an industrial field site is given in Table E.15. This tailings pile is the same as the reference tailings pile assumed in this study.

In addition, an industrial field site may have more than one element requiring decommissioning. If this is the case, all that needs to be done is to apply the procedure for each element and add the final costs together to generate a cost estimate to decommission the entire site.

Finally, in addition to the industrial field sites assumed in this study, there exists many other different types of industrial facilities that use or generate radioactive materials for one reason or another. Examples of these types of facilities include those applying nuclear medicine, radiation sterilization, activation analysis, food irradiation, manufacture of smoke detectors, and so on. However, it was not within the scope of this addendum to generate decommissioning costs for facilities other than those already present in NUREG/CR-1754. For this reason, no procedure is provided to specifically allow estimating the decommissioning of these types of facilities, although the procedure for laboratories and laboratory components could, in most cases, be used.

TABLE E.1. Procedure for Developing a Cost Estimate for Decommissioning Individual Components

Step Number	Description	Equation	Units
1.	Determine the dimensional parameter (DIM_PAR) for the components to be decommissioned as follows: a. fume hood - volume (m^3) of the hood b. glove box - volume (m^3) of the box c. hot cell - volume (m^3) of the cell d. workbench - length (m) of bench e. sink and drain - length (m) of drain line f. ductwork - length (m) of ductwork g. walls - area (m^2) of walls h. floors - area (m^2) of floor	The DIM_PAR parameter will have different units depending on the component being decommissioned. The unit factors in the equations below will correspondingly have different units. The units of the unit factors are given in Tables E.2 - E.9 for each of the different components.	
2.	Calculate the manpower cost to decommission the component.	C_{MP} = (UNIT_C_{MP}) x (DIM_PAR)	($K/component)
3.	Calculate the cost of equipment and supplies needed to decommission the component.	C_{ES} = (UNIT_C_{ES}) x (DIM_PAR)	($K/component)
4.	Calculate the quantity of waste generated, before volume reduction, from decommissioning of the component.	V = (UNIT_V) x (DIM_PAR)	(m^3/component)

(contd)

TABLE E.1. (contd)

Step Number	Description	Equation	Units
5.	Calculate the volume reduction cost, if applicable, for supercompaction or incineration.	C_{VR} = (UNIT_C_{VR}) x (V)	($K/component)
6.	Calculate the cost to package the waste.	C_P = (UNIT_C_P) x (V)	($K/component)
7.	Calculate the cost to transport the waste to the disposal site (and regional volume reduction center, if applicable).	C_T = (UNIT_C_T) x (V)	($K/component)
8.	Calculate the cost to dispose of the waste.	C_D = (UNIT_C_D) x (V)	($K/component)
9.	Add up all of the calculated costs.	SUB_TOT = $C_{MP} + C_{ES} + C_{VR} + C_P + C_T + C_D$	($K/component)
10.	Calculate the total estimated cost including a 25% contingency.	COST_TOT = (SUB_TOT) x (1.25)	($K/component)
11.	For hot cells only: Calculate the salvage value of the lead present in the hot cell.	CR_{LS} = (UNIT_CR_{LS}) x (DIM_PAR)	($K/component)

TABLE E.2. Unit Factors for DECON of a Fume Hood[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
UNIT_C_{MP} (\$K/m^3 component)	0.59	0.50	0.59	0.59	1.02
UNIT_C_{ES} (\$K/m^3 component)	0.64	0.64	0.64	0.64	0.64
UNIT_V (m^3 waste/m^3 component)	0.37	0.37	0.37	0.37	0.37
UNIT_C_P (\$K/m^3 waste)	0.18	0.26	0.26	0.26	0.26
UNIT_C_T (\$K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
UNIT_C_D (\$K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/o Volume Reduction					
UNIT_C_{MP} (\$K/m^3 component)	0.57	0.57	0.57	0.57	0.76
UNIT_C_{ES} (\$K/m^3 component)	0.46	0.46	0.46	0.46	0.46
UNIT_V (m^3 waste/m^3 component)	1.38	1.38	1.38	1.38	1.38
UNIT_C_P (\$K/m^3 waste)	0.10	0.10	0.10	0.10	0.10
UNIT_C_T (\$K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
UNIT_C_D (\$K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/Compaction & Supercompaction					
UNIT_C_{MP} (\$K/m^3 component)	0.95	0.95	0.95	0.95	1.14
UNIT_C_{ES} (\$K/m^3 component)	0.51	0.51	0.51	0.51	0.51
UNIT_V (m^3 waste/m^3 component)	1.38	1.38	1.38	1.38	1.38
UNIT_C_{VR} (\$K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
UNIT_C_P (\$K/m^3 waste)	0.04	0.04	0.04	0.04	0.04
UNIT_C_T (\$K/m^3 waste)	0.02	0.02	0.02	0.02	0.02
UNIT_C_D (\$K/m^3 waste)	0.14	0.14	0.14	0.14	0.14

(contd)

TABLE E.2. (contd)

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction & Incineration					
UNIT_C_{MP} (\$K/m^3 component)	0.95	0.95	0.95	0.95	1.14
UNIT_C_{ES} (\$K/m^3 component)	0.51	0.51	0.51	0.51	0.51
UNIT_V (m^3 waste/m^3 component)	1.38	1.38	1.38	1.38	1.38
UNIT_C_{VR} (\$K/m^3 waste)	0.09	0.09	0.09	0.09	0.09
UNIT_C_P (\$K/m^3 waste)	0.04	0.04	0.04	0.04	0.04
UNIT_C_T (\$K/m^3 waste)	0.01	0.01	0.01	0.01	0.01
UNIT_C_D (\$K/m^3 waste)	0.24	0.24	0.24	0.24	0.24

(a) Costs are in January 1988 dollars.

TABLE E.3. Unit Factors for DECON of a Glove Box[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
UNIT_C_{MP} (\$K/m^3 component)	3.08	2.26	3.08	--[b]	6.17
UNIT_C_{ES} (\$K/m^3 component)	4.48	4.48	4.48	--	4.48
UNIT_V (m^3 waste/m^3 component)	2.57	2.57	2.57	--	2.57
UNIT_C_P (\$K/m^3 waste)	0.17	0.22	0.22	--	0.22
UNIT_C_T (\$K/m^3 waste)	0.06	0.06	0.06	--	0.06
UNIT_C_D (\$K/m^3 waste)	1.05	1.05	1.05	--	1.05
Packaging & Disposal w/o Volume Reduction					
UNIT_C_{MP} (\$K/m^3 component)	3.11	3.11	3.11	--[b]	4.33
UNIT_C_{ES} (\$K/m^3 component)	3.15	3.15	3.15	--	3.15
UNIT_V (m^3 waste/m^3 component)	2.83	2.83	2.83	--	2.83
UNIT_C_P (\$K/m^3 waste)	0.21	0.21	0.21	--	0.21
UNIT_C_T (\$K/m^3 waste)	0.05	0.05	0.05	--	0.05
UNIT_C_D (\$K/m^3 waste)	1.05	1.05	1.05	--	1.05
Packaging & Disposal w/Compaction & Supercompaction					
UNIT_C_{MP} (\$K/m^3 component)	4.33	4.33	4.33	--[b]	6.20
UNIT_C_{ES} (\$K/m^3 component)	3.61	3.61	3.61	--	3.61
UNIT_V (m^3 waste/m^3 component)	2.83	2.83	2.83	--	2.83
UNIT_C_{VR} (\$K/m^3 waste)	0.05	0.05	0.05	--	0.05
UNIT_C_P (\$K/m^3 waste)	0.13	0.13	0.13	--	0.13
UNIT_C_T (\$K/m^3 waste)	0.02	0.02	0.02	--	0.02
UNIT_C_D (\$K/m^3 waste)	0.31	0.31	0.31	--	0.31

(contd)

TABLE E.3. (contd)

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Packaging & Disposal w/Compaction & Incineration					
$UNIT\_C_{MP}$ ($K/$m^3$ component)	4.33	4.33	4.33	--(b)	6.20
$UNIT\_C_{ES}$ ($K/$m^3$ component)	3.61	3.61	3.61	--	3.61
UNIT_V (m^3 waste/m^3 component)	2.83	2.83	2.83	--	2.83
$UNIT\_C_{VR}$ ($K/$m^3$ waste)	0.18	0.18	0.18	--	0.18
$UNIT\_C_{P}$ ($K/$m^3$ waste)	0.11	0.11	0.11	--	0.11
$UNIT\_C_{T}$ ($K/$m^3$ waste)	0.02	0.02	0.02	--	0.02
$UNIT\_C_{D}$ ($K/$m^3$ waste)	0.35	0.35	0.35	--	0.35

(a) Costs are in January 1988 dollars.
(b) There are no glove boxes in the reference ^{137}Cs laboratory facility.

TABLE E.4 Unit Factors for DECON of a Hot Cell[a]

Unit Factor (Units)	Decontamination	Packaging & Disposal w/o Volume Reduction w/o Lead Salvage	Packaging & Disposal w/o Volume Reduction w/Lead Salvage	Packaging & Disposal w/ Compaction and Super-compaction w/ Lead Salvage	Packaging $ Disposal w/ Compaction and incen-eration w/ Lead Salvage
UNIT_C_{MP} ($\$K/m^3$ component)	1.07	0.85	1.71	1.90	1.90
UNIT_C_{ES} ($\$K/m^3$ component)	0.92	0.77	0.83	0.88	0.88
UNIT_V (m^3 waste/m^3 component)	0.38	0.38	0.38	0.38	0.38
UNIT_C_{VR} ($\$K/m^3$ waste)	--	--	--	0.02	0.18
UNIT_C_P ($\$K/m^3$ waste)	0.26	0.41	0.32	0.27	0.25
UNIT_C_T ($\$K/m^3$ waste)	0.05	0.05	0.05	0.04	0.03
UNIT_C_D ($\$K/m^3$ waste)	1.05	1.05	1.05	0.72	0.72
UNIT_CR_{LS} ($\$K/m^3$ component)	--	--	3.41	3.41	3.41

(a) Costs are in January 1988 dollars.

TABLE E.5. Unit Factors for DECON of a Workbench[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
UNIT_C_{MP} (\$K/m component)	0.09	0.09	0.09	0.09	0.09
UNIT_C_{ES} (\$K/m component)	0.14	0.14	0.14	0.14	0.14
UNIT_V (m^3 waste/m component)	0.09	0.09	0.09	0.09	0.09
UNIT_C_P (\$K/m^3 waste)	0.18	0.29	0.29	0.29	0.29
UNIT_C_T (\$K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
UNIT_C_D (\$K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/o Volume Reduction					
UNIT_C_{MP} (\$K/m component)	0.18	0.18	0.18	0.18	0.18
UNIT_C_{ES} (\$K/m component)	0.13	0.13	0.13	0.13	0.13
UNIT_V (m^3 waste/m component)	1.09	1.09	1.09	1.09	1.09
UNIT_C_P (\$K/m^3 waste)	0.08	0.08	0.08	0.08	0.08
UNIT_C_T (\$K/m^3 waste)	0.05	0.05	0.05	0.05	0.05
UNIT_C_D (\$K/m^3 waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/Compaction & Supercompaction					
UNIT_C_{MP} (\$K/m component)	0.26	0.26	0.26	0.26	0.26
UNIT_C_{ES} (\$K/m component)	0.13	0.13	0.13	0.13	0.13
UNIT_V (m^3 waste/m component)	1.09	1.09	1.09	1.09	1.09
UNIT_C_{VR} (\$K/m^3 waste)	0.06	0.06	0.06	0.06	0.06
UNIT_C_P (\$K/m^3 waste)	0.03	0.03	0.03	0.03	0.03
UNIT_C_T (\$K/m^3 waste)	0.01	0.01	0.01	0.01	0.01
UNIT_C_D (\$K/m^3 waste)	0.30	0.30	0.30	0.30	0.30

(a) Costs are in January 1988 dollars.

TABLE E.6. Unit Factors for DECON of a Sink and Drain Line[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
$UNIT\_C_{MP}$ ($K/m component)	--[b]	0.05	0.05	0.05	--[b]
$UNIT\_C_{ES}$ ($K/m component)	--	0.03	0.03	0.03	--
UNIT_V (m^3 waste/m component)	--	0.02	0.02	0.02	--
$UNIT\_C_{P}$ ($K/$m^3$ waste)	--	0.15	0.15	0.15	--
$UNIT\_C_{T}$ ($K/$m^3$ waste)	--	0.05	0.05	0.05	--
$UNIT\_C_{D}$ ($K/$m^3$ waste)	--	1.05	1.05	1.05	--
Packaging & Disposal w/o Volume Reduction					
$UNIT\_C_{MP}$ ($K/m component)	--[b]	0.07	0.07	0.07	--[b]
$UNIT\_C_{ES}$ ($K/m component)	--	0.05	0.05	0.05	--
UNIT_V (m^3 waste/m component)	--	0.05	0.05	0.05	--
$UNIT\_C_{P}$ ($K/$m^3$ waste)	--	0.15	0.15	0.15	--
$UNIT\_C_{T}$ ($K/$m^3$ waste)	--	0.05	0.05	0.05	--
$UNIT\_C_{D}$ ($K/$m^3$ waste)	--	1.05	1.05	1.05	--
Packaging & Disposal w/Compaction & Supercompaction					
$UNIT\_C_{MP}$ ($K/m component)	--[b]	0.09	0.09	0.09	--[b]
$UNIT\_C_{ES}$ ($K/m component)	--	0.05	0.05	0.05	--
UNIT_V(m^3 waste/m component)	--	0.05	0.05	0.05	--
$UNIT\_C_{VR}$ ($K/$m^3$ waste)	--	0.06	0.06	0.06	--
$UNIT\_C_{P}$ ($K/$m^3$ waste)	--	0.03	0.03	0.03	--
$UNIT\_C_{T}$ ($K/$m^3$ waste)	--	0.01	0.01	0.01	--
$UNIT\_C_{D}$ ($K/$m^3$ waste)	--	0.09	0.09	0.09	--

(a) Costs are in January 1988 dollars.
(b) There are no sinks in the reference ^{3}H and ^{241}Am laboratory facilities.

TABLE E.7. Unit Factors for DECON of Ventilation Ductwork[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{2} Am
Packaging & Disposal w/o Volume Reduction					
UNIT_C_{MP} ($K/m component)	0.05	0.05	0.05	0.05	0.06
UNIT_C_{ES} ($K/m component)	0.03	0.03	0.03	0.03	0.03
UNIT_V (m^3 waste/m component)	0.14	0.14	0.14	0.14	0.14
UNIT_C_P ($K/$m^3$ waste)	0.10	0.10	0.10	0.10	0.10
UNIT_C_T ($K/$m^3$ waste)	0.05	0.05	0.05	0.05	0.05
UNIT_C_D ($K/$m^3$ waste)	1.05	1.05	1.05	1.05	1.05
Packaging & Disposal w/Compaction & Supercompaction					
UNIT_C_{MP} ($K/m component)	0.06	0.06	0.06	0.06	0.08
UNIT_C_{ES} ($K/m component)	0.03	0.03	0.03	0.03	0.03
UNIT_V (m^3 waste/m component)	0.14	0.14	0.14	0.14	0.14
UNIT_C_{VR} ($K/$m^3$ waste)	0.06	0.06	0.06	0.06	0.06
UNIT_C_P ($K/$m^3$ waste)	0.03	0.03	0.03	0.03	0.03
UNIT_C_T ($K/$m^3$ waste)	0.01	0.01	0.01	0.01	0.01
UNIT_C_D ($K/$m^3$ waste)	0.09	0.09	0.09	0.09	0.09
Packaging & Disposal w/Compaction & Incineration					
UNIT_C_{MP} ($K/m component)	0.06	0.06	0.06	0.06	0.08
UNIT_C_{ES} ($K/m component)	0.03	0.03	0.03	0.03	0.03
UNIT_V (m^3 waste/m component)	0.14	0.14	0.14	0.14	0.14
UNIT_C_{VR} ($K/$m^3$ waste)	0.08	0.08	0.08	0.08	0.08
UNIT_C_P ($K/$m^3$ waste)	0.02	0.02	0.02	0.02	0.02
UNIT_C_T ($K/$m^3$ waste)	0.01	0.01	0.01	0.01	0.01
UNIT_C_D ($K/$m^3$ waste)	0.19	0.19	0.19	0.19	0.19

(a) Costs are in January 1988 dollars.

TABLE E.8. Unit Factors for DECON of Walls[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
UNIT_C_{MP} ($K/$m^2$ component)	0.06	0.06	0.06	0.06	0.06
UNIT_C_{ES} ($K/$m^2$ component)	0.04	0.04	0.04	0.04	0.04
UNIT_V (m^3 waste/m^2 component)	0.05	0.05	0.05	0.05	0.05
UNIT_C_P ($K/$m^3$ waste)	0.19	0.19	0.33	0.33	0.33
UNIT_C_T ($K/$m^3$ waste)	0.05	0.05	0.05	0.05	0.05
UNIT_C_D ($K/$m^3$ waste)	1.05	1.05	1.05	1.05	1.05

(a) Costs are in January 1988 dollars.

TABLE E.9. Unit Factors for DECON of Floors[a]

Unit Factor (Units)	Unit Factors for DECON of a Component Contaminated by the Indicated Radioisotope				
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am
Decontamination					
UNIT_C_{MP} ($K/$m^2$ component)	0.03	0.03	0.03	0.03	0.03
UNIT_C_{ES} ($K/$m^2$ component)	0.03	0.03	0.03	0.03	0.03
UNIT_V (m^3 waste/m^2 component)	0.04	0.04	0.04	0.04	0.04
UNIT_C_P ($K/$m^3$ waste)	0.33	0.33	0.33	0.33	0.33
UNIT_C_T ($K/$m^3$ waste)	0.06	0.06	0.06	0.06	0.06
UNIT_C_D ($K/$m^3$ waste)	1.05	1.05	1.05	1.05	1.05

(a) Costs are in January 1988 dollars.

TABLE E.10. Example: Generating a Cost Estimate to Decontaminate a Fume Hood Contaminated with ^{3}H

Step Number	Numerical Value of Parameter	Cost Calculation
1	DIM_PAR = 2.835	NA
2	UNIT_C_{MP} = 0.57	C_{MP} = (0.59) x (2.835) = $1.67K
3	UNIT_C_{ES} = 0.64	C_{ES} = (0.64) x (2.835) = $1.81K
4	UNIT_V = 0.37	V = (0.37) x (2.835) = 1.05 m^3
5	UNIT_C_{VR} = NA	NA
6	UNIT_C_P = 0.18	C_P = (0.18) x (1.05) = $0.19K
7	UNIT_C_T = 0.05	C_T = (0.05) x (1.05) = $0.05K
8	UNIT_C_D = 1.05	C_D = (1.05) x (1.05) = $1.10K
9	NA	SUB_TOT = 1.67 + 1.81 + 0.19 + 0.05 + 1.10 = $4.82K
10	NA	COST_TOT = (4.82) x (1.25) = $6.03K

TABLE E.11. Procedure for Developing a Cost Estimate for Decommissioning Entire Laboratories

Step Number	Description	Equation
1.	Determine the number and types of the major individual components present within the laboratory.	
2.	Calculate the costs to decommission each of the different types of components by performing steps 1-8 in the procedure given in Table E.1.	
3.	Sum up similar costs for all components (NC = Number of Components).	$COST\_TOT_{MP} = \sum_{i=1}^{NC} C_{MP}(i)$
		$COST\_TOT_{ES} = \sum_{i=1}^{NC} C_{ES}(i)$
		$COST\_TOT_{VR} = \sum_{i=1}^{NC} C_{VR}(i)$
		$COST\_TOT_{P} = \sum_{i=1}^{NC} C_{P}(i)$
		$COST\_TOT_{T} = \sum_{i=1}^{NC} C_{T}(i)$
		$COST\_TOT_{D} = \sum_{i=1}^{NC} C_{D}(i)$

(contd)

TABLE E.11. (contd)

Step Number	Description	Equation
4.	Revise the equipment and supplies total cost to reflect improved utilization.	$COST\_TOT_{ES} = COST\_TOT_{ES} \times 1/3$
5.	Revise all costs to reflect the additional costs to decommission miscellaneous components (i.e., refrigerators, freezers, cabinets, ceilings, etc.)	$COST\_TOT_{MP} = COST\_TOT_{MP} \times 1.20$ $COST\_TOT_{ES} = COST\_TOT_{ES} \times 1.20$ $COST\_TOT_{VR} = COST\_TOT_{VR} \times 1.20$ $COST\_TOT_{P} = COST\_TOT_{P} \times 1.20$ $COST\_TOT_{T} = COST\_TOT_{T} \times 1.20$ $COST\_TOT_{D} = COST\_TOT_{D} \times 1.20$
6.	Revise the manpower total cost to reflect the planning and preparation that occurs before decommissioning operations begin and to reflect the cost of the final radiation survey.	$COST\_TOT_{MP} = COST\_TOT_{MP} \times 1.5$
7.	For transuranic laboratories only: Revise the manpower and equipment and supplies cost to reflect the added hazards of decontaminating a laboratory contaminated with transuranic elements.	$COST\_TOT_{MP} = COST\_TOT_{MP} \times 1.25$ $COST\_TOT_{ES} = COST\_TOT_{ES} \times 1.25$
8.	For cases involving both the decontamination and volume reduction options: Revise the volume reduction, packaging, transportation, and disposal costs to reflect the additional volume reduction of waste generated from decontamination operations (waste generated from the packaging and disposal option have already been accounted for).	$COST\_TOT_{VR} = COST\_TOT_{VR}/(0.8)$ $COST\_TOT_{P} = (COST\_TOT_{P}) \times (0.8)$ $COST\_TOT_{T} = (COST\_TOT_{T}) \times (0.8)$ $COST\_TOT_{D} = (COST\_TOT_{D}) \times (0.8)$
9.	Add up all of the calculated costs.	$SUB\_TOT = COST\_TOT_{MP} + COST\_TOTES + COST\_TOT_{VR} + COST\_TOT_{P} + COST\_TOT_{T} + COST\_TOT_{D}$

(contd)

TABLE E.11. (contd)

Step Number	Description	Equation
10.	Calculate the total estimated cost including a 25% contingency.	COST_TOT = (SUB_TOT) x (1.25)
11.	For hot cells only: Calculate the salvage value of the lead present in the hot cells by performing step 11 in the procedure given in Table E.1. Sum over all hot cells.	$SV_L = \sum_{i=1}^{NC} CR_{LS}(i)$

TABLE E.12. Example: Generating a Cost Estimate to Decontaminate a Laboratory for the Manufacture of ^3H-Labeled Compounds[a]

Step Number	Cost Calculation

1.

- 5 fume hoods with a volume of 2.835 m^3 each; 3 are decontaminated, 2 are packaged for disposal with no volume reduction
- 6 glove boxes with a volume of 0.324 m^3 each; 3 are decontaminated, 3 are packaged for disposal with no volume reduction
- 20 linear meters of workbenches
- 40 linear meters of ventilation ductwork
- 132 m^2 of wall space
- 120 m^2 of floor space.

2.

fume hoods:	C_{MP} = 8.25	glove boxes:	C_{MP} = 6.02
	C_{ES} = 8.05		C_{ES} = 7.42
	C_P = 1.35		C_P = 1.00
	C_T = 0.55		C_T = 0.29
	C_D = 11.52		C_D = 5.51
workbenches:	C_{MP} = 1.80	ductwork:	C_{MP} = 2.00
	C_{ES} = 2.80		C_{ES} = 1.20
	C_P = 0.32		C_P = 0.56
	C_T = 0.11		C_T = 0.28
	C_D = 1.89		C_D = 5.88
walls:	C_{MP} = 7.92	floors:	C_{MP} = 3.60
	C_{ES} = 5.28		C_{ES} = 3.60
	C_P = 1.25		C_P = 1.58
	C_T = 0.33		C_T = 0.29
	C_D = 6.93		C_D = 5.04

(contd)

TABLE E.12. (contd)

Step Number	Cost Calculation
3.	$\text{COST\_TOT}_{MP} = 8.25 + 6.02 + 1.80 + 2.00 + 7.92 + 3.60 = 29.59$ $\text{COST\_TOT}_{ES} = 8.05 + 7.42 + 2.80 + 1.20 + 5.28 + 3.60 = 28.35$ $\text{COST\_TOT}_{VR} = \text{NA}$ $\text{COST\_TOT}_{P} = 1.35 + 1.00 + 0.32 + 0.56 + 1.25 + 1.58 = 6.06$ $\text{COST\_TOT}_{T} = 0.55 + 0.29 + 0.11 + 0.28 + 0.33 + 0.29 = 1.85$ $\text{COST\_TOT}_{D} = 11.52 + 5.51 + 1.89 + 5.88 + 6.93 + 5.04 = 36.77$
4.	$\text{COST\_TOT}_{ES} = (28.35) \times (1/3) = 9.45$
5.	$\text{COST\_TOT}_{MP} = (29.59) \times 1.20 = 35.51$ $\text{COST\_TOT}_{ES} = (9.45) \times 1.20 = 11.34$ $\text{COST\_TOT}_{P} = (6.06) \times 1.20 = 7.27$ $\text{COST\_TOT}_{T} = (1.85) \times 1.20 = 2.22$ $\text{COST\_TOT}_{D} = (36.77) \times 1.20 = 44.12$
6.	$\text{COST\_TOT}_{MP} = (35.51) \times (1.5) = 53.26$
7.	$\text{SUB\_TOT} = 53.26 + 11.34 + 7.27 + 2.22 + 44.12 = 118.21$
8.	$\text{COST\_TOT} = (118.21) \times (1.25) = 147.76$

(a) Costs are in thousands of January 1988 dollars.

TABLE E.13. Procedure for Developing a Cost Estimate for Decommissioning Industrial Field Sites

Step Number	Description	Equation	Units
1.	Determine the dimensional parameters (DIM_PAR) for each element of the site that requires decommissioning as follows: a. Exhumation of tank and drain pipe - depth that the pipe is buried (m), the rectangular volume occupied by the tank and drain pipe (H in m^3), and the linear length of the drain pipe (L in m) b. Removal of contaminated ground - total area of the site to be decommissioned (m^2) c. Site stabilization of a tailings pile/evaporation pond - total area occupied by the pile (m^2) d. Removal of a tailings pile/evaporation pond - total volume of the pile (m^3)	The DIM_PAR parameter will have different units depending on the characteristics of the site element being decommissioned. The unit factors in the equations below will corresponingly have different units. The units of the unit factors are given in Table E.14 for each of the different possible site elements.	
2.	Calculate the manpower costs to decommission the site element.	C_{MP} = (UNIT_C_{MP}) x (DIM_PAR)	($K)
3.	Calculate the equipment costs to decommission the site element.	C_E = (UNIT_C_E) x (DIM_PAR)	($K)
4.	Calculate the cost of the materials needed to decommission the site element.	C_M = (UNIT_C_M) x (DIM_PAR)	($K)

(contd)

TABLE E.13. (contd)

Step Number	Description	Equation	Units
5.	Calculate the cost for soil analyses necessary during decommissioning of the site element.		
	a. For contaminated group and tailings piles	C_{SA} = (UNIT_C_{SA}) x (DIM_PAR)	($K)
	b. For tank and drain line	C_{SA} = (UNIT_C_{SA}) x (L)	($K)
6.	Calculate the volume of low-level waste generated from decommissioning of the site element.	V = (UNIT_V) x (DIM-PAR)	(m^3)
7.	Calculate the cost to package the waste.	C_P = (UNIT_C_P) x (DIM-PAR)	($K)
8.	Calculate the cost to transport the waste to the low-level waste disposal site.	C_T = (UNIT_C_T) x (DIM_PAR)	($K)
9.	Calculate the cost to dispose of the waste at a low-level waste disposal site.	C_D = (UNIT_C_D) x (DIM_PAR)	($K)
10.	Calculate the fee for the contractor performing the decommissioning work.	$C_C = (C_{MP} + C_E + C_M + C_P) \times (0.08)$	($K)
11.	Add up all of the calculated costs.	SUB_TOT = $C_{MP} + C_E + C_M + C_{SA} + C_P + C_T + C_P + C_C$	($K)
12.	Calculate the total estimated cost, including a 25% contingency.	COST_TOT = (SUB_TOT) x (1.25)	($K)

TABLE E.14. Unit Factors for DECON of an Industrial Field Site[a]

Unit Factor (Units)	Value of Unit Factor
Tank and Drain Pipe:	
$UNIT\_C_{MP}$ ($K/$m^3$ of tank and drain pipe)	3.23 + 0.29 H[b]
$UNIT\_C_E$ ($K/$m^3$ of tank and drain pipe)	2.90 + 0.26 H[b]
$UNIT\_C_M$ ($K/$m^3$ of tank and drain pipe)	0.50 + 0.05 H[b]
$UNIT\_C_{SA}$ ($K/m of pipe)	0.32
UNIT_V (m^3 waste/m^3 of tank and drain pipe)	1.40
UNIT_P ($K/$m^3$ waste)	0.10
UNIT_T ($K/$m^3$ waste)	0.05
UNIT_D ($K/$m^3$ waste)	1.05
Contaminated Ground:	
$UNIT\_C_{MP}$ ($K/$m^2$ of site)	0.005
$UNIT\_C_E$ (($K/$m^2$ of site)	0.004
$UNIT\_C_M$ ($K/$m^2$ of site)	0.002
$UNIT\_C_{SA}$ ($K/$m^2$ of site)	0.008
UNIT_V (m^3 waste/m^2 of site)	0.100
UNIT_P ($K/$m^3$ waste)	0.094
UNIT_T ($K/$m^3$ waste)	0.103
UNIT_D ($K/$m^3$ waste)	1.066
Tailings Pile/Evaporation Pond:	
Site Stabilization	
$UNIT\_C_{MP}$ ($K/$m^2$ of site)	0.0086
$UNIT\_C_E$ ($K/$m^2$ of site)	0.0073
$UNIT\_C_M$ ($K/$m^2$ of site)	0.0321
$UNIT\_C_{SA}$ ($K/$m^2$ of site)	0.0016

(contd)

TABLE E.14. (contd)

Unit Factor (Units)	Value of Unit Factor
Annual Long-Term Care	
UNIT_C_{MP} ($K/m^2 of site)	0.0010
UNIT_C_E ($K/m^2 of site)	0.0003
UNIT_C_M ($K/m^2 of site)	0.0002
UNIT_C_{SA} ($K/m^2 of site)	0.0003
Removal	
UNIT_C_{MP} ($K/m^3 of pile)	0.0267
UNIT_C_E ($K/m^3 of pile)	0.0100
UNIT_C_M ($K/m^3 of pile)	0.0077
UNIT_C_{SA} ($K/m^3 of pile)	0.0007
UNIT_V (m^3 waste/m^3 of pond)	1.1585
UNIT_P ($K/m^3 of pile)	0.0942
UNIT_T ($K/m^3 of pile)	0.1052
UNIT_D ($K/m^3 of pile)	1.0668

(a) Costs are in January 1988 dollars.
(b) H is the depth at which the drain line is buried.

TABLE E.15. Example: Generating a Cost Estimate to Decontaminate an Industrial Field Site by Removing a Tailings Pile

Step Number	Numerical Value of Parameter	Cost Calculation
1.	DIM_PAR = 16,400 m^3	
2.	UNIT_C_{MP} = 0.0267	C_{MP} = (0.0267) x (16,400) = \$437.88K
3.	UNIT_C_E = 0.0100	C_E = (0.0100) x (16,400) = \$164.00K
4.	UNIT_C_M = 0.0077	C_M = (0.0077) x (16,400) = \$126.28K
5.	UNIT_C_{SA} = 0.0007	C_{SA} = (0.0007) x (16,400) = \$11.48K
6.	UNIT_V = 1.1585	V = (1.1585) x (16,400) = 18,999.4 m^3
7.	UNIT_P = 0.0942	C_P = (0.0942)(18,999.4) = \$1789.74K
8.	UNIT_T = 0.1052	C_T = (0.1052)(18,999.4) = \$1998.74K
9.	UNIT_D = 1.0668	C_D = (1.0668)(18,999.4) = \$20,268.56K
10.	NA	C_C = (437.88 + 164.00 + 126.28 + 1789.74) x (0.08) = \$201.43K
11.	NA	SUB_TOT = 437.88 + 164.00 + 126.28 + 11.48 + 1789.74 + 1998.74 + 20,268.56 = \$24,998K
12.	NA	TOT_COST = (24,998)(1.25) = \$31,248K

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11. ABSTRACT (200 words or less)

The objective of this study is to provide a current compendium of relevant information on the technology, safety, and costs for decommissioning non-fuel cycle nuclear facilities. The information in this report revises and/or updates the information already provided in the original document on the same subject (NUREG/CR-1754). The study is intended to provide background information for use by NRC staff in evaluating licensee cost estimates and decommissioning plans, as required by the final decommissioning rule. A procedure for use by NRC staff in estimating decommissioning costs of non-fuel-cycle nuclear facilities is provided in Appendix E. This procedure is also intended for use by materials licensees in planning for the decommissioning of their facilities.

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