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Revised Analyses of Decommissioning Reference Non-Fuel-Cycle Facilities

Pacific Northwest National Laboratory
Operated by
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Revised Analyses of Decommissioning Reference Non-Fuel-Cycle Facilities

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Prepared by
M. C. Bierschbach, D. R. Haffner,
K. J. Schneider, S. M. Short

Pacific Northwest National Laboratory
Richland, WA 99352

C. W. Prichard, NRC Project Manager

Prepared for
Division of Industrial and Medical Nuclear Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
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Abstract

Cost information is developed for the conceptual decommissioning of non-fuel-cycle nuclear facilities that represent a significant decommissioning task in terms of decontamination and disposal activities. This study is a re-evaluation of the original study (NUREG/CR-1754 and NUREG/CR-1754, Addendum 1). The reference facilities examined in this study are the same as in the original study 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
- an institutional user laboratory.

In addition to the laboratories, three reference sites that require some decommissioning effort were also examined. These sites are:

- 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.

Decommissioning of these reference facilities and sites can be accomplished using techniques and equipment that are in common industrial use. Essentially the same technology assumed in the original study is used in this study.

For the reference laboratory-type facilities, the study approach is to first evaluate the decommissioning of individual components (e.g., fume hoods, glove boxes, and building surfaces) that are common to many laboratory facilities. The information obtained from analyzing the individual components of each facility are then used to determine the cost, manpower requirements and dose information for the decommissioning of the entire facility. DECON, the objective of the 1988 Rulemaking for materials facilities, is the decommissioning alternative evaluated for the reference laboratories because it results in the release of the facility for restricted or unrestricted use as soon as possible. For a facility, DECON requires that contaminated components either be: 1) decontaminated to restricted or unrestricted release levels or 2) packaged and shipped to an authorized disposal site. This study considers unrestricted release only. The new decommissioning criteria of July 1997 are too recent for this study to include a cost analysis of the restricted release option, which is now allowed under these new criteria.

The costs of decommissioning facility components are generally estimated to be in the range of $140 to $27,000, depending on the type of component, the type and amount of radioactive contamination, the remediation options chosen, and the quantity of radioactive waste generated from decommissioning operations. Estimated costs for decommissioning the example laboratories range from $130,000 to $205,000, assuming aggressive low-level waste (LLW) volume reduction. If only minimal LLW volume reduction is employed, decommissioning costs range from $150,000 to $270,000 for these laboratories. 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 $25,000 for the decommissioning of a small room containing one or two 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 $130,000 for the removal of a contaminated drain line and hold-up tank to more than $23 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 0.00007 person-rem to 13 person-rem for decommissioning the laboratory facilities of this study.

The results of this study are: (1) decommissioning costs have continued to increase since publication of the original study, due primarily to rapidly escalating costs for disposal of radioactive wastes at the available LLW burial sites; (2) these swiftly increasing LLW disposal costs provide a significant incentive for NRC licensees to effectively manage LLW generation, treatment, and disposal from decommissioning activities; and (3) decommissioning costs have increased on the order of 34% to 66% since the Final Decommissioning Rule was issued in 1988, due in large part to the 3.5-fold increase in burial costs.

Contents

Figures

Tables

Page

Contents

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1 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 information provided in this report is a re-analysis of the decommissioning of the facilities and sites considered in NUREG/CR-1754 and its Addendum.[1,2] This information will be used by the NRC to develop financial assurance rulemakings for by-product, source, and special nuclear materials licensees. The material in this report may also be useful to the licensees in planning for the decommissioning of their facilities. This report covers two broad categories: facilities and sites. As used herein, a facility is a building whose internal contents (walls, floors, ceilings, and equipment) are to be decommissioned. Site, as defined in this report, is an external area or volume (not a building) which contains elements that require decommissioning, such as a hold-up tank, a contaminated ground surface, or a tailings pile/evaporation pond. Decommissioning a site means decommissioning one or more of these site elements.

The example facilities decommissioned in this study are the same as those used in Reference 1 and are considered representative of actual facilities. The reference laboratory facilities include individual laboratories 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, and exhaust system ductwork, 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 of decommissioning entire facilities. This study analyzes the decommissioning of example laboratories to unrestricted release levels by the immediate removal of contaminated components and material and disposal of waste at authorized sites. Facilities may also be decontaminated to *restricted* release levels; however, the new radiological criteria permitting this[3] are so recent that it was not possible to incorporate cost estimates for the restricted release case into this study.

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, well-established technology and that conform to the principle of keeping public and occupational radiation doses as low as reasonably achievable (ALARA). Since the publication of the base study,[1,2] promising new technologies are beginning to be applied (Chapter 4) to the decommissioning of nuclear facilities. However, because these technologies are not yet widely available, and because data concerning their cost and effectiveness are sparse, none of these new technologies is used in decommissioning facilities in this study.

Following this introductory chapter, a summary of the important information and results of this study are presented in Chapter 2. Chapter 3 contains a review of decommissioning experience at three non-fuel-cycle nuclear facilities. Advanced 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. Cost estimating bases and algorithms are presented in Appendices A and B. Appendices C through E provide the details of the decommissioning analyses set forth in the main report.

1.1 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. S. M. Short. 1989. *Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities.* NUREG/CR-1754, Addendum 1. U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

3. U.S. Nuclear Regulatory Commission. *Radiological Criteria for License Termination: Final Rule.* Federal Register, Vol. 2, No. 139, pp. 39057-39092, July 21, 1997.

2 Summary

The objective of this study is to provide relevant information on the technology and costs for decommissioning non-fuel-cycle nuclear facilities. The information in this report updates the information already provided in the original document and its addendum on the same subject.[1,2] This study provides information for use by NRC staff in the development of financial assurance rulemakings for by-product materials, source materials, and special nuclear materials licensees. 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

DECON is the decommissioning alternative analyzed in this study. DECON requires that, shortly after a facility ceases operation, all of its contaminated components either be (1) decontaminated to restricted or unrestricted release levels or (2) packaged and shipped to an authorized disposal site. Although facilities may be decontaminated to restricted release levels, the new radiological criteria permitting this[3] were promulgated so recently it was not possible to incorporate cost estimates for restricted release into this study. 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) 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 of decommissioning entire facilities.

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 (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.

2.2 Review of Decommissioning Experience

A number of non-fuel-cycle facilities have been decommissioned over the last several years. Three of these facilities of particular relevance to this study are discussed in Chapter 3: a facility for conducting U.S. Government nuclear materials research, a facility for the manufacture of radiopharmaceuticals, and a radiological laundry facility used to decontaminate clothing and other articles that have been radiologically contaminated at nuclear facilities. These facilities were selected for inclusion in this study because they represent the broad range of types of facilities classified as non-fuel-cycle facilities and the resulting broad range in decommissioning requirements.

The intent of Chapter 3 is to provide information on the types of non-fuel-cycle facilities that have been decommissioned over the last several years and to provide some perspective of the complexity and level-of-effort required to decommission different types of facilities.

2.3 Review of Emerging Technologies

The rapidly escalating cost for disposing of radioactive waste at the available shallow-land disposal sites has provided the impetus to develop technologies that reduce the volume of waste that must be shipped for disposal. Three such technologies, including two surface decontamination methods and a molten metal process, are discussed in Chapter 4. Although they are not used in the development of the cost methodology discussed in this study, these technologies are evaluated at some length because of the potential impact they may have on the overall cost of decommissioning in the future.

2.4 Characterization of Reference Facilities and Sites

The reference facilities and sites analyzed in this study are the same as those 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, storage cabinets, filters, small appliances, sinks, drains, ventilation ductwork, filters, and building surfaces (floors, walls, and ceilings). Some of these components become significantly contaminated during the operational phase of the laboratory. Release of a laboratory for unrestricted use and termination of the radioactive material license require 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.

As with reference facilities, unrestricted release of reference sites would require that the contamination be removed and disposed of at an authorized disposal facility before the license could be terminated. Some situations may exist, such as at the site of a tailings pile, where the cost of remediation necessary to reduce contamination levels to allow unrestricted release may be prohibitively expensive. Decommissioning of such sites could be completed with restricted release of the site, provided arrangements were established to assure that further use of the site would be limited to certain activities. Surveillance of the remaining contamination may be required of the original licensee or another qualified alternate until residual radioactivity decays to levels allowing unrestricted release.

Two decommissioning options for the site with a contaminated tailings pile are analyzed in this study: (1) removal of all contaminated material to allow unrestricted release, and (2) site stabilization followed by periodic surveillance to allow restricted release.

2.5 Decommissioning of Facility Components

Facility components may be decommissioned by decontamination to restricted release levels, unrestricted release levels, or by shipment to a low-level waste (LLW) facility. Previous studies[1,2] analyzed several options for removable components: (1) decontamination to unrestricted release levels, (2) packaging and disposal without volume reduction, (3) packaging and disposal with supercompaction, and (4) packaging and disposal with incineration. The labor cost of decontaminating components to unrestricted levels is potentially very high, usually higher than the salvage value of the decontaminated component. Such intensive decontamination efforts also generate significant amounts of secondary waste that must be disposed of. For these reasons, option 1 was not considered in this study. Since disposal charges ($/m^3) at the LLW disposal sites have increased dramatically since the original study, option 2 is no longer considered viable. Based on these considerations, only options 3 and 4 are analyzed for the removable components in this study; building surfaces are decontaminated to unrestricted release levels. A summary of estimated costs for decommissioning facility components is given in Table 2.1. A

Table 2.1 Summary of estimated costs ($ thousands) for decommissioning facility components

Component & option[a]	^{3}H laboratory	^{14}C laboratory	^{125}I laboratory	^{137}Cs laboratory	^{241}Am laboratory	User laboratory
Fume hood						
Option 1	7.5	8.0	7.5	9.1	8.0	7.6
Option 2	7.9	8.3	7.7	9.4	8.4	7.9
Glove box						
Option 1	3.3	3.5	4.0	--	6.7	3.5
Option 2	3.5	3.6	4.0	--	7.0	3.7
Hot cell						
Option 1	--	--	--	26.5	--	--
Option 2	--	--	--	26.8	--	--
Workbench[b]						
Option 1	2.6	9.9	8.7	11.8	10.6	9.3
Option 2	2.7	12.4	9.0	14.4	10.8	11.9
Ductwork[c]						
Option 1	13.1	13.6	15.9	17.2	15.1	14.2
Option 2	13.5	14.0	16.3	17.6	15.5	14.6
Cabinet						
Option 1	2.4	2.4	2.3	--	2.4	--
Option 2	3.0	3.0	2.3	--	2.9	--
Appliance[d]						
Option 1	5.9	6.0	6.3	--	--	5.9
Option 2	6.2	6.3	6.7	--	--	6.2
Filter						
Option 1	0.1	0.2	0.2	0.2	0.2	0.2
Option 2	0.2	0.2	0.3	0.3	0.2	0.2
Sink & drain						
Option 1	--	2.3	2.4	2.5	--	2.2
Option 2	--	2.3	2.4	2.5	--	2.2
Ceiling[e]						
Option 1	11.8	12.0	15.1	24.0	12.8	17.6
Option 2	15.6	15.8	17.6	32.1	14.9	25.1
Walls[e]						
Option 1	10.0	10.6	14.8	15.3	11.5	15.6
Option 2	11.9	12.5	16.6	17.1	13.0	17.9
Floor[e]						
Option 1	10.1	11.1	12.5	13.6	13.4	11.5
Option 2	10.1	11.4	12.8	14.0	15.4	11.8

(a) Option 1 is supercompaction. Option 2 is supercompaction with incineration.
(b) Cost for a "typical" work bench, 4.6 m long.
(c) Cost for 40 m of ventilation ductwork.
(d) Appliance is a refrigerator or freezer, as described in Appendix D.
(e) Cost for 60 m^2 of surface area.

summary of estimated occupational radiation doses for decommissioning facility components is given in Table 2.2.

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 decontamination to the unrestricted release levels specified in the NRC guidelines of Reference 1.

Disposal is postulated to be by shallow-land disposal at a site located 800 km from both the laboratory being decommissioned and from the centrally located super-compaction facility. The supercompaction and incineration facility is postulated to be located 350 km from the laboratory. Wastes are packaged in 208-liter steel drums and are shipped by truck either to the disposal site or to the supercompaction and incineration 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.

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 1998 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 crew-hours required to decommission a component by the costs per crew-hour. 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 allow for preparation and set-up time and rest periods.

Table 2.2 Summary of estimated occupational radiation doses (person-rem) for decommissioning facility components

Component & option[a]	^{3}H laboratory	^{14}C laboratory	^{125}I laboratory	^{137}Cs laboratory	^{241}Am laboratory	User laborator
Fume hood	8×10^{-3}	8×10^{-6}	3×10^{-5}	1×10^{-1}	5×10^{-2}	8×10^{-3}
Glove box	7×10^{-4}	2×10^{-7}	4×10^{-3}	–	2×10^{0}	7×10^{-4}
Hot cell	–	–	–	2×10^{0}	–	–
Workbench[a]	2×10^{-7}	6×10^{-7}	1×10^{-5}	3×10^{-5}	4×10^{-3}	6×10^{-7}
Ductwork[b]	2×10^{-6}	2×10^{-5}	6×10^{-5}	3×10^{-3}	1×10^{-2}	2×10^{-6}
Cabinet	2×10^{-6}	7×10^{-7}	2×10^{-5}	–	3×10^{-3}	–
Appliance[c]	2×10^{-6}	1×10^{-6}	2×10^{-5}	–	–	2×10^{-6}
Filter	1×10^{-7}	5×10^{-8}	1×10^{-6}	2×10^{-6}	2×10^{-4}	1×10^{-7}
Sink & drain	–	9×10^{-8}	1×10^{-6}	1×10^{-5}	–	9×10^{-8}
Ceiling[d]	7×10^{-6}	3×10^{-6}	9×10^{-5}	1×10^{-4}	2×10^{-2}	8×10^{-6}
Wall[d]	6×10^{-6}	3×10^{-6}	9×10^{-5}	1×10^{-4}	2×10^{-2}	1×10^{-5}
Floor[d]	1×10^{-6}	4×10^{-6}	5×10^{-5}	2×10^{-4}	4×10^{-2}	1×10^{-6}

(a) Dose from a "typical" workbench, 4.6 m long.
(b) Dose from 40 m of ventilation duct.
(c) Appliance is a refrigerator or freezer, as described in Appendix D.
(d) Dose from 60 m² of surface area.

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 cut up into pieces that will efficiently fill a 208-liter drum. The drums are then compacted on-site and sent to a facility for supercompaction, after which they are sent to a shallow-land disposal site as LLW. To provide a basis for cost comparisons, an alternative option is analyzed which is identical to the base case except that burnable waste is incinerated and the remainder is super-compacted. Costs of these two options are summarized in Chapter 5.

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 person-hours 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 the 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 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.

Previous studies[1,2] assumed that ceilings, walls, and floors of the facilities were to be decontaminated to unrestricted release levels and that some of the facility components were to be decontaminated to unrestricted release levels, while others were to be sectioned and packaged for disposal. The original study[1] discussed the relative merits of compacting components before disposal. But in the analyses of complete facilities, novolume reduction of components was assumed. The follow-on study[2] considered options of compaction and supercompaction. The present study differs from the previous two studies in that only surfaces (walls, ceilings, floors) are decontaminated to unrestricted release levels; no facility components are decontaminated. Instead, all components are to be supercompacted or incinerated before they are disposed of. Decommissioning requirements and costs for the six reference laboratories are summarized in Table 2.3.

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 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 represent reasonable approaches to the decommissioning of particular components. All components (fume hoods, glove boxes, filters, ducting, workbenches, cabinets, refrigerators, sinks and drains, and other similar items) are sectioned to the extent possible, compacted, and then packaged for disposal. The only surface decontamination performed on these items is the minimum amount needed to prevent the spread of contamination during the sectioning and packaging operations. 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.

Table 2.3 Summary of estimated requirements and costs for DECON of six reference laboratories that process or use radioisotopes

Parameter	^{3}H laboratory	^{14}C laboratory	^{125}I laboratory	^{137}Cs laboratory	^{241}Am laboratory	User laboratory
	Requirement or cost for reference laboratory					
Supercompaction option						
Time (days)	61	57	50	48	58	68
Manpower (person-days)	194	178	149	143	179	220
Dose (person-rem)	0.04	<0.001	0.02	4	13	0.04
Costs ($ thousands)						
Staff labor	85.1	77.9	65.0	62.4	78 0	96.5
Equipment & supplies	30.0	29.4	28.5	28.4	29.4	30.5
Waste management	59 0	58 6	35.4	64 8	39 4	77.9
Totals	174.1	165.9	128.8	155.4	146 8	204.8
Supercompaction with incineration						
Time (days)	61	57	50	48	58	68
Manpower (person-days)	194	178	149	143	179	220
Dose (person-rem)	0.04	<0.001	0.02	4	13	0 04
Costs ($ thousands)						
Staff labor	85.1	77.9	65.0	62.4	78.0	96.5
Equipment & supplies	30.0	29.4	28.5	28.4	29.4	30.5
Waste management	77.3	80.9	43.3	78.8	52.3	109.5
Totals	192.3	188.1	136.7	169.4	159.7	236.5

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 and supplies, and waste management. Costs are estimated for planning and preparation, for the actual decommissioning, and for the termination survey. Total costs, listed in Table 2.3, are the sum of all of these costs. All costs are expressed in January 1998 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 person-days required to decommission a facility.

A note regarding the ^{241}Am laboratory is in order. As discussed in Appendix D, the walls and ceiling in this facility are concrete and sealed with acrylic paint. As a result, the postulated cleanup of these surfaces involved only wet-wiping and the application of strippable paint. Thus, decontamination to release levels was easily achieved. However, had the surfaces not been sealed, the decontamination to release levels of surfaces impregnated by ^{241}Am could have required extensive surface washing and scabbling of concrete to depths of at least 0.6 cm. Assuming, as a worst case, that all 60 m^2 of ceiling and floor area and all 168 m^2 of wall area required washing and scabbling, using procedures like those discussed in References 3 and 4, the cost of decommissioning this facility would have increased about $67,000. This amounts to a 46% increase in decommissioning costs for the supercompaction option and a 42% increase for the supercompaction with incineration option.

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 removing 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, occupational doses, and costs for the three reference sites are summarized in Table 2.4.

Because concentrations of radioactivity are assumed to be low and inhalation of re-suspended particulates is not a serious consideration, removal of the waste and contaminated soil is accomplished with standard earthmoving equipment. Radioactive material is packaged in 208-liter drums or B-25 metal containers for shipment to a shallow-land disposal site.

Table 2.4 Summary of estimated labor requirements, costs, and radiation doses for decommissioning three reference sites

	Requirement or cost			
Site	Time (days)	Labor (person-days)	Costs[a] ($ thousands)	Occupational radiation dose (person-rem)
Underground drain line & hold-up tank	17	72.5	126	0.052
Contaminated ground surface	42	209	1,396	0.149
Tailings pile				
Stabilization option	32	174	237	0.139
Long-term care	10	27	17	0.022
Removal option	139	1,657	22,790	1.311

(a) Costs are in January 1998 dollars and include a 25% contingency.

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 before releasing the 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 2.4 are the sum of planning and preparation, actual decommissioning, and termination survey costs. All costs are expressed in early 1998 dollars and include a 25% contingency. Approximately 77% of the cost of decommissioning a site with contaminated ground surface, and approximately 91% 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 LLW disposal sites and chosen conservatively.

2.8 Study Conclusions

The major conclusions of this study are:

- Decommissioning of materials facilities can be accomplished using techniques and equipment that are in common industrial use.
- Decommissioning costs vary over a wide range, from thousands to millions of dollars, depending on the type and size of the facility, the nature and extent of the radioactive contamination, and the operating history of the facility.
- Materials facilities can be decommissioned with a minimum of radiation exposure to decommissioning workers and with no significant impact on the safety of the general public.
- Facility design and construction and operating practices can have a significant effect on the time and cost of decommissioning materials facilities.
- While new, commercially available radioactive waste volume-reduction technology can significantly reduce the costs of waste disposal, the rapidly escalating disposal charges at the LLW sites, coupled with the inevitable increases in labor and materials, have resulted in an overall increase in decommissioning costs. These cost increases are on the order of 34% to 66%, since issuance of the Final Decommissioning Rule in 1988.
- The decommissioning cost methodology presented in this report is in fairly good agreement with decommissioning cost estimates provided by licensees to the NRC.

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.

2. S. M. Short. 1989. *Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities.* NUREG/CR-1754, Addendum 1. U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

3. U.S. Nuclear Regulatory Commission. *Radiological Criteria for License Termination: Final Rule.* Federal Register, Vol. 2, No. 139, pp. 39057-39092, July 21, 1997.

3 Review of Decommissioning Experience

Since publication of the Addendum to NUREG/CR-1754,[1] several commercial and Department of Energy (DOE) non-fuel-cycle facilities have been decommissioned. Three of these facilities relevant to this study are discussed in this chapter. These examples were chosen to illustrate the variety of facilities that have been decommissioned in the past few years. The nature, size, and complexity of these example facilities vary, but the same basic decommissioning methods apply to each of them. These methods were used in the analyses of the reference laboratory facilities and reference sites in Chapters 5, 6, and 7.

3.1 Battelle Memorial Institute Building KA-3[2]

Historically, Building KA-3, referred to as the Materials Building, was used for various types of nuclear materials research programs for the U.S. Government, primarily DOE and its predecessor agencies. Operations in Building KA-3, which is located in Columbus, Ohio, included a powder metallurgy facility, a melt/cast facility, a radioactive metallurgy facility, a ceramics research facility, and a ^{235}uranium processing facility. While characterization for D&D of this building began as early as 1986, major D&D activities actually began in March 1989 and were completed in February 1995. The building has been released for unrestricted use. The total cost of D&D was approximately $25 million, not including costs associated with low-level waste (LLW) disposal.

3.1.1 Description of Building KA-3

Building KA-3, which was built in 1946, is a two-story (three floors), rectangular steel frame brick and block structure with a poured concrete ground floor footing and foundation. The ground floor consists of a reinforced concrete slab floor below grade. The elevated floors consist of reinforced concrete slab floors supported by the structural framework and the foundation walls. The building is divided into six segments by north/south and east/west hallways with stairwells on each floor. The interior room partitions are mainly non-load bearing concrete block walls.

Building KA-3 was completed in 1947. It was built to serve as a nuclear materials research laboratory for the melting, processing, and research of enriched and depleted uranium and thorium isotopes. The building consisted of 191 rooms, over 73,000 square feet, and contained a wide range of equipment.

General Description of Second Floor Rooms

The second floor of Building KA-3 had approximately 20 offices; an eight-room, 2000-square-foot beryllium laboratory; a hot isostatic press development laboratory; an arc melt facility including power supplies; and a plasma spray coating facility. Many of the rooms on the second floor had false ceilings and others had space heaters located in the overhead. A five-ton monorail crane traversed the length of the rooms in the middle of the building from the overhead door to the inside north wall. Although the crane and some services in the overhead were contaminated, the area above 2 m on the second floor was generally clean. A floor plan of the second floor of Building KA-3 as it was at the beginning of remediation is presented in Figure 3.1.

General Description of First Floor Rooms

The first floor of Building KA-3 had approximately 15 offices, a uranium fluoridation laboratory, chemical testing laboratories, and several large areas dedicated to the shipping, receiving, and storage of nuclear materials. There was also a hot metalography and polishing laboratory that established new cladding properties through the melting and casting of radioactive materials. The traffic and storage areas on the first floor were widely contaminated within the structure of the building both above and below 2 m in height. The first floor had a 12 ft by 16 ft roll-up garage door on the south side of the building that led onto Fifth Avenue to receive and ship bulk radioactive material from the vault in Room 25, located near the middle of the building. An 8 ft by 8 ft garage door located on the east side of the building lined up with an 8-ft corridor into Building KA-2. This door was used for small equipment deliveries and office supplies for Building KA-3.

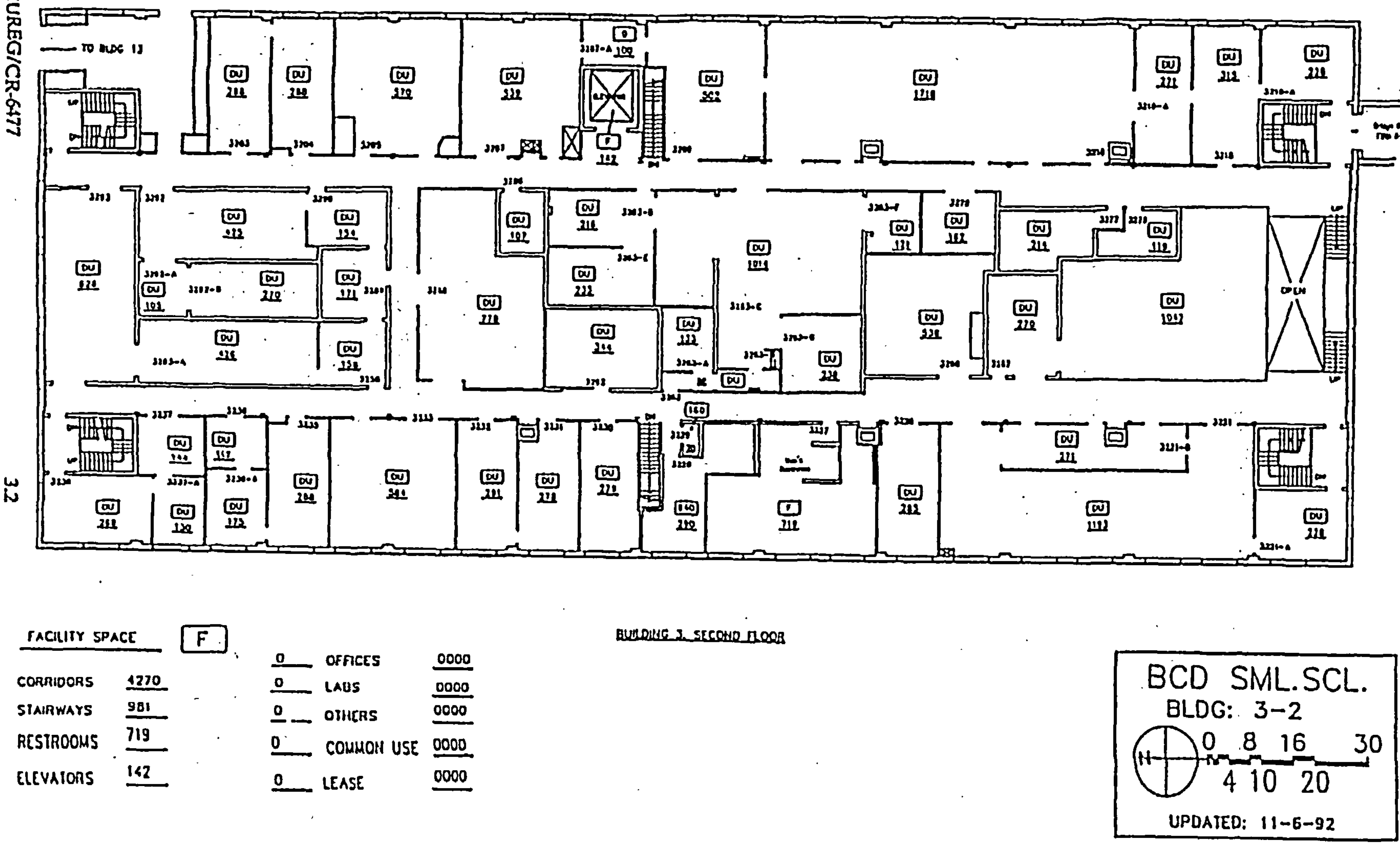


Figure 3.1 Floor plan of the second floor of Building KA-3

The 12 ft by 16 ft north side garage door was used by Battelle personnel for internal shipments. A floor plan of the first floor of Building KA-3 as it was constructed prior to remediation is presented in Figure 3.2.

General Description of Ground Floor Rooms

The ground floor of Building KA-3 consisted of approximately 10 offices, a ceramics laboratory for sintering uranium dioxides, a powder metallurgy laboratory, several ^{235}U processing areas, a process drain collection sump, a substation, and most of the service headers for the building. This area had a fairly large amount of piping wrapped with asbestos insulation. The northwest side of the ground floor was devoted to wet chemistry work in support of other laboratories within Building KA-3 and contained fume hoods and conventional laboratory benches. On the north side of the ground floor in what was room 3002, ^{235}U processing occurred, which necessitated the removal of the entire concrete floor slab. Equipment included vacuum furnaces, isostatic presses, glove boxes, and machining equipment. Other areas of the ground floor became satellite storage areas for processing.

From a services standpoint, the ground floor became the collection point for the radioactive drains, water, debris and waste from the other processes. In the latter part of the remediation process, Building KA-3 was found to have a fairly shallow footer system with only a minimal amount of reinforcement. This condition required modifications to the building structure prior to the remediation of the underground process drain system. A floor plan of the ground floor of Building KA-3 as it was constructed prior to remediation is presented in Figure 3.3.

General Description of the Contaminated Rooms

The rooms determined to be contaminated consisted of painted concrete block walls, cast concrete floors, and painted concrete ceilings. The floors were sealed but some of the sealant had worn away. Other areas were tiled with asbestos-laden tile. There were drains in the floors. Fixed equipment in the rooms included laboratory benches, sinks, furnaces, ovens, presses, lathes, and a variety of other equipment. Ventilating air supply ducts were present in each room. Room lighting consisted of several fluorescent light fixtures suspended from the ceiling. Electrical conduit, which passed through the rooms, was mounted on the walls and supplied power to surface-mounted outlets and the suspended fluorescent lights. In addition, there were several surface-mounted switch boxes which supplied power to various equipment.

Several 1- and 2-inch water lines were suspended near the ceiling. The 2-inch lines passed through the rooms, and the smaller lines extended into the rooms to supply the laboratory sinks. Some of the 2-inch lines were wrapped with asbestos insulation. Doors, mostly wooden, accompanied each of the 191 rooms.

3.1.2 Radiological History

Direct-reading radiological surveys of facility surfaces were performed using radiation detection instruments. Indirect radiological surveys (smear surveys) were also performed in designated grids showing direct readings above established decision level value (DLV).

Floor Drains

A comprehensive survey was performed on the floor drains in Building KA-3. As a result of drain contamination, the majority of the process drains were removed during the remediation phase of the project. The following is a summary of the contamination detected in the Building KA-3 drains.

Ground Floor (3000 Area). Twenty-five drain samples were collected and found to be contaminated in the 3000 North area. Alpha contamination levels ranged from 13 pCi/g in Room 3065 to 5,990 pCi/g in Drain #1, Room 3002B. Beta contamination levels ranged from 18 pCi/g in Room 3065 to 4,710 pCi/g in Room 3002. Mercury was also detected in Drain #1, Room 3002B.

A total of 66 drain samples were collected and found to be contaminated in the 3000 South area. Alpha contamination levels ranged from 12 pCi/g in Room 3023 to 1,470 pCi/g in the south drain of Room 3054. No samples were taken in the shower drains in Rooms 3083 and 3083B since these drains were not accessible, or in the shower drain in Room 3075 since it had been removed. Low levels of mercury were found in drain samples from Room 3014.

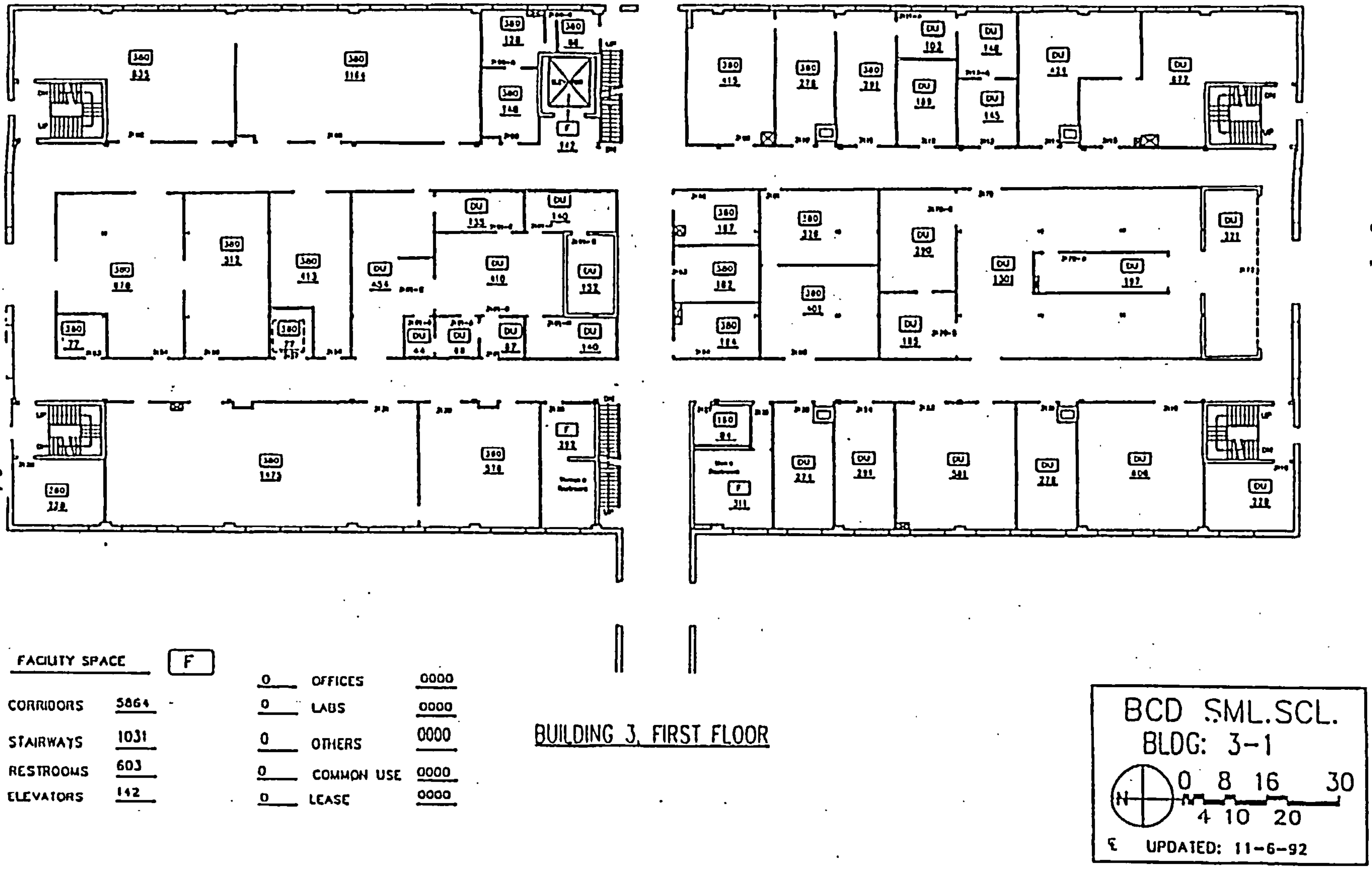


Figure 3.2 Floor plan of the first floor of Building KA-3

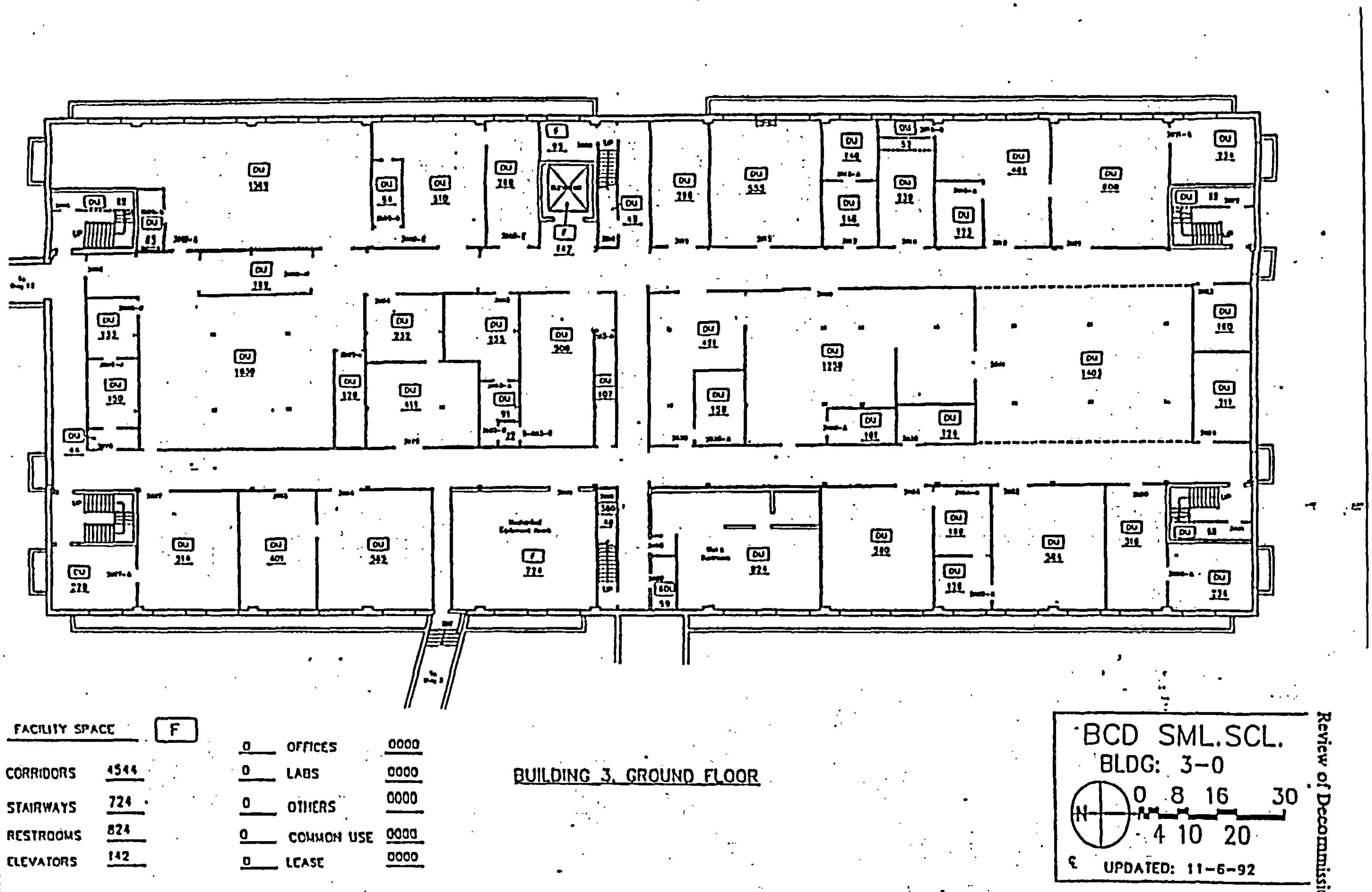


Figure 3.3 Floor plan of the ground floor of Building KA-3

First Floor (3100 Area). Twenty-five drain samples were collected and found to be contaminated in the 3100 North area. Alpha contamination levels ranged from 21 pCi/g in Drain #5, Room 3132, to 19,700 pCi/g in Drain #1, Room 3161. Beta contamination levels ranged from 7 pCi/g in the shower drain of Room 3161 to 3,250 pCi/g in Drain #1, Room 3161. Mercury was also detected in the northeast drain of Room 3154.

Twenty-eight drain samples were collected and found to be contaminated in the 3100 South area. Alpha contamination levels ranged from 28 pCi/g in Room 3114 to 21,500 pCi/g in Room 3169B. Beta contamination levels ranged from 24 pCi/g in Room 3114 to 21,300 pCi/g in the center west drain of Room 3169. No nonradiological hazardous contaminants were detected in drain samples collected in this area.

Second Floor (3200 Area). Eight drain samples were collected in the 3200 North area. Alpha contamination levels ranged from 9 pCi/g in Room 3208A to 1,290 pCi/g in Room 3232. Beta contamination levels ranged from 9 pCi/g in Room 3208A to 548 pCi/g in Room 3232. No nonradiological hazardous contaminants were detected in drain samples collected in this area.

Thirty drain samples were collected in the 3100 South area. Alpha contamination levels ranged from 22 pCi/g in Drain #4, Room 3216, to 6,490 pCi/g in the southeast end of the Bay area. Beta contamination levels ranged from 19 pCi/g in Room 3266 to 15,600 pCi/g in the southeast end of the Bay area. No nonradiological hazardous contaminants were detected in drain samples collected in this area.

Collection Pits

Surveys were performed of the collection pits in Building KA-3. As a result, the pits were cleaned and the identified sinks removed. The following is a summary of the contamination found in the collection pits of Building KA-3.

Sludge samples were collected from five well-type pits in the 3000 North area and from the main sump for the building. All six samples were found to be contaminated. Net alpha contamination levels ranged from 154 pCi/g in Room 3067A to 6,470 pCi/g in Room 3010. Net beta contamination levels ranged from 82 pCi/g in Room 3002 to 2,660 pCi/g in the well in Room 3010. No nonradiological hazardous contaminants were detected in drain samples collected in this area.

Thirteen sludge samples were collected from twelve well-type pits in the 3100 South area. Twelve of the thirteen sludge samples were found to be contaminated. Net alpha contamination levels ranged from 5 pCi/g to 56,600 pCi/g in Rooms 3119 and 3114 North, respectively. Net beta contamination levels ranged from 1 to 112,000 pCi/g, in Rooms 3119 and 3114 North, respectively. Mercury was also found in the sink trap of a hood in Room 3119.

Hoods/Ductwork/Convectors/Attached Equipment

Ventilation hoods and air conditioning/heating convector units were surveyed as part of the characterization efforts. Hoods and ventilation units that were radioactively contaminated were removed and disposed of as radioactive waste. Hoods in Rooms 3065, 3158, 3263B, 3263C, 3263E, and 3263F were not surveyed since they were inaccessible. The interior of inactive ventilation hoods and equipment ductwork was surveyed by direct and indirect monitoring methods, most often at disconnected hook-up junctions. Solid material samples were collected from ductwork interiors, when possible.

Six single hoods, three double hoods and associated ductwork, and ductwork on three equipment items in the 3200 North area were found to be contaminated. The maximum net alpha direct reading was 7,370 dpm/100 cm^2 on top of the hood in Room 3232. The maximum net beta direct reading was 69,800dpm/100 cm^2 inside the hood in Room 3293. All heating/air conditioning convector units were contaminated with net beta activity levels ranging from 1,370 dpm/100 cm^2 to 12,700 dpm/ 100 cm^2. Several pieces of large equipment such as dry boxes, hydraulic presses, metal cabinets, and miscellaneous items were identified either by direct measurements or by posted information as being contaminated.

Five hoods and 31 ductwork sections in the 3200 South area were detected to be contaminated. The maximum net alpha direct reading was 1,320 dpm/100 cm^2 in the ductwork in Room 3218. The maximum net beta direct reading was 49,500 dpm/100 cm^2 in the center vent of the hood in Room 3054. Maximum removable contamination levels were 329 dpm/100 cm^2 net alpha and 235 dpm/100 cm^2 net beta. These were detected in Rooms 3054 and 3112 North, respectively. Several pieces of large equipment such as dry boxes, hydraulic presses, metal cabinets, and miscellaneous items were identified either by direct measurements or by posted information as being contaminated.

Roof

Roof-top gravel samples were collected from 29 locations on the north roof. Three samples located on the northeast and southwest corners of the north center roof exceeded the background levels of 49 pCi/g alpha activity and 50 pCi/g beta activity. The net alpha activities of these samples were 47, 43, and 45 pCi/g, respectively. During remediation, all contaminated surfaces were cleaned by removing the contaminated material. The ductwork interior from four laboratory hoods was also determined to be contaminated. These four ductwork locations were on the roof over Room 3204, Room 3205, Room 3206, and Room 3293. Net alpha activity levels ranged from 94 dpm/100 cm^2 (Room 3204) to 756 dpm/100 cm^2 (Room 3206). Net beta activity levels ranged from 2,139 dpm/100 cm^2 (Rooms 3204 and 3205) to 19,219 dpm/100 cm^2 (Room 3206).

Direct beta measurements were taken inside and outside of seven risers, 60 hood/hood vents, and three chimneys on the south roof. Of these 140 measurements, only three exceeded the derived limit value (DLV). These three measurements were located inside the hood in Room 3010, inside the cap of the hood in Room 3178, and inside the cap of the hood in Room 3119. Net beta surface contamination levels ranged from 1,510 dpm/100 cm^2 to 9,200 dpm/100 cm^2. No alpha activity associated with these measurements was detectable above background levels. Smearable contamination associated with these measurements ranged from minimum detectable activity (MDA) to 9 dpm/100 cm^2 for net alpha activity and from MDA to 17 dpm/100 cm^2 for net beta activity.

Surfaces

The contaminated surfaces of Building KA-3 were all remediated in accordance with the release criteria established for the building. In conjunction with the final survey of Building KA-3, the exterior surfaces of the building were also gridded and verified to have contamination levels below MDA.

Ground Floor (3000 Area). By establishing a total of 594 floor grids, characterization of the 3000 area (ground floor) floors of Building KA-3 determined that 54 rooms were contaminated. The highest direct survey readings were 7,650 dpm/100 cm^2 net alpha activity and 166,000 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 654 dpm/100 cm^2 net alpha activity and 803 dpm/100 cm^2 net beta activity. A total of 594 m^2 of floor area was determined to be contaminated.

Characterization of the Building KA-3 3000 area walls below 2 m in height determined that a total of 75 wall grids in 28 rooms were contaminated. Highest direct survey readings were 1,900 dpm/100 cm^2 net alpha activity and 73,800 dpm/100 cm^2 net beta activity. Maximum removable levels of contamination were 269 dpm/100 cm^2 net alpha activity and 39 dpm/100 cm^2 net beta activity. A total of 75 m^2 of wall surface area was determined to be contaminated.

Characterization of the horizontal surfaces above 2 m determined that a total of 77 wall grids in 20 rooms were contaminated. Highest direct survey readings were 6,610 dpm/100 cm^2 net alpha activity and 19,200 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 139 dpm/100 cm^2 net alpha activity and 232 dpm/100 cm^2 net beta activity. A total of 77 m^2 of horizontal surface area above 2 m was determined to be contaminated.

First Floor (3100 Area) Floors. Characterization of the 3100 area of Building KA-3 determined that a total of 549 floor grids in 52 rooms were contaminated. Highest direct survey readings were 33,200 dpm/100 cm^2 net alpha activity and 191,000 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 1,300 dpm/100 cm^2 net alpha activity and 138 dpm/100 cm^2 net beta activity. A total of 594 m^2 of floor area was determined to be contaminated.

Characterization of the 3100 area walls below 2 m of Building KA-3 determined that a total of 161 wall grids in 28 rooms were contaminated. Highest direct survey readings were 13,500 dpm/100 cm^2 net alpha activity and 32,200 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 763 dpm/100 cm^2 net alpha activity and 534 dpm/100 cm^2 net beta activity. A total of 161 m^2 of wall surface area was determined to be contaminated.

Characterization of the horizontal surfaces above 2 m determined that a total of 92 wall grids in 19 rooms were contaminated. Highest direct survey readings were 46,500 dpm/100 cm^2 net alpha activity and 63,300 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 2,350 dpm/100 cm^2 net alpha activity and 277 dpm/100 cm^2 net beta activity. A total of 92 m^2 of horizontal surface area above 2 m was determined to be contaminated.

Second Floor (3200 Area) Floors. Characterization of the 3200 area of Building KA-3 determined that a total of 421 floor grids in 49 rooms were contaminated. Highest direct survey readings were 7,380 dpm/100 cm^2 net alpha activity and 73,800 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 90 dpm/100 cm^2 net alpha activity and 58 dpm/100 cm^2 net beta activity. A total of 421 m^2 of floor area was determined to be contaminated.

Characterization of the 3200 area walls below 2 m of Building KA-3 determined that a total of 57 wall grids in 18 rooms were contaminated. Highest direct survey readings were 18,600 dpm/100 cm^2 net alpha activity and 17,500 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 492 dpm/100 cm^2 net alpha activity and 78 dpm/100 cm^2 net beta activity. A total of 57 m^2 of wall surface area was determined to be contaminated.

Characterization of the horizontal surfaces above 2 m determined that a total of 39 wall grids in 20 rooms were contaminated. Highest direct survey readings were 1,840 dpm/100 cm^2 net alpha activity and 17,700 dpm/100 cm^2 net beta activity. Maximum removable contamination levels were 112 dpm/100 cm^2 net alpha activity and 15 dpm/100 cm^2 net beta activity. A total of 39 m^2 of horizontal surface area above 2 m was determined to be contaminated.

Soil

Forty-six samples were collected from 10 locations beneath the ground floor of Building KA-3. Holes were cut in the concrete floor of the ground floor level, and holes of varying depths were cored in the soil beneath the floor. Samples ranged in depth from the surface (directly under the floor) to 85 inches below the floor level. The samples were analyzed for gross alpha and gross beta activity. Two of the sample locations were approximately 30 feet from the drain lines, and the radioanalytical results were used to represent the soil background. Background samples were calculated to be 23 pCi/g alpha and 22 pCi/g beta activity.

The results of the gamma spectroscopy show that net alpha activity greater than background concentrations occurred in 22 of 45 samples, and net beta activity greater than background concentrations occurred in 19 of 45 samples. Uranium-235 concentrations ranged from MDA to 5 pCi/g. Activity levels in the vicinity of the bell fittings connecting the drain sections were generally higher than those along the length of the pipe. Gross alpha activities ranged from 11 pCi/g to 184 pCi/g at the bell connectors in the ground floor and Room 3002B (north), respectively. Gross beta activities ranged from 15 pCi/g to 83 pCi/g at the bell connectors in the ground floor and Room 3016, respectively. Analysis of the data indicated that radioactive contamination in the soil likely resulted from the release of radioactive materials from the drain lines, probably at the bell fittings.

Since contamination was found in the soil inside the footprint of Building KA-3, representative soil samples were taken on the exterior of the building. All results from these samples were below MDA.

A sample of soil from Room 3016 was analyzed for Toxic Compound Leaching Process (TCLP) Extractable Metals and showed concentrations of Ba at 0.32 mg/liter, Cd at 0.017 mg/liter, and Cr at 0.012 mg/liter; As, Pb, Hg, Se, and Ag were not detected. When the soil and drains were removed during the remediation process, however, nine of the 309 cubic yards of soil were determined to be contaminated with uranium and thorium. A considerable quantity of Hg (mercury) was found outside the drain connections in the surrounding soil. The mercury was remediated by aspiration and removal in-situ. The soil was verified clean.

3.1.3 Release Criteria

The radiological release criteria established for this building were approved by both the DOE and the NRC. These criteria are based upon the acceptable residual surface contamination levels for unrestricted release defined in DOE Order 5400.5, "Radiation Protection of the Public and the Environment," and NRC Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors." As discussed in Section 3.1.2, most of the rooms in Building KA-3 had measured contamination levels above these guideline release limits; therefore, a reasonable amount of decontamination effort was required before releasing the building for use without radiological restrictions.

3.1.4 Summary of Building KA-3 Decontamination Activities

The overall decommissioning activities for Building KA-3 were guided by general requirements documented in a Quality Assurance (QA) Plan, a Decommissioning Work Plan, and specific operating procedures. The contamination was not widespread and radiation levels were low. Thus, the chief concern was not the radiation level but rather the control of the spread of the contamination and the danger from inhalation of airborne particulates during the decontamination effort.

The overall sequence of D&D activities was carried out as follows:

(1) Engineering and Preparation.

(2) Removal of Laboratory Chemicals, Services, and Equipment.

(3) Decontamination of Surfaces, Services, and Equipment.

(4) Final Radiation Surveys.

(5) Independent Verification Survey.

(6) Restoration of the Facility.

(7) Radioactive Waste Management.

Engineering and Preparation

The Engineering and Preparation efforts for the D&D activities were conducted as follows:

(1) Training of D&D workers.

(2) Installation of a staging area for handling and interim packaging of contaminated waste for transfer to the central staging area in Building KA-2.

(3) Selection of D&D equipment.

(4) Installation of control barriers.

Training D&D Workers. Training included targeted training in the specific procedures to be employed and refresher training in radiological and occupational safety. Each worker assigned to perform a specific activity was fully trained and qualified to perform the assigned D&D activity.

Installation of the Staging Area. The function of the staging area was to control the spread of contamination from the D&D rooms, to provide facilities for personnel to change clothes when entering and leaving the D&D area, and to provide areas for local waste packaging operations. In Building KA-3, there were several staging areas within the building at any given time so that multiple crews of workers could perform work simultaneously.

The staging area isolated the D&D area from the rest of Building KA-3. Within the staging area, "clean" and "contaminated" change areas were established for use as personnel entered and left the work areas undergoing decontamination. Facilities were provided at this location for radiological surveys of personnel leaving the area. The staging area also included an initial packaging area so that waste could be properly packaged for transfer to the waste handling area in a separate building. The most feasible location for the staging area was determined to be in the main corridors along the access barriers of the building and at the access areas between the floors.

Selection of D&D Equipment. This activity identified the types of equipment that were specifically required for use in the remediation process. The list of D&D equipment used included vacuum blasters, scabblers, containment enclosures, strippable paints and solvents, cherry pickers, manlifts, concrete cutters, core drills, rock drills, grout pumps, backhoes, on-site radiological support, cutting torches, and hand tools. Support equipment included air monitors, radiological survey meters, waste containers, protective clothing, air purifying respirators, bubble suits, radiation scanners, and personal dosimeters.

Installation of Control Barrier

Access control barriers were installed to isolate the D&D areas. Physical barriers such as temporary walls, plywood barriers, doors, locks, and alarms were used. Prominent signs designated locations as a D&D operation areas. After access control barriers were installed, the contamination control barriers and staging areas were established so that they fell within the confines of the access control barriers.

During installation of contamination control barriers, air in the D&D area was continuously monitored. The air was not recirculated in order to eliminate the potential for introducing airborne contamination from other parts of the building into the clean areas. Instead, the air was exhausted on the first floor by two large HEPA units. The contamination control barriers were either erected at normal room openings or were erected at the main corridors, dividing the floors into six sections.

Removal of Chemicals, Services, and Equipment

The sequence for removing laboratory chemicals, services, and equipment for D&D activities was as follows:

(1) removal of laboratory chemicals
(2) removal of services
(3) removal of equipment.

Removal of Laboratory Chemicals. The removal of laboratory chemicals from the building first played a key role in the overall D&D effort. Since the building had many laboratories and the research was quite varied, there were many different kinds of chemicals present. By utilizing the remaining operations and waste management personnel trained in hazardous waste, the dedicated D&D personnel did not have to be trained for or be exposed to the large variety of chemicals. Periodically, monitoring for chemicals was conducted in the event that there could be significant residual chemicals present. However, problems did not arise in Building KA-3. The major chemicals encountered in the D&D process were lead in the paint at times and mercury in the drain lines.

Removal of Services. During the D&D process, the removal of laboratory services such as water, gas, and air was necessary in order to access the wall, ceiling, and floor surfaces. Some services were inaccessible without first removing equipment. Electrical power to each room and area being decontaminated was left connected as long as possible to facilitate the use of powered D&D equipment. Likewise, the common services in the building were left intact to accommodate heat, fire service, and electrical distribution systems. As the D&D activities progressed and these services were affected, the services for the rooms and areas were either disconnected or rerouted to accommodate the D&D process.

Removal of Equipment. The process of removing equipment was slightly more involved than initially anticipated. During the D&D process, the removal of equipment was necessary in order to access the wall, ceiling, and floor surfaces. However, during the removal, determinations had to be made as to the equipment's disposition. If the unit was radioactively contaminated, it was determined to be Low Specific Activity (LSA) Waste, Mixed Waste, or TRU Waste. If the unit was not radioactively contaminated, it was determined to be reusable, sellable, hazardous waste, or trashed. Since these determinations had a bearing on how the unit would be removed, systematic planning for the D&D and removal of equipment was made.

Decontamination of Surfaces, Services, and Equipment

The sequence for decontamination of surfaces, services, and equipment was carried out as follows:

(1) survey of the exposed surfaces
(2) removal of the attached equipment and services
(3) decontamination of the stairways and common areas

(4) decontamination of the floor drains
(5) decontamination of the floors, ceilings, and walls.

Survey of the Exposed Surfaces. The first activity implemented in this sequence was surveying the exposed surfaces so that the extent of decontamination efforts could be assessed. In Building KA-3, it was determined that the walls up to a height of 2 m needed to be decontaminated and that the ceiling was virtually clean. Minor contamination was detected on the horizontal beams of the ceiling and on services along the ceiling but these surfaces were easily cleaned. There was, however, one laboratory that had served as a beryllium research area that had to be completely remediated.

Removal of the Attached Equipment and Services. The removal of the attached equipment and services was an important step since most of the equipment was contaminated and the walls and floors behind the equipment were inaccessible. The equipment, which included hoods, sinks, benches, etc., was monitored and removed to the Waste Management Area for packaging. The major service concerns involved the ductwork that ran between the floors of the building through openings called penetrations. After surveying, the contaminated ductwork was capped on the bottom floor, removed through the penetration, and the penetration decontaminated. Although some of the building ventilation was contaminated on the outside within the floors of the building, the building ventilation system was not required to be removed. The common services in the building were remained connected to accommodate heat, fire service, and electrical distribution systems.

Decontamination of the Stairways and Common Areas. The surfaces of stairways and common areas were decontaminated by scrubbing, washing, and/or grit blasting with a HEPA filtered vacuum. After all contamination was removed, barriers were installed to limit access to the clean areas and provide contamination control between the floors of the building.

Decontamination of the Floor Drains. Removing floor drains was a slightly more involved process than initially anticipated. Mercury was discovered in many of the drains; therefore, the drains had to be carefully disassembled joint by joint and wrapped for processing. They were then transported to a controlled area where they were honed, packaged, and disposed of properly. Furthermore, drain lines beneath the ground floor had leaked, causing radioactive and mercury contamination in the soil. This soil was removed for disposal, which first required removal of large sections of the basement floor. Because the basement floor also served as foundation support for the building, the foundation soil required strengthening in order to support the building. This strengthening was achieved via in-situ grouting of the soil.

Decontamination of the Floors, Ceilings, and Walls. The results of characterization surveys showed that the concrete floors and lower walls were contaminated. A dry process mechanical grit blaster with a HEPA vacuum was used to remove surface layers from the concrete floors and walls up to 2 m high. Several passes were required in some areas after which the intermediate radiation surveys showed that the residual contamination had been removed and that the floors and walls were at or below background levels.

In some instances, the contamination had seeped deeply into the concrete through cracks. In these cases, the contamination was removed by chipping out the contaminated concrete using a pneumatically operated chisel or maul point.

Final Radiation Surveys

The effectiveness of the decontamination operations was determined by radiation surveys. "Interim" surveys were used during decontamination activates to determine whether further actions were required. The term "interim" was used to distinguish them from the pre-D&D surveys (characterization) and from the post-D&D surveys (final status surveys) that provided the data that indicated decontamination was complete. The final surveys were conducted in concurrence with plans and procedures and were the final step taken to assure a satisfactory level of remediation was performed on Building KA-3. The building was then sealed and controlled pending the independent verification survey.

Independent Verification Survey

After all contaminated areas were cleaned and monitored, the Independent Verification Contractor (IVC) conducted a survey to verify the adequate removal of residual contamination from Building KA-3. Results of this survey indicated that contamination levels on floors, walls, and ceilings were well below acceptable limits for release of the building for use without radiological restrictions.

Restoration of Building KA-3

Restoration was initiated after all contamination had been removed and the independent verification survey found no remaining areas where additional decontamination would be required based on the ALARA guidelines. This restoration sequence is expected to be typical of the refurbishment efforts of any older facility and no unique sequencing problems were anticipated.

Radioactive Waste Management

Throughout the decontamination operation, beginning with the removal of the laboratory chemicals and ending with the removal of the last traces of contamination, low level waste was generated. All contaminated materials were bagged in plastic and placed in transfer containers. The containers were transported to another building for characterization and final packaging of the waste for shipment to appropriate disposal sites.

These operations were performed in accordance with the applicable waste management procedures, which fulfill the requirements of the low-level waste certification plan and the waste management QA plan.

Waste Management Guidelines. Most of the radioactive waste generated during D&D of Building KA-3 was sent to the Hanford site for disposal or storage. Wastes were segregated by radioactive material content, physical form and chemical content:

- Radioactive Material Content - low-level wastes (LLW).
- Physical Form - Wastes were further segregated by physical state as follows: (1) solid materials, (2) liquids, (3) absorbed liquids, (4) organic liquids, (5) biological waste (6) gas (7) high-efficiency particulate filters, (8) resins, (9) sludges, and (10) lead waste from lead shielding.
- Chemical Content - Wastes were segregated by DOT hazard class (e.g., oxidizer, flammable liquid, flammable solid, acid, caustic, poison) and tracked by the following (1) U.S. Nuclear Regulatory Commission's (NRC) shallow-land burial classes (i.e., A, B, C, and C+) and (2) specific waste categories as they became defined.

These requirements were imposed on every activity in the waste management program. Some metals and compactable wastes were shipped to Scientific Ecology Group, Inc. (SEG) for processing. If the metals qualified, SEG melted them for overall size reduction. Likewise, the compactable wastes were either incinerated or supercompacted depending on waste cost factors. Bulk waste and some mixed waste was disposed of at the Envirocare disposal facility in Utah.

Waste Transfer and Interim Storage. The D&D Work Plan for Building KA-3 envisioned one central waste staging area to handle all waste from Building KA-3. The location was in a separate building where a suitable enclosed shipping area already existed.

In terms of waste management, the central staging area was where all the required certification measurements for transport were taken. It is also the place where waste from Building KA-3 was stored in the interim until sufficient waste had been accumulated to make up a waste shipment. Because of the segregation requirements imposed for waste acceptance at the disposal facility, any sorting and repackaging was performed at this staging area.

Waste Characterization. Upon arrival in the staging area, the transfer containers were opened and the contained waste was monitored in detail. The material was inventoried and surface readings were recorded. This became part of the shipping documentation characterizing the package. Gamma-ray isotopic analysis of samples from the waste showed that the principal isotopes were ^{235}U and ^{238}U with some thorium. From this data and the total volume of waste, the total activity of the packaged waste from Building KA-3 was determined.

Waste Volumes and Volume Reduction. The waste received from Building KA-3 was reduced in volume mainly by decontaminating the drains and manually crushing the waste, particularly the suspect plastics. Most of the waste could not be decontaminated and was packaged as LLW. The other miscellaneous compactible wastes such as paper suits, gloves, and other items were compacted. A total estimated waste volume from D&D activities is not available because LLW generated was included with LLW generated from the D&D of other buildings on the Battelle-owned site.

However, more than 8,000 ft^3 of contaminated sub-floor soil was excavated to remove more than 3,000 linear feet of contaminated drain lines.

Waste Package Certification. In order to meet the package requirements for acceptance of the D&D waste at the disposal site at Hanford, the D&D waste from KA-3 had to be classified and the package certified for shipment. The waste package data included the principal radioactive elements in the package, listed by isotope; the activity level, in curies, of each isotope; the physical form of the material; and the specific activity of the materials in the shipment in microcuries/gram for solids. The waste package was certified acceptable to meet the requirements of the disposal site in accordance with the proposed LLW certification plan for safe interim storage of the waste at Hanford.

3.2 Hoffmann-la Roche, Inc. Medi-physics Cyclotron Facility[3,4]

This facility, located in Nutley, New Jersey, contained a 22-MeV cyclotron used in the manufacture of radiopharmaceuticals from about 1968 through 1984. In 1984, the cyclotron was shut down and decommissioned. It was sold in 1985. A vendor was contracted to remove radioactive concrete from the inner surface of the concrete vault used to house the cyclotron and provide a radiation shield. The intent was to remove sufficient concrete to allow the remainder of the vault to be disposed of as nonradioactive industrial waste. For a variety of reasons, final D&D of the facility was not initiated until March 1991; the radioactive materials license was terminated in June 1991.

3.2.1 Description of the Facility

The cyclotron vault was located within a warehouse which, in turn, was located within a building occupied by other companies. Attached to the exterior of the concrete vault were six rooms made of concrete block walls. After removal of the cyclotron, the vault was used as a storeroom that had an accumulation of old furniture, lumber, production supplies, wood and metal cabinets and shelves, small electrical parts, empty radioactive waste containers, and concrete-lined steel drums.

A predecommissioning inspection of the warehouse revealed a facility that apparently had been vacated in haste. Discovered during this inspection were:

- office furniture in an extreme state of ill-repair and disarray
- laboratories full of glassware, chemicals, electronic equipment, refrigerators, and lead shielding of various sorts
- a car in the warehouse section with a flat tire, broken window, and thick coating of crud
- a wide variety of hazardous waste including partially used bottles of propanol, acetone (and other solvents), brake fluid, oil, turpentine, acids, used crankcase oil, transmission fluid, etc.
- old unwanted periodicals, journals, books, and stationery
- unsecured gas cylinders of various sizes and contents (HCL, nonradioactive xenon, acetylene, nitrogen, etc.)
- asbestos floor tiles and laboratory benches
- fluorescent light fixtures containing PCBs
- a large steel safe used for storage of computer records
- wood and metal cabinets and shelves
- concrete-lined steel drums
- telephones connected through a service board somehow tied also to the facility next door
- many storage containers and waste cans brightly

labeled with radioactive material warning labels.

3.2.2 Radiological History

A radiation survey was performed in the cyclotron vault in October 1986. In addition, concrete core samples taken in July 1985 were sectioned and scanned to obtain the radioisotopic composition as a function of depth in the concrete. The results of these analyses were as follows:

- exposure levels in the vault ranged from 130 to 425 μR/hr
- background levels outside the vault were about 10 μR/hr
- the hottest areas in the vault were the floor and ceiling near the center of the room
- the radioisotopes measured in the concrete were ^{60}Co, ^{152}Eu, ^{154}Eu, ^{134}Cs, and ^{40}K
- ^{60}Co and ^{152}Eu made up about 92% of the total activity in the concrete
- ^{60}Co activity was about 10% higher than that of ^{152}Eu in the concrete
- the combined activity of ^{60}Co and ^{152}Eu decreased to the background ^{40}K activity in the concrete at a depth of 13 inches
- the background ^{40}K activity was fairly constant at 12.4 pCi/g average
- 90% of the induced activity in the concrete was in the first 12 inches
- the specific activity in the rebar in the concrete was about three to four times that of the concrete in the same area.

3.2.3 Summary of D&D Activities

The first step in decommissioning the cyclotron facility was to remove all of the residual debris described previously. All of the gas cylinders were retrieved by an industrial gas firm. A contractor was hired to classify, segregate, package, and ship all hazardous material for proper disposal. Clean laboratory glassware was packaged and donated to a high school for reuse. Other debris in the warehouse and vault were retrieved, surveyed for radioactivity, and free-released for disposal. Identified radioactive waste was packaged and disposed at the Barnwell LLW disposal site.

Based on the radiological survey of the facility described previously, the following D&D plan was developed:

(1) Perform on-site baseline radiological surveys.

(2) Remove about 12 inches of radioactive concrete from the inner surface of the walls and floor, package the rubble in steel boxes, and ship to the Barnwell LLW site.

(3) Radiologically survey the vault at a 1 m distance and achieve a 56 μR/hr level; obtain regulatory approval to free release the remainder of the vault.

(4) Demolish the remainder of the vault from the outside.

(5) Radiologically survey each batch of concrete as a QA step before it is shipped to an industrial landfill.

(6) Perform final radiological surveys of the facility after the vault has been removed.

(7) Pour a new concrete floor in the hole created by removing the vault floor.

(8) Terminate the radioactive material license.

The 12 inches of radioactively contaminated concrete were removed from the floor and walls using a remote-controlled hydraulic hammer. Rebar in the floor was cut using torches. The vault was then painted into a grid pattern with 1 m squares, and a complete radiation level survey was completed using three hand-held instruments. All three instruments were within 10% and reading an average of 50 μR/hr. The concrete was subsequently free-released.

Demolition of the concrete vault commenced following free-release. Radiation measurements above the hole in the concrete floor indicated a level of about 20

μR/hr, which was about four times above background. However, the shielding effect of pouring an 8-inch-thick concrete floor back into the hole reduced the radiation level by a factor of eight, bringing the final radiation level below background.

The last radiological issue for this facility was the radioactively contaminated lead containers. Since these containers were classified as a mixed waste, disposal was not an alternative for disposition; therefore, the containers were transferred to a properly licensed facility for use as radiation shielding. About 2,000 pounds of lead were dispositioned in this manner.

A thorough walk-over radiological survey with two hand-held radiation detectors was performed after completion of all D&D activities. The result was background radiation levels of 5 μR/hr, with no location being more than 1 μR/hr above this level. The state regulatory agency subsequently terminated the license for this facility in June 1991.

3.2.4 LLW Generation

Ten trailer truckloads containing 400,000 pounds (approximately 3,400 ft^3) of radioactive concrete were sent to the Barnwell LLW site for disposal. In addition, 15,000 ft^3 of concrete was shipped to an industrial landfill for disposal. This "clean" concrete was surveyed in 90 ft^3 batches as part of the QA program. Only one batch was rejected for repackaging. This batch contained a steel plate used to hold the vault door rollers, which contained ^{60}Co, and was shielded during the free release survey. The 15,000 ft^3 of concrete was calculated to contain a total radioactivity of 15 mCi.

3.2.5 Cost of D&D

The total effort to D&D the cyclotron facility and restore it for reuse required approximately 5,100 person-hours and $1.2 million. Of this total, approximately $390,000 was for transportation and disposal of radioactive waste.

3.3 Interstate Nuclear Services Laundry Facility[1]

This facility, located in Charleston, South Carolina, is a radiological laundry used to decontaminate clothing and other articles that have been radiologically contaminated at nuclear facilities. The facility was shut down in 1993 and decontaminated and decommissioned during June to September of that year. This facility was slated for decommissioning because its primary client was ceasing operations and because upgrading of the water processing system was deemed uneconomical.

3.3.1 Description of the Facility

A layout of this facility is provided in Figure 3.4. Key equipment in the facility includes large commercial washers and dryers to clean the clothing. Associated with these systems are a water treatment system, filtration systems, settling tanks, pumps, screens, etc., to ensure that radioactivity removed from the clothing is contained and not released to the environment.

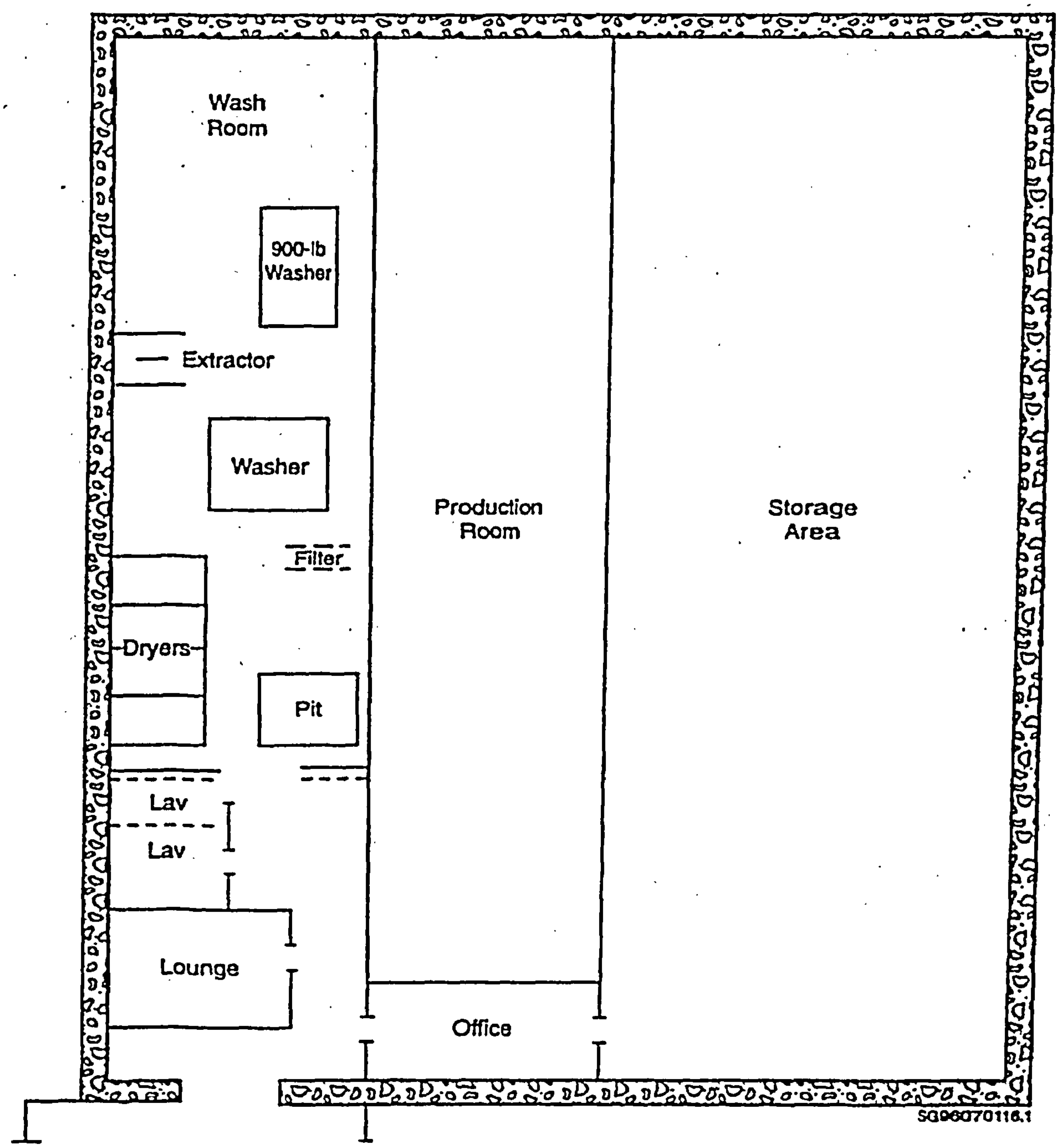
After cleaning, the clothing and associated items are monitored on automated special equipment with instrumentation designed to alarm if the levels of acceptable fixed contamination as established by the client are not met. After confirmation that the residual radioactivity criteria have been met, the clothing is sorted, folded, packaged, and shipped back to the client according to their specifications. These activities are conducted in the Production Room.

3.3.2 Summary of D&D Activities

Because of the nature of activities performed in this facility, low levels of radioactive contamination were spread throughout the facility, including the machinery and equipment, tanks, pits, filter housings, exterior washer parts, pipes, overhead ceilings, walls, and so on.

[1] Letter from Michael J. Bovino to Dennis R. Haffner. November 10, 1994 Interstate Nuclear Services, Springfield, Massachusetts

Figure 3.4 Layout of the radiological laundry facility



While doses from this residual contamination were not high, the entire facility and associated equipment required monitoring during decommissioning. The following is a summary of the basic events that transpired during the decommissioning process:

- mobilization of technicians, equipment, etc. at the facility beginning in early June 1993
- performance of presurveys and preparation of set-up areas, instrumentation, and work schedules
- dismantlement of equipment, tearing down walls, cutting lines, turning off gas, electricity, sewage, etc.
- packaging radioactive materials and removing ceilings, lights, fans, air conditioning, and duct work
- removing vinyl flooring, insulation, office furniture, and fixtures
- cleaning pits, flushing lines, and inspecting surrounding sewage systems
- tracing old lines and removing as necessary
- having regulatory inspectors perform their own inspections and surveys for release of the facility.

A major activity during the decommissioning process was to section the dryers and washers into pieces to be decontaminated or disposed as radioactive waste. This sectioning was performed using a plasma arc torch because of its quick cutting rate that allowed handling of the sectioned material essentially immediately after the cut had been made. Smoke generated by the plasma arc torch was treated using a high efficiency particulate air (HEPA) filter system.

A high-pressure washer was used to spray down the entire area after the equipment had been removed. This washer system delivered water at a pressure of about 2,000 psi mixed with detergent mix. It consisted of a high-pressure pumping system mounted on wheels and a length of high-pressure hose with an extended wand and adjustable tip section.

When washing with the high-pressure water system was complete and the areas dry, the floors, walls, etc. were monitored. If determined to be clean of smearable contamination, they were then monitored for fixed contamination. Areas determined to be contaminated with fixed contamination were scabbled. Four different types of scabblers were used: a needle gun, a hand scabbler, a large floor scabbler, and jackhammers. The type of scabbler used for any particular situation depended on the extent and difficulty of removing the fixed contamination. A HEPA filtration system was used to remove airborne radioactivity generated from these operations and sometimes temporary tents were set up around the area being scabbled to contain the radioactivity.

3.3.3 Cost of D&D

The total cost to D&D this facility was approximately $220,000, with approximately $60,000 attributed to disposal of low-level radioactive waste. This cost does not include such items as restoring the building for reuse, compensation for terminating employees, taxes, lease, etc. Since the facility was decommissioned in-house, this cost also does not include health physics or engineering support staff, nor does it include purchase of most of the equipment used in the D&D process.

3.4 References

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3. Drzyzga, M. July 1991. *Decommissioning and Disposal Project for Cyclotron Vault Structure*. Hoffmann-La Roche, Inc. Nutley, New Jersey.

4. Moore, J. D., M. E. Remley, and V. A. Swanson. February 1988. *Supplemental Radiological Survey, Medi-Physics Cyclotron Cell*. Rockwell International Corporation, Canoga Park, California.

4 Review of Emerging Decontamination Technologies

This chapter discusses three new processes: a CO_2 pellet decontamination technology used for non-destructive surface decontamination, a molten metal bath technology for dissolving waste compounds into their constituent elements, and a supersonic gas-liquid surface cleaning technology. Although none of these technologies contributed to the development of the cost methodologies used in this study, a discussion of them is in order because they are representative of important new developments that may soon join the collection of standard decommissioning techniques that will lead to significant decommissioning cost savings in the future.

In general, the three technologies cited are relatively new with limited commercial deployment. Their cost-effective use depends heavily on the ultimate destiny of the contaminated components. If recycle of the components (or the base material) is likely, the added cost of these new technologies may be justified when salvage value is considered. If the component is unlikely to be reused, decontamination efforts should be limited to that necessary for disposal as LLW.

4.1 CO_2 Pellet Decontamination Technology

The carbon dioxide (CO_2) pellet decontamination process is a unique dry process that uses dry ice as the exclusive decontamination medium, and does not use any hazardous chemicals, water, solid grit or aggregate materials. This process generates no secondary wastes and is a non-destructive surface cleaner. A forerunner in the development of this promising new decontamination process is Non-Destructive Cleaning, Inc. (NDC) based in Walpole, Massachusetts.

The NDC patented process/facility uses small, solid carbon dioxide particles propelled by dry compressed air. The CO_2 particles shatter upon impact with the surface of the material to be cleaned and flash into dry CO_2 gas. This flashing into a gas results in a rapid volume expansion of approximately ten to one. Cleaning is accomplished by the rapidly expanding CO_2 gas flashing into the surface of the material to be cleaned (which is porous at the microscopic level) and flushing the foreign materials out. The microscopic particles of foreign material are captured on high efficiency particulate air (HEPA) filters. Larger-sized fragments are lifted off the surface by the flashing CO_2 gas and are removed using HEPA-filtered vacuum cleaners. The only waste product from the NDC facility is the dry HEPA filters that are easily disposed of as dry active waste. CO_2 levels have been demonstrated to remain below OSHA limits, and a CO_2 monitor verifies the levels during operation. Examples of items successfully decontaminated include: hand tools, power tools, pumps, tanks, glass, pipes, computer components and circuitry, respirators, manipulators, and lead shielding.

The NDC mobile CO_2 decontamination unit is a stand-alone, transportable, steel enclosure. The unit has a single, direct 480-volt power connection. No special mountings are required, and the unit can be placed on any firm flat surface, such as a paved lot or crushed stone. The unit is designed for cleaning items ranging in size from small hand tools to items up to 20 feet long, with no weight limit.

The CO_2 decontamination unit is designed with four separate rooms: a machinery and electrical room, a large decontamination room, a decontamination cell room, and a count room where cleaned items are surveyed after cleaning. All electrical interconnections are managed by a central power cable that is connected to a power control and distribution panel located within the mobile unit. The unit has been designed with a complete HVAC system, allowing operation in any environment.

The CO_2 decontamination room is completely lined with stainless steel, and includes a large entry door and an internal hoist that can handle up to two tons. The floor loading capacity is unlimited. The decon room ventilation system includes two pre-filters and a HEPA filter system. The decontamination room is pre-piped for the use of supplied breathing air for worker safety. A special rolling lift table equipped with an air-driven vise to hold items for cleaning has also been designed for use in the unit.

4.2 Molten Metal Technology

An attractive feature of the new molten metal technology process, developed by Molten Metal Technology, Inc., is the ability to process both hazardous and radioactive waste materials (commonly referred to as mixed wastes) simultaneously. The new process is also referred as the Quantum-CEP™ technology.

Quantum-CEP™ is an adaptation of the CEP (Catalytic Extraction Process) technology. Quantum-CEP allows both destruction of hazardous components and controlled partitioning of radionuclides. This leads to decontamination and recycling of a large portion of the waste components to commercial products as well as volume reduction and concentration of radionuclides for final disposal.

A Quantum-CEP demonstration system has recently begun processing radioactively contaminated ion exchange resins, depleted uranium hexafluoride (UF_6) from the U.S. Enrichment Corporation (USEC), and mixed hazardous and radioactive waste from the Department of Energy and commercial customers.

The new technique uses a molten metal bath to dissolve waste compounds into their constituent elements. More precisely, the catalytic and solvent properties of molten metal dissolve the wastes' molecular bonds, which allows the company to separate reusable chemicals for recycling.

The process begins in a sealed tank that contains a molten metal bath, usually comprised of iron that is heated to around 1650°C. The composition of the bath may be altered, however, depending on what metal products the generator hopes to recover.

Once the bath is ready, wastes are injected into the tank by way of special pipes. Bits of wastes—powders, for example—are injected into the bottom of the tank though small pipes called "tuyeres"; bigger chunks of solid waste are deposited on top of the metal bath by way of larger tubes called "lances."

Upon entering the bath, the molecular bonds of the contaminants begin to break down as a result of specific separation reagents added to the molten metal bath. The waste then begins to separate into three distinct layers: gas, which rises to the top of the tank; metals, which remain in the metal bath; and ceramic, which forms on top of the metal layer. Proponents of the technology say that melting waste in solution is preferable to applying flame directly to it as a means of recovering the elements, primarily because the chemical reaction is more controllable.

The process also separates the radionuclides from non-radioactive elements, and the radioactive components of the waste become trapped either in the ceramic or metal layers. The process allows for the recovery of the non-radioactive elements for reuse or recycle.

Processing the waste using the technology ranges from $150 per ton for hazardous waste to upwards of $2,000 per ton for LLW or mixed waste.

4.3 Supersonic Gas-Liquid Cleaning Technology

The supersonic gas-liquid cleaning technology is a relatively new cleaning technology, developed by the U.S. National Aeronautics and Space Administration (NASA) primarily as a replacement for solvent flush methods using Freon 113 (CFC 113). Applications for radioactive decontamination have not yet been developed but show promise because of the significantly reduced liquid volumes used in the cleaning operation.

The system works by mixing air and water from separate pressurized tanks and ejecting this mixture at supersonic speeds from a series of nozzles at the end of a hand-held wand. At these speeds, the water droplets have the kinetic energy to forcibly remove the contaminant material.

The system consists of a supersonic converging-diverging nozzle, a liquid orifice, a regulated high-pressure gas source, a high-pressure liquid tank, and miscellaneous hoses, fittings, valves, and gauges. Liquid is injected into the gas flow stream just upstream of the converging-diverging section of the nozzle. The liquid-gas mixture then enters the converging-diverging nozzle where it is accelerated to supersonic speeds. The supersonic gas-liquid stream exits the nozzle where it is directed onto the component to be decontaminated. The velocity imparted to the liquid by the gas flow gives the liquid sufficient momentum at impact to remove contaminants from the surface while simultaneously dissolving or emulsifying the contaminants into the liquid. The flow parameters for the gas-liquid nozzle can be set so that virtually any gas and liquid may be used for the desired flow and mixing ratio. In addition, the size and number of nozzles are adjustable, making it possible to create various sizes of nozzles configurations.

One of the many advantages of the supersonic gas-liquid cleaning system over other pressurized cleaning methods is that it does not abrade the surface of the hardware being cleaned. It requires much lower levels of pressure—320 psig for water and 300 psig for gas (air or nitrogen). The relatively low volume of water required, approximately 30 milliliters per minute, means much less secondary contaminated waste. These system design parameters result in a cleaning rate of one square foot in three minutes.

Separate patent license agreements have been developed between NASA and two independent companies for commercial applications. The companies are Precision Fabricating and Cleaning Co. of Cocoa, Florida, and Va-tran Systems, Inc., of Chula Vista, California. The agreement is a means for NASA to effectively transfer technology initially developed for the space program to companies that may derive innovative commercial uses from it.

5 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, duct work, filters, and building surfaces such as floors, wall 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. Since the first alternative is considered to be too costly and time-consuming, only the second alternative is analyzed in this study.

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 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]

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 in estimating 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

	Laboratory					
Facility component	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User
Fume hood	x[a]	x	x	x	x	x
Glove box	x	x	x		x	x
Small hot cell				x		
Laboratory workbench	x	x	x	x	x	x
Ventilation ductwork	x	x	x	x	x	x
Cabinet	x	x	x		x	
Refrigerators/freezer	x	x	x			x
Filters	x	x	x	x	x	x
Sinks and drains		x	x	x		x
Building surfaces	x	x	x	x	x	x

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

5.1 Technical Approach

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

This study analyzes two decommissioning options:

(1) Disassembly and disposal of contaminated facility components using sectioning, compaction, and supercompaction.

(2) Disassembly and disposal of contaminated facility components using sectioning, compaction, and a combination of compaction and incineration

Both options require that the components be cut up, packaged in 208-liter drums and compacted on-site before being sent to a facility for supercompaction and/or incineration.

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/incinerator 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. Waste is transported 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. All costs are expressed in January 1998 dollars.

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 person-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 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 contaminate the facility. Craftsmen such as electricians, pipefitters, and sheet metal workers are assumed to be added to a work crew as the situation requires. 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-liter steel drums or eighty 208-liter drums of supercompacted waste. 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 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, 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 for the supercompaction and supercompaction/incineration options. Total costs include the costs of manpower, equipment and supplies, and waste management (e.g., the packaging, transportation, and disposal of radioactive waste).

Detailed cost estimates for decommissioning facility components are presented in Appendix C. Manpower estimates for all components in all the reference laboratories are shown in Tables D.1.a through D.6.b of Appendix D. Appendix A summarizes the key bases and assumptions used in estimating the requirements and costs of decommissioning.

Occupational radiation doses are estimated by multiplying the dose rates appropriate to each contaminant (Reference 1) by the person-days required to decommission the component. It is assumed that components 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 component 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 component or to provide for interim storage of the contaminated hood, since facilities for the permanent disposal of transuranic wastes are not yet available.

The mild surface decontamination of the small hot cells in the ^{137}Cs lab and the lead vault in the user facility (Appendix D) will result in radioactive mixed waste. This 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 LLW 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 packaging and disposal option 1) with supercompaction only and 2) with both supercompaction and incineration are shown in Table 5.2. A typical 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 consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON the fume hoods are discussed in Appendix D. The average time to DECON a fume hood is 1.5 days. The average manpower requirement is 5.3 person-days. Costs average $8,000 for supercompaction and $8,300 for supercompaction with incineration.

Occupational radiation doses range from 8×10^{-6} person-rem to 1×10^{-1} person-rem, depending on the type of contamination.

Table 5.2 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a fume hood

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	1.5	1.4	1.4	1.6	1.5	1.5
Manpower (pers-days)	5.3	5.3	5.2	5.6	5.4	5.3
Radiation dose (person-rem)	8×10^{-3}	8×10^{-6}	3×10^{-5}	1×10^{-1}	5×10^{-2}	8×10^{-3}
Costs ($ 000)[a]	7.5 7.9	8.0 8.3	7.5 7.7	9.1 9.4	8.0 8.4	7.6 7.9

(a) First row is cost for supercompaction option. Second row is cost for supercompaction with incineration

5.2.2 Glove Boxes

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a glove box by the two options are shown in Table 5.3. A typical glove box 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 consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON the glove boxes are discussed in Appendix D. The average time to DECON a glove box is 0.6 days. The average manpower requirement is 2.2 person-days. Costs average $4,200 for supercompaction and $4,400 for supercompaction with incineration. Occupational radiation doses range from 2×10^{-7} person-rem to 2 person-rem, depending on the type of contamination.

5.2.3 Small Hot Cell

The only reference laboratory that contains hot cells is the laboratory for the manufacture of ^{137}Cs sealed sources described in Section 7.1.4 of NUREG/CR-1754.[1] It is estimated that 1.9 days and 7.7 person-days will be required to DECON one of these hot cells. The occupational radiation dose is estimated to be about 2 person-rem. For the supercompaction option, the cost is estimated to be $26,500; for the supercompaction with incineration option the cost is estimated at $26,800. A work crew consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON a hot cell are discussed in Appendix D.

5.2.4 Laboratory Workbenches

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a workbench by the two options are shown in Table 5.4. Workbenches decommissioned in this study varied from facility to facility (Appendix C), but a "typical" bench measured 0.9 m high by 0.75 m wide by 4.6 m long. A work crew consisting of a foreman and two technicians is assumed to perform the decommissioning work. Postulated procedures used to DECON the workbenches are discussed in Appendix D. The average time to DECON a bench is 1.7 days. The average manpower requirement is 6.1 person-days. Costs averaged $8,800 for supercompaction and $10,200 for supercompaction with incineration. Occupational radiation doses range from 2×10^{-7} person-rem to 4×10^{-3} person-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.

Table 5.3 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a glove box

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.4	0.4	0.4	–	1.3	0.5
Manpower (pers-days)	1.7	1.6	1.6	–	4.4	1.9
Radiation dose (person-rem)	7×10^{-4}	2×10^{-7}	4×10^{-3}	–	2×10^{0}	7×10^{-4}
Costs ($ 000)[a]	3.3 3.5	3.5 3.6	4.0 4.0	– –	6.7 7.0	3.5 3.7

(a) First row is cost for supercompaction option Second row is cost for supercompaction with incineration.

Table 5.4 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a workbench

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.6	1.8	2.0	1.9	2.4	1.7
Manpower (pers-days)	2.2	6.1	6.7	6.7	8.7	6.0
Radiation dose (person-rem)	2×10^{-7}	6×10^{-7}	4×10^{-5}	3×10^{-5}	4×10^{-3}	6×10^{-7}
Costs ($ 000)[a]	2.6 2.7	9.9 12.4	8.7 9.0	11.8 14.4	10.6 10.8	9.3 11.9

(a) First row is cost for supercompaction option Second row is cost for supercompaction with incineration.

5.2.5 Ventilation Ductwork

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning ductwork by the two options are shown in Table 5.5. 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 sheet metal ductwork. A work crew consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON the ductwork are discussed in Appendix D.

The average time to DECON ductwork is 3.6 days. The average manpower requirement is 13 person-days. Costs averaged $14,900 for supercompaction and $15,300 for supercompaction with incineration. Occupational radiation doses ranged from 2×10^{-6} person-rem to 1×10^{-2} person-rem, depending on the type of contamination. 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.

Table 5.5 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of ventilation ducts

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	3.5	3.3	3.6	3.7	3.6	3.8
Manpower (pers-days)	12.2	11.7	12.7	13.1	12.7	13.2
Radiation dose (person-rem)	2×10^{-6}	2×10^{-5}	6×10^{-5}	3×10^{-3}	1×10^{-2}	2×10^{-6}
Costs ($ 000)[a]	13.1 13.5	13.6 14.0	15.9 16.3	17.2 17.6	15.1 15.5	14.2 14.6

(a) First row is cost for supercompaction option Second row is cost for supercompaction with incineration.

5.2.6 Cabinets

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a storage cabinet by the two options are shown in Table 5.6. A work crew consisting of a foreman and two technicians is assumed to perform the work Postulated procedures used to DECON the cabinets are discussed in Appendix D. The average time to DECON a cabinet is 0.4 days. The average manpower requirement is 1.6 person days. Costs average $2,400 for supercompaction and $2,800 for supercompaction with incineration Occupational radiation doses ranged from 7×10^{-7} person-rem to 3×10^{-3} person-rem, depending on the type of contamination.

5.2.7 Freezers and Refrigerators

The freezers and refrigerators in the ^{3}H, ^{14}C, and ^{125}I laboratories are all assumed to be upright units with dimensions of 0.6 m x 0.6 m x 1.5 m. The estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a freezer or refrigerator by the two options are shown in Table 5.7. A work crew consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON these appliances are discussed in Appendix D. The average time to DECON a freezer or refrigerator is 0.6 days. The average manpower requirement is 2.1 person days. Costs average $6,000 for supercompaction and $6,400 for supercompaction with incineration. Occupational radiation doses range from 1×10^{-6} person-rem to 2×10^{-5} person-rem, depending on the type of contamination.

5.2.8 Filters

All the reference laboratories contain HEPA and roughing filters on the ventilation exhaust systems connected to the fume hoods and glove boxes. The ^{137}Cs laboratory contains one HEPA and roughing filter on each of the air outlets from its two hot cells. Each HEPA filter is 0.2 m in diameter and 0.2 m high; a roughing filter is 0.2 m in diameter x 0.1 m high.[1] Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a HEPA or roughing filter by the two options are shown in Table 5.8. A work crew consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON the filters are discussed in Appendix D. The average time to DECON a filter is 0.03 days. The average manpower requirement is 0.1 person days. Costs average $170 for supercompaction and $210 for supercompaction with incineration. Occupational radiation doses ranged from 5×10^{-8} person-rem to 2×10^{-4} person-rem, depending on the type of contamination.

Table 5.6 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a storage cabinet

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.5	0.5	0.5	--	0.5	--
Manpower (pers-days)	1.7	1 4	1.8	--	1.6	--
Radiation dose (person-rem)	2×10^{-6}	7×10^{-7}	2×10^{-5}	--	3×10^{-3}	--
Costs ($ 000)[a]	2.4 3.0	2.4 3.0	2.3 2.3	-- --	2.4 2.9	-- --

(a) First row is cost for supercompaction option Second row is cost for supercompaction with incineration.

Table 5.7 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a freezer or refrigerator

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.6	0.6	0.6	–	–	0.6
Manpower (pers-days)	2.1	2.1	2.1	–	–	2.1
Radiation dose (person-rem)	2×10^{-6}	1×10^{-6}	2×10^{-5}	–	–	2×10^{-6}
Costs ($ 000)[a]	5.9	6.0	6.3	–	–	5.9
	6.2	6.3	6.7	–	–	6.2

(a) First row is cost for supercompaction option. Second row is cost for supercompaction with incineration.

Table 5.8 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a HEPA or roughing filter

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.03	0.03	0.03	0.03	0.03	0.03
Manpower (pers-days)	0.1	0.1	0.1	0.1	0.1	0.1
Radiation dose (person-rem)	1×10^{-7}	5×10^{-8}	1×10^{-6}	2×10^{-6}	2×10^{-4}	1×10^{-7}
Costs ($ 000)[a]	0.14	0.15	0.20	0.21	0.18	0.15
	0.17	0.18	0.25	0.26	0.22	0.18

(a) First row is cost for supercompaction option. Second row is cost for supercompaction with incineration.

5.2.9 Sinks and Drains

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 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.

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning a sink and associated drain piping by the two options are shown in Table 5.9. 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. A work crew consisting of a foreman and two technicians is assumed to perform the work. A pipefitter is temporarily added to the work crew to disconnect the sink and cut the pipe. Postulated procedures used to DECON the cabinets are discussed in Appendix D.

Table 5.9 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of a sink and drain

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	--	0.2	0.2	0.3	--	0.3
Manpower (pers-days)	--	0.9	0.9	1.0	--	1.0
Radiation dose (person-rem)	--	9×10^{-8}	1×10^{-6}	1×10^{-5}	--	9×10^{-8}
Costs ($ 000)[a]	--	2.3	2.4	2.5	--	2.2
	--	2.3	2.4	2.5	--	2.2

(a) First row is cost for supercompaction option. Second row is cost for supercompaction with incineration.

The average time to DECON a sink and drain is 0.3 days. The average manpower requirement is 1 person days. Since the sinks contain virtually nothing that can be incinerated, the average costs were the same, $2,400, for both options. Occupational radiation doses ranged from 9×10^{-8} person-rem to 1×10^{-5} person-rem, depending on the type of contamination.

5.2.10 Building Surfaces

Building surfaces include ceilings, walls, and floors. Concrete surfaces are decontaminated to unrestricted release levels. Contaminated material such as fiberboard, floor tiles or concrete chipped from walls is packaged, supercompacted and/or incinerated, and then shipped to a shallow-land burial ground. A work crew consisting of a foreman and two technicians is assumed to perform the work. Postulated procedures used to DECON building surfaces are discussed in Appendix D.

Ceilings

The ceilings in the ^{3}H, ^{14}C and user laboratories consist of acoustically treated fiberboard. The ceilings in the remaining laboratories are concrete, coated with epoxy paint (^{125}I laboratory), latex paint (^{137}Cs laboratory), or acrylic paint (^{241}Am laboratory). Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning one square meter of ceiling surface to unrestricted release levels for each reference laboratory are shown in Table 5.10. The average time to DECON a square meter of surface is 0.03 days. The average manpower requirement is 0.13 person days. Costs average $260 for supercompaction and $340 for supercompaction with incineration. Occupational radiation doses range from 1×10^{-8} person-rem to 3×10^{-4} person-rem, depending on the type of contamination.

Walls

The walls in the ^{3}H, ^{14}C, and user laboratories consist of plasterboard painted with latex enamel. The walls in the remaining laboratories are concrete, coated with epoxy paint (^{125}I laboratory), latex paint (^{137}Cs laboratory), or acrylic paint (^{241}Am laboratory). Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning one square meter of wall surface to unrestricted release levels for each reference laboratory are shown in Table 5.11. The average time to DECON a square meter of surface is 0.03 days. The average manpower requirement is 0.13 person days. Costs average $220 for supercompaction and $250 for supercompaction with incineration. Occupational radiation doses range from 5×10^{-8} person-rem to 3×10^{-4} person-rem, depending on the type of contamination.

Floors

All of the floors are covered with asphalt tile except the floor in the ^{241}Am laboratory, which is covered with

Table 5.10 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of one square meter of ceiling area

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.03	0.03	0.04	0.04	0.04	0.03
Manpower (pers-days)	0.11	0.11	0.14	0.16	0.14	0.13
Radiation dose (person-rem)	1×10^{-7}	6×10^{-8}	1×10^{-6}	2×10^{-6}	3×10^{-4}	1×10^{-7}
Costs ($ 000)[a]	0.20	0.20	0.25	0.40	0.21	0.29
	0.26	0.26	0.29	0.53	0.25	0.42

(a) First row is cost for supercompaction option. Second row is cost for supercompaction with incineration.

Table 5.11 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of one square meter of wall area

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User lab
Time (days)	0.03	0.03	0.04	0.04	0.03	0.05
Manpower (pers-days)	0.10	0.10	0.14	0.14	0.13	0.18
Radiation dose (person-rem)	1×10^{-7}	5×10^{-8}	1×10^{-6}	2×10^{-6}	3×10^{-4}	1×10^{-7}
Costs ($ 000)[a]	0.17	0.18	0.25	0.25	0.19	0.26
	0.20	0.21	0.28	0.28	0.22	0.30

(a) First row is cost for supercompaction option Second row is cost for supercompaction with incineration

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.

Estimated time and manpower requirements, total costs, and occupational radiation doses for decommissioning one square meter of wall surface to unrestricted release levels for each reference laboratory are shown in Table 5.12. The average time to DECON a square meter of surface is 0.04 days. The average manpower requirement is 0.15 person days. Costs average $200 for supercompaction and $210 for supercompaction with incineration. Occupational radiation doses range from 2×10^{-8} person-rem to 7×10^{-4} person-rem, depending on the type of contamination.

Table 5.12 Summary of estimated manpower requirements, occupational radiation dose, and total costs for DECON of one square meter of floor area

	Laboratory					
	^{3}H	^{14}C	^{125}I	^{137}Cs	^{241}Am	User Lab
Time (days)	0.04	0.04	0.04	0.04	0.04	0.04
Manpower (pers-days)	0.15	0.15	0.15	0.16	0.15	0.16
Radiation dose (person-rem)	2×10^{-8}	7×10^{-8}	8×10^{-7}	3×10^{-6}	7×10^{-4}	2×10^{-8}
Costs ($ 000)[a]	0.17	0.19	0.21	0.23	0.22	0.19
	0 17	0.19	0.21	0.23	0.26	0.20

(a) First row is cost for supercompaction option Second row is cost for supercompaction with incineration.

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 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 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 D.

6.1 Technical Approach

The technical approach and some of the key bases used to define requirements and to estimate costs and safety of decommissioning the six reference 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 C. Cost estimating bases are listed in Appendix A. Algorithms for estimating task completion times are given in Appendix B. All costs are expressed in January 1998 dollars.

Each reference laboratory is assumed to be decommissioned by employees of the owners or operators of the laboratory. The basic decommissioning work crew is assumed to consist of a foreman and two technicians, assisted half-time by a health physicist. Craftsmen (electricians and pipefitters) are added to this crew on a part-time basis to perform specific tasks. Manpower costs are determined by multiplying work crew times by the hourly charge-out rate per crew. Manpower costs include the salary of a supervisor on a half-time basis.

To determine the time for decommissioning, an estimate is made for 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 and rest periods (ancillary time).

As mentioned in Section 2.6, previous studies[1,2] assumed that some of the facility components were to be decontaminated to unrestricted release levels while other components were to be sectioned and packaged for disposal. In the original study,[1] no facility components were assumed to be compacted. The follow-on study[2] considered options of compaction and supercompaction.

The present study differs from the previous two studies in that only surfaces are decontaminated to unrestricted levels; no facility components are decontaminated. Instead, all components are to be supercompacted or incinerated before they are buried. For the first option, all compactible waste is sent to a central facility for supercompaction and subsequent burial at an LLW site. Uncompactible waste is sent directly to the LLW site. For the second option, waste is sent to a central facility where it is either incinerated or supercompacted, as appropriate. For both options, it is assumed that the components are sectioned as efficiently as practicable to fit into 208-liter drums and compacted on-site with a portable compactor. Both options tend to increase the time and manpower costs of the packaging operations, but minimize the volume of radioactive waste shipped to the shallow-land burial ground, and, consequently, minimize transportation and waste disposal charges that are determined on a volume basis.

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-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 $100,000. 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 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 for both options discussed in Section 6.1.1. 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 D.

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 Tables D.1.a and D.1.b of Appendix D.

Planning and preparation is estimated to require about 6 weeks and 70 person-days of effort before the start of decommissioning operations. Decommissioning operations for both options are estimated to require about 5 weeks and 101 person-days of effort and to result in a total occupational radiation dose of about 0.04 person-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $174,000 for the supercompaction option (Option 1) and $192,000 for the supercompaction/incineration option (Option 2). Planning and preparation activities account for about 17% of the total cost for Option 1 and 15% for Option 2. Approximately 49% and 44% of the total cost is for staff labor (including planning and preparation activities and final radiation survey) and approximately 34% and 40% is for waste management for the first and second options, respectively.

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 Tables D.2.a and D.2.b of Appendix D.

Table 6.1 Summary of estimated values of manpower requirements, occupational radiation doses, and costs for decommissioning the reference laboratory for the manufacturer of ^3H-labeled compounds

Parameter	Planning and preparation	Decommissioning	Final radiation survey	Total
Supercompaction				
Time (days)	30	26	5	61
Manpower (pers-days)	70	101	23	194
Occupational dose (pers-rem)	<0.1	<0.1	--	<0.1
Cost ($ 000)				
Staff labor	23.5	37.7	6.9	68.1
Equipment	--	20.2	--	20.2
Supplies	--	3.7	--	3.7
Waste management	--	47.2	--	47.2
Subtotals	23.5	108.8	6.9	139.2
25% Contingency	5.9	27.2	1.7	34.8
Totals	29.4	136.0	8.6	174.1
Supercompaction/w incineration				
Time (days)	30	26	5	61
Manpower (pers-days)	70	101	23	194
Occupational dose (pers-rem)	<0.1	<0.1	--	<0.1
Cost ($ 000)				
Staff labor	23.5	37.7	6.9	68.1
Equipment	--	20.2	--	20.2
Supplies	--	3.7	--	3.7
Waste management	--	61.8	--	61.8
Subtotals	23.5	123.4	6.9	153.8
25% Contingency	5.9	30.9	1.7	38.4
Totals	29.4	154.3	8.6	192.3

Table 6.2 Summary of estimated values of manpower requirements, occupational radiation doses, and costs for decommissioning the reference laboratory for the manufacturer of ^{14}C-labeled compounds

Parameter	Planning and preparation	Decommissioning	Final radiation survey	Total
Supercompaction				
Time (days)	29	24	5	58
Manpower (pers-days)	66	90	23	179
Occupational dose (pers-rem)	< 0.1	< 0.1	--	< 0.1
Cost ($ 000)				
Staff labor	21.9	33.5	6.9	62.3
Equipment	--	20.2	--	20.2
Supplies	--	3.2	--	3.2
Waste management	--	46.9	--	46.9
Subtotals	21.9	103.8	6.9	132.6
25% Contingency	5.5	26.0	1.7	33.2
Totals	27.4	129.8	8.6	165.8
Supercompaction/w incineration				
Time (days)	29	24	5	58
Manpower (pers-days)	66	90	23	179
Occupational dose (pers-rem)	< 0.1	< 0.1	--	< 0.1
Cost ($ 000)				
Staff labor	21.9	33.5	6.9	62.3
Equipment	--	20.2	--	20.2
Supplies	--	3.2	--	3.2
Waste management	--	64.7	--	64.7
Subtotals	21.9	121.6	6.9	150.4
25% Contingency	5.5	30.4	1.7	37.6
Totals	27.4	152.0	8.6	188.1

Planning and preparation is estimated to require about 6 weeks and 66 person-days of effort before the start of decommissioning operations. Decommissioning operations for both options are estimated to require about 5 weeks and 90 person-days of effort and to result in a total occupational radiation dose of less than 0.001 person-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $166,000 for Option 1 and $188,000 for Option 2. Planning and preparation activities account for about 17% of the total cost for Option 1 and 15% for Option 2. Approximately 47% and 41% of the total cost is for staff labor (including planning and preparation activities and final radiation survey) and approximately 35% and 43% 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 Tables D.3.a and D.3.b of Appendix D.

Planning and preparation is estimated to require about 6 weeks and 66 person-days of effort before the start of decommissioning operations. Decommissioning operations for both options are estimated to require about 4 weeks and 70 person-days of effort and to result in a total occupational radiation dose of about 0.01 person-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $129,000 for Option 1 and $137,000 for Option 2. Planning and preparation activities account for about 21% of the total cost for Option 1 and 20% for Option 2. Approximately 50% and 48% of the total cost is for staff labor (including planning and preparation activities and final radiation survey) and approximately 27% and 32% 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 Tables D.4.a and D.4.b of Appendix D.

Planning and preparation is estimated to require about 6 weeks and 63 person-days of effort before the start of decommissioning operations. Decommissioning operations for both options are estimated to require about 4 weeks and 67 person-days of effort and to result in a total occupational radiation dose of about 4 person-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $155,000 for Option 1 and $169,000 for Option 2. Planning and preparation activities account for about 17% of the total cost for Option 1 and 15% for Option 2. Approximately 40% and 37% of the total cost is for staff labor (including planning and preparation activities and final radiation survey) and approximately 42% and 47% is for waste management for the first and second options, respectively.

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 Tables D.5.a and D.5.b of Appendix D.

Planning and preparation is estimated to require about 6 weeks and 69 person-days of effort before the start of decommissioning operations. Decommissioning operations

Table 6.3 Summary of estimated values of manpower requirements, occupational radiation doses, and costs for decommissioning the reference laboratory for the manufacturer of ^{125}I-labeled compounds

Parameter	Planning and preparation	Decommissioning	Final radiation survey	Total
Supercompaction				
Time (days)	29	18	3	50
Manpower (pers-days)	66	70	14	150
Occupational dose (pers-rem)	< 0.1	< 0.1	—	< 0.1
Cost ($ 000)				
Staff labor	21.9	25.9	4.2	52.0
Equipment	—	20.2	—	20.2
Supplies	—	2.6	—	2.6
Waste Management	—	28.3	—	28.3
Subtotals	21.9	77.0	4.2	103.1
25% Contingency	5.5	19.3	1.1	25.8
Totals	27.4	96.3	5.3	128.8
Supercompaction/w Incineration				
Time (days)	29	18	3	50
Manpower (pers-days)	66	70	14	150
Occupational dose (pers-rem)	< 0.1	< 0.1	—	< 0.1
Cost ($ 000)				
Staff labor	21.9	25.9	4.2	52.0
Equipment	—	20.2	—	20.2
Supplies	—	2.6	—	2.6
Waste management	—	34.6	—	34.6
Subtotals	21.9	83.3	4.2	109.4
25% Contingency	5.5	20.8	1.1	27.4
Totals	27.4	104.1	5.3	136.7

Table 6.4 Summary of estimated values of manpower requirements, occupational radiation doses, and costs for decommissioning the reference laboratory for the manufacturer of ^{137}Cs sealed sources

Parameter	Planning and preparation	Decommissioning	Final radiation survey	Total
Supercompaction				
Time (days)	28	18	3	48
Manpower (pers-days)	62	67	14	143
Occupational dose (pers-rem)	0.4	3.8	—	4.2
Cost ($ 000)				
Staff labor	20.8	24.9	4.2	49.9
Equipment	—	20.2	—	20.2
Supplies	—	2.3	—	2.3
Waste management	—	51.8	—	51.8
Subtotals	20.8	99.2	4.2	124.2
25% Contingency	5.2	24.8	1.1	31.1
Totals	26.0	124.0	5.3	155.3
Supercompaction/w Incineration				
Time (days)	28	18	3	48
Manpower (pers-days)	62	67	14	143
Occupational dose (pers-rem)	0.4	3.8	—	4.2
Cost ($ 000)				
Staff labor	20.8	24.9	4.2	49.9
Equipment	—	20.2	—	20.2
Supplies	—	2.3	—	2.3
Waste management	—	63.0	—	63.0
Subtotals	20.8	110.4	4.2	135.4
25% Contingency	5.2	27.6	1.1	33.9
Totals	26.0	138.0	5.3	169.4

Table 6.5 Summary of estimated values of manpower requirements, occupational radiation doses, and costs for decommissioning the reference laboratory for the manufacturer of ^{241}Am sealed sources

Parameter	Planning and preparation	Decommissioning	Final radiation survey	Total
Supercompaction				
Time (days)	30	23	5	58
Manpower (pers-days)	68	88	23	179
Occupational dose (pers-rem)	1.8	11.7	--	13.5
Cost ($ 000)				
Staff labor	22.9	32 6	6.9	62.4
Equipment	--	20.2	--	20.2
Supplies	--	3.2	--	3.2
Waste management	--	31.5	--	31.5
Subtotals	22.9	87.5	6.9	117.5
25% Contingency	5.7	21 9	1.7	29.3
Totals	28.6	109.4	8.6	146.8
Supercompaction/w Incineration				
Time (days)	30	23	5	58
Manpower (pers-days)	68	88	23	179
Occupational dose (pers-rem)	1.8	11.7	--	13.5
Cost ($ 000)				
Staff labor	22.9	32.6	6.9	62.4
Equipment	--	20.2	--	20.2
Supplies	--	3.2	--	3.2
Waste management	--	41.8	--	41.8
Subtotals	22.9	97.8	6.9	127.6
25% Contingency	5.7	24.5	1.7	31.9
Totals	28.6	122.3	8.6	159.7

for both options are estimated to require about 5 weeks and 88 person-days of effort and to result in a total occupational radiation dose of about 12 person-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $147,000 for Option 1 and $160,000 for Option 2. Planning and preparation activities account for about 19% of the total cost for Option 1 and 18% for Option 2. Approximately 53% and 49% of the total cost is for staff labor (including planning and preparation activities and final radiation survey) and approximately 27% and 33% 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 Tables D.6.a and D.6.b of Appendix D.

Planning and preparation is estimated to require about 6 weeks and 70 person-days of effort before the start of decommissioning operations. Decommissioning operations for both options are estimated to require about 6 weeks and 114 person-days of effort and to result in a total occupational radiation dose of about 1.4 person-rem.

The total cost of decommissioning the reference laboratory is estimated to be about $205,000 for Option 1 and $237,000 for Option 2. Planning and preparation activities account for about 14% of the total cost for Option 1 and 12% for Option 2. Approximately 47% and 41% of the total cost is for staff labor (including planning and preparation activities and final radiation survey) and approximately 38% and 46% is for waste management for the first and second options, respectively.

6.3 Analyses and Conclusions

How does the methodology used in this report compare with real-world costs? In general, it is extremely difficult to obtain detailed data on the actual costs of decommissioning a facility since costs actually expended on decommissioning are usually considered to be proprietary, especially if a decommissioning operations contractor was contracted (competitively) to do the work.

In Chapter 3, three facilities actually decommissioned in the last five years were discussed. (These three were representative of the range of types of facilities requiring decommissioning.) In each case, the total cost of decommissioning the facilities was available, but no breakdown of these costs into categories was obtainable. However, from the data available on two of these facilities, the Battelle Building KA-3 and INS laundry facility, a rough independent estimate using the methodology in this report was made. These results are presented in Table 6.7. It must be noted, however, that numerous judgements about the requirements for decommissioning each facility had to be made in order to generate an estimate. In the case of the Battelle facility particularly, it is known that a number of non-supporting walls were completely removed rather than be decontaminated, that extensive grouting of the soil beneath the building was required to provide sufficient foundation support to the building during decommissioning, and that DOE Operational Safety and Health requirements, in addition to NRC requirements, were followed during decommissioning.

Cost comparisons with facilities like the six reference laboratories discussed in this chapter are possible. For example, a few licensees with decommissioning funding plans available in the NRC dockets have sufficient information from which independent decommissioning cost estimated can be generated. While these independent estimates cannot be compared to actual costs incurred from decommissioning, they can at least be compared to the cost estimates actually provided by the licensees to the NRC for certification. Results of analyzing five such facilities suggest the following:

- Costs development by the methodology of this report are generally in fairly good agreement with the licensee-provided estimates (i.e., within a band of +50, -70%). The estimates using the methodology presented in this report, are greater in 2 out the 5 cases.
- In the three cases where the methodology estimate is lower than the licensee estimate, the licensee estimate for disposal cost is exceptionally high (from the available information, it is not clear why this would be the case).

Table 6.6 Summary of estimated values of manpower requirements, occupational radiation doses, and costs for decommissioning the reference institutional user laboratory

Parameter	Planning and preparation	Decommissioning	Final radiation survey	Total
Supercompaction				
Time (days)	30	30	8	68
Manpower (pers-days)	70	114	36	220
Occupational dose (pers-rem)	<0.1	<0.1	–	<0.1
Cost ($ 000)				
Staff labor	23.5	42.6	11.1	77.2
Equipment	–	20.2	–	20.2
Supplies	–	4.2	–	4.2
Waste management	–	62.3	–	62.3
Subtotals	23.5	129.3	11.1	163.9
25% Contingency	5.9	32.3	2.8	41.0
Totals	29.4	161.6	13.9	204.8
Supercompaction/w Incineration				
Time (days)	30	30	8	68
Manpower (pers-days)	70	114	36	220
Occupational dose (pers-rem)	<0.1	<0.1	–	<0.1
Cost ($ 000)				
Staff labor	23.5	42.6	11.1	77.2
Equipment	–	20.2	–	20.2
Supplies	–	4.2	–	4.2
Waste management	–	87.6	–	87.6
Subtotals	23.5	154.6	11.1	189.2
25% Contingency	5.9	38.7	2.8	47.3
Totals	29.4	193.3	13.9	236.5

Table 6.7 Comparison of decommissioning costs for Battelle and INS facilities

Building	Cost ($)	
	Actual	Estimated
Battelle KA-3	$25M	$8M
INS facility	$220K	$110K

- In many of the cases, it is clear that licensees consider the costs associated with the planning and actual D&D of facilities to be a part of their everyday operations (since they already employ the necessary staff and will pay them whether it is for these D&D operations or other on-going operations) and therefore do not provide estimates for the total cost of performing the decommissioning. By comparison, the methodology used in the present study includes the costs for all activities associated with decommissioning a facility.

From these comparisons it can be concluded that the decommissioning cost estimating methodology used in this report is in fairly close agreement with licensee-estimated decommissioning costs. Given the wide variation in the types and operational histories of facilities categorized as non-fuel-cycle facilities, the methodology used in this report does provide estimates that are representative of real-world decommissioning costs.

6.4 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.

7 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 E.

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

Costs estimates are made in this study for the decommissioning of three example sites: (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. 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 1998 dollars and include a 25% contingency. Some key bases and assumptions for estimating costs are given in Appendix A. Cost estimating bases are also given in Appendix A.

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

Labor costs are determined by multiplying the person-days required to decommission a site by the cost per person-day shown in Table A.1 in Appendix A. For ease in evaluating time and labor 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., labor, equipment, and material costs), plus a fee to provide a reasonable profit for his efforts. For this study, the contractor's fee is calculated on the basis of 8% of the sum of his labor, equipment, material, and packaging 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 A.1 in Appendix A, an overhead rate on direct staff labor of 110%, plus 15% profit on labor and its overheads, is applied 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 used by the decommissioning contractor are calculated on the basis of rental from equipment dealers. Rental rates are based on 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 labor 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 labor 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 labor, equipment, materials, waste management (e.g., the packaging, transportation, and disposal of radioactive waste), and contractor's fees where applicable.

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

Table 7.1. Decommissioning options for reference sites

	Decommissioning option	
Site	Site stabilization	Removal
Underground drain line and hold-up tank		x[a]
Contaminated ground surface		x
Tailings pile/evaporation pond	x	x

(a) x indicates that the site is decommissioned 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 labor 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 E.1 of Appendix E. 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 $126,000. Occupational radiation doses are estimated to total about 0.1 person-rem, based on an average worker dose rate of 0.1 mrem/hr.

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 208-liter drums and shipped by truck to a disposal site.

Cost details are presented in Table E.2 of Appendix E. Labor costs represent about 42% of the total decommissioning cost. Costs of the initial and final site surveys (including labor, equipment, soil analysis costs) are about 21% 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 soil.

Estimated time and labor 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 E.2 of Appendix E.

Table 7.2 Summary of estimated labor 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
Labor (person-days)	15	50.5	7	72.5
Occupational dose (person-rem)	< 0.1	< 0.1	--	0.1
Costs ($000)[a]				
Staff labor	5.6	27.4	2.6	35.6
Equipment	1.9	12.9	1.0	15.8
Materials	0.5	4.0	0.2	4.8
Soil analyses	6.0	--	2.0	8.0
Contractor's fee	--	3.7	--	3.7
Waste management	--	32.9	--	32.9
Subtotal	14.0	80.9	5.8	100.7
25% Contingency	3.5	20.2	1.5	25.2
Totals	17.5	101.1	7.3	125.9

(a) Costs are in January 1998 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

Table 7.3 Summary of estimated labor 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
Labor (person-days)	75	111.5	22.5	209
Occupation dose (person-rem)	<0.1	0.1	--	0.1
Costs ($000)[a]				
Staff labor	27.4	56.4	8.2	92.0
Equipment	9.3	21.0	1.5	31.8
Materials	2.5	12.3	0.7	15.5
Soil analyses	90.0	--	6.0	96.0
Contractor's fee	--	26.1	--	26.1
Waste management	--	855.6	--	855.6
Subtotal	129.3	971.4	16.4	1,117.0
25% Contingency	32.3	242.8	4.1	279.3
Totals	161.6	1,214.2	20.5	1,396.3

(a) Costs are in January 1998 dollars Number of figures shown is for computational accuracy only and does not imply that level of precision.

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 $1,396,000. Occupational radiation doses are estimated to total about 0.1 person-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 4×10^4 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 B-25 metal boxes and shipped to a disposal site. 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 on-site burial of radioactive waste. The costs for on-site disposal could, however, be considerably less than costs for disposal at a shallow-land burial ground.

Cost details are presented in Table E.4 of Appendix E. Labor costs represent only about 8% of the total decommissioning cost, with waste management costs (cost of packaging, transportation, and disposal of the exhumed soil) accounting for about 77% of the total decommissioning cost. Costs of the initial and final site surveys (including labor, equipment, and soil analysis) are about 12% of the total cost.

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. The reference tailings pile/evaporation pond is described in Section 7.3 of NUREG/CR-1754.[1] The pile contains the residue from ore refinery operation 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/pond and its contents is shown in Table 7.4.

Table 7.4 Some characteristics of the reference tailings pile/evaporation pond

Parameter	Value
Volume of pond	16,000 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	2.02×10^5 kg

Estimated time and labor requirements, total costs, and occupational doses for decommissioning a tailings pile/evaporation pond by the option of stabilization are presented in Table 7.5 summarized from Section E.3 of Appendix E. The annual requirements and costs of long-term care following stabilization are also shown in Table 7.5. The cost of stabilization is estimated to be about $237,000, and the occupational radiation dose for this option is estimated to be 0.1 person-rem. The annual cost of long-term care is estimated to be about $17,000, and the annual occupational radiation dose is estimated to be about 0.02 person-rem.

Requirements and costs for removal of the pile/pond are shown in Table 7.6. The cost of removal of the pile/pond and its disposal at a shallow-land burial ground is estimated to be about $23 million, and the occupational radiation dose for this option is estimated to be 1.3 person-rem.

Decommissioning begins with planning and preparation activities that include a radiological survey to determine the radiological condition of the 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 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 35% 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. Labor costs represent about 39% of the total cost of this option.

Long-term care activities include administrative control, site maintenance, environmental surveillance, and vegetation management. Labor costs represent almost 66% 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 B-25 metal boxes and shipped to a disposal site. After the pile/pond is removed, the site is backfilled and graded.

The site is then surveyed to verify its suitability for unrestricted release. Finally, grass is seeded to establish a vegetative cover.

Table 7.5 Summary of estimated labor requirements, costs, and occupational radiation doses for the stabilization of a reference tailings pile/evaporation pond

	Site stabilization			
Parameter	Planning & preparation	Decommissioning	Totals	Long-term care annual values
Time (days)	20	12	32	10
Labor (person-days)	70	104	174	27
Occupational dose (person-rem)	< 0.1	0.1	0.1	0.02
Costs ($000)[a]				
Staff labor	22.0	51.4	73.4	8.7
Equipment	9.3	11.9	21.2	1.8
Materials	2.0	72.5	74.5	0.8
Soil analyses	10.0	–	10.0	2.0
Contractor's fee	–	10.9	10.9	–
Waste management	–	–	–	–
Subtotal	43.4	146.6	189.9	13.3
25% Contingency	10.8	36.7	47.5	3.3
Totals	54.2	183.3	237.4	16.6

(a) Costs are in January 1998 dollars Number of figures shown is for computational accuracy only and does not imply that level of precision.

Table 7.6 Summary of estimated labor 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
Labor (person-days)	70	1569	17.5	1,656.5
Occupational dose (person-rem)	<0.1	1.3	—	1.3
Costs ($000)[a]				
Staff labor	22.0	785.4	6.5	813.8
Equipment	9.3	88.1	1.5	98.9
Materials	2.0	176.6	0.6	179.2
Soil analyses	90.0	—	6.0	96.0
Contractor's fee	—	452.0	—	452.0
Waste management	—	16,598.4	—	16,598.4
Subtotal	123.4	18,100.5	14.5	18,238.3
25% contingency	30.8	4,525.1	3.6	4,559.6
Totals	154.2	22,625.6	18.1	22,797.9

(a) Costs are in January 1998 dollars. Number of figures shown is for computational accuracy only and does not imply that level of precision.

Approximately 91% of the total cost of the removal option is waste management costs ($16.6 million). Waste management costs could be reduced by about $4.0 million if the contaminated material was transported to the disposal site in plastic-lined 10-m^3-capacity dump trucks instead of being packaged in (2.72-m^3) B-25 metal 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 Discussion of Results

The conclusions reached in this report are:

(1) Decommissioning costs have continued to increase since publication of References 1 and 2, due primarily to rapidly escalating costs for disposal of radioactive wastes generated during decommissioning operations at the available LLW disposal sites.

(2) Rapidly escalating fees for disposal of LLW provide a significant incentive for NRC licensees to effectively manage LLW generation, treatment, and disposal from D & D activities.

(3) Decommissioning costs have increased on the order of 34% to 66% since the issuance of the Final Decommissioning Rule in 1988.

Each of these conclusions is discussed below.

8.1 Decommissioning Costs

Costs are estimated for the decommissioning of facility components (hoods, glove boxes, workbenches, ductwork, building surfaces, etc.) by the DECON options of (1) supercompaction and (2) supercompaction and incineration. Cost estimates for individual components are then used as bases for estimating the costs of decommissioning several reference laboratories (described in Chapter 7 of Reference 2).

The costs of decommissioning facility components are generally estimated to be in the range of $140 to $27,000, depending on the 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 $129,000 to $237,000. 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 $25,000. The cost of decommissioning an entire industrial plant or research facility containing several laboratories used to prepare and/or use radiochemicals and radioactive sources could cost several million dollars (refer to Section 3.1).

Costs estimates are made for decommissioning three reference sites. Costs are estimated to range from about $130,000 for the removal of a contaminated drain line to $23 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 Waste Generation, Treatment, and Disposal Management

Since 1988, LLW disposal costs have escalated by approximately a factor of 3.5 for the U.S. Ecology site in Washington and by a factor of 10 for the Chem-Nuclear site in South Carolina. Thus, effective management of LLW generation during D & D operations and its subsequent treatment and disposal can significantly reduce the total cost of decommissioning of nuclear facilities. The greatest potential for minimizing LLW management costs is with minimizing its generation to begin with. New technologies are actively under development to minimize, if not eliminate altogether, the generation of secondary LLW from decontamination operations. The CO_2 pellet decontamination process and the supersonic gas-liquid cleaning technologies discussed in Section 4 provide examples of such technologies.

Using 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 average waste management cost (without contingency) for the six facilities when supercompaction is used is about $45,000; without supercompaction this cost increases by 111% to $95,000. 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 waste 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 radioactive waste incineration facilities have only been designed and built to incinerate a select few waste types (i.e., radioactively contaminated waste oil from nuclear power plants).

While supercompaction and incineration can significantly reduce waste volumes, both are applicable only to dry-active waste. A significant cost from decommissioning operations is from disposal of solidified liquid wastes, for the reference facilities, 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. Also, a new LLW/mixed waste disposal site in Utah (operated by Envirocare of Utah, Inc.) offers disposal services for very low-level radioactive and mixed wastes at costs significantly below the current regional commercial LLW disposal sites at Richland, Washington, and Barnwell, South Carolina.

8.3 Escalation Since the Final Decommissioning Rule

The present study indicates that decommissioning costs for non-fuel-cycle nuclear facilities, such as those described in Section 2.6, are in the range of $130,000 to $205,000, assuming aggressive LLW volume reduction, and $150,000 to $270,000, assuming minimal LLW volume reduction. (See columns 4 and 5, respectively, in Table 8.1.) The decommissioning fund certification amounts established in the 1988 Final Decommissioning Rule were derived by escalating the costs as estimated in the original study (Reference 2) to 1986 dollars, which were in the range of $100,000 to $140,000. (See columns 1 and 2 in Table 8.1.) These results suggest that decommissioning costs since the 1988 Decommissioning Rule have increased by 34% (assuming aggressive volume reduction) to 66% (assuming minimal volume reduction).

Table 8.1 Comparison of decommissioning costs

Reference laboratory	NUREG/CR-1754 (1978 $ 000)	NUREG/CR-1754 (escalated to 1986 $ 000)	Present report, Section 2.6 (1998 $ 000)	Present report (w/o supercompaction, 1998 $ 000)
^{3}H	67	140	174	228
^{14}C	59	119	166	219
^{125}I	53	101	129	150
^{137}Cs	53	99	155	170
^{241}Am	74	141	147[a]	172[a]
User	63	126	205	269

(a) The ^{241}Am lab cost increases are relatively low because of changes in assumptions in how the facility is decommissioned NUREG/CR-1754 assumed that the alpha-contaminated glove boxes were decontaminated for re-use (an expensive proposition because of worker protection requirements), while the present report assumes that the glove boxes are merely packaged, compacted, and disposed of as LLW.

8.4 References

1. S. M. Short. 1989. *Technology, Safety, and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities*. NUREG/CR-1754, Addendum 1, U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

2. 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

Cost Estimating Bases

Appendix A

Cost Estimating Bases

The cost estimate information developed in this reevaluation study is based on unit cost data presented in this appendix. Categories for which basic unit cost estimating data are given include: salaries, waste packaging, transport, waste disposal, special equipment and services, and supplies. The following major bases and assumptions apply to the decommissioning cost estimates in this reevaluation of the reference non-fuel-cycle facilities and their components.

- The estimated cost data presented in this report are early-1998 costs.
- A contingency of 25% is added to all estimated costs.
- Decommissioning involves removal of facility components or decontamination of selected components of the facility only to the extent that the NRC license may be terminated and the remaining facility and site may be released for unrestricted use. This study, unlike the original study described in References 1 and 2, does not consider the option of complete decontamination of the facility components before disposal. Extensive decontamination of the small number of small components in facilities such as these is expensive, and does not warrant the extra clean-up of the components needed for unrestricted use. Rather, minimal decontamination is carried out in this study, followed by cutting and packaging and volume reduction of the radioactively-contaminated material for disposal at a licensed LLW burial ground.
- The study does not address the removal of bulk, packaged, inventory quantities of radionuclides from the facilities and their ultimate disposition. Removal off-site of these quantities is assumed to have been completed before physical decommissioning begins.
- The cost estimates in this reevaluation study, just as in References 1 and 2, take into consideration only those decommissioning costs that affect public health and safety (i.e., costs to reduce the residual radioactivity in a facility to a level that permits the facility to be released for unrestricted use and the NRC license to be terminated). Hence, the cost estimates in this study do not include such items as the cost to remove clean materials and equipment nor to restore the land to a "green field," which would require additional demolition and site restoration activities in some cases. Although the additional costs for site restoration may be needed from the viewpoint of public relations or site resale value, they are not related to health and safety, and therefore were considered to be outside of NRC's area of responsibility.
- An alternate cost estimate is developed for the decommissioning of the tailing pile/evaporation pond site which assumes the relatively low activity contaminated material can be stabilized on-site followed by annual surveillance and maintenance of the site. This would be considered a restricted land use situation without license termination, but would assure minimal risk to public health and safety.
- To develop the cost estimates for a facility, the "building block" technique is used. First the cost of decommissioning each component of the facility is estimated. These costs are then added together to determine the total cost for decommissioning the entire facility. This approach allows for generation of simple algorithms for decommissioning other facilities that are not the same as the reference facilities studied here.

- The estimated costs for decommissioning the reference facilities in this study include the costs for staff labor, equipment, supplies, and waste management (treatment or volume reduction, packaging, transportation, and disposal of radioactive waste).

- The study assumes that all the applicable radioactive waste materials that result from the decommissioning are treated by volume reduction, if practical, (i.e., supercompaction or incineration by off-site contractors) before final packaging and disposal. Reference 2 (in 1988 dollars) showed a significant financial incentive for such action, as controlled by the high costs of radioactive waste disposal. Since that time, low-level radioactive waste disposal costs have continued to increase dramatically. Thus, decommissioning without volume reduction would only be done at a significant cost penalty and would not likely be done in the future. In this study, the removal of soils or tailings characterized by low concentrations of radioactive material assumes no volume reduction.

- Some facilities of the types covered in this report may have sinks into which low activity liquids are discharged to an outside, buried holdup tank. The costs for decommissioning the contaminated outside-buried pipe and holdup tank are not included in the estimated costs for each facility, but are estimated separately. Thus, if a specific facility has such outside-contaminated features, the estimated costs for decommissioning these features must be added to the costs for decommissioning the facility. It is assumed in this study that an outside contractor is used for this part of the decommissioning.

- The cost estimate is not site-specific for the facilities. Generic, nationwide values are used for unit costs for all categories unless otherwise identified.

- Labor rates and overheads for owner/operator and contractor personnel are shown in Table A.1. Except where noted in this table, labor rates and overhead costs are taken from Reference 3. Overhead rates applied to direct staff labor are expected to be significantly higher for subcontracting organizations than for the facility operator because of the larger

Table A.1 Labor costs for decommissioning

Position	Annual salary	Overhead (%)	Annual salary/ w overhead	Hourly rate/ w overhead
Supervisor	61,110	70.0[a]	103,887	56.46
Foreman	55,545	60.0	88,872	48.30
Craftsman	54,495	60.0	87,192	47.39
Technician	52,500	53.7	80,693	43.85
H. P. Tech	51,030	53.7	78,433	42.63
Clerk	12,860	61.2	20,730	11.27
Equipment Operator[b]	53,970	141.5	130,338	70.84
Laborer[b]	41,580	141.5	100,416	54.57
Truck Driver[b]	43,470	141.5	104,980	57.05

(a) Estimated.
(b) Subcontractor Workers.

ratio of supervisory and support personnel to direct labor that usually exists in subcontracting organizations. Having personnel in the field rather than in the home office also increases the overhead costs, because of travel and living expenses for some of the personnel. In view of these factors, an overhead rate on direct staff labor of 110%, plus 15% profit on labor and its overheads, is assumed to be applicable to all subcontractor workers in this reevaluation study.

- Estimated time requirements to efficiently carry out a decommissioning task for a work crew are increased by 50% to allow for work inefficiencies, unforeseen situations, preparation and set-up times, and rest periods.

- All decommissioning activities within a facility, starting with the predecommissioning work (e.g., planning, activity specifications and procedures), and continuing through the final license termination, are assumed to be carried out by the facility staff, except where otherwise identified (e.g., supercompacting, incineration, waste transportation, waste disposal). Decommissioning of outside facilities (e.g., sink drain line and buried holdup tank) and site land where necessary, and waste volume reduction, are assumed to be performed by a contractor hired by the facility operator.

- In most cases, a single work crew is used, and one component at a time is decommissioned. For decommissioning a given component, a work crew is assumed to work 8 hours/day and consists of a foreman and two technicians, assisted by a half-time health physicist monitor. In some cases (identified where used), craftsmen (e.g., electricians, pipe fitters, etc.) are added to perform specific tasks such as disconnecting services and preparing a component for packaging. A supervisor is assumed to be assigned to the decommissioning staff on a half-time basis for the total facility. He performs overview functions, such as Q.A., documentation, and management of the decommissioning. A clerk is used for 15 to 20 person-days during the total decommissioning activities, including planning, and final license termination.

- Labor, materials, and equipment costs for conventional cleaning and construction activities were taken from References 3 and 4.

- All waste is assumed to be placed in 208-liter drums or B-25 metal containers. No other containers are used. After compacting at the facility, void space is assumed to be 30%. Supercompaction is assumed to reduce the post-compacted waste by an additional factor of three. In this study, the cost for supercompaction is assumed to be $100 per 208-liter drum.[1] Incineration is assumed to reduce the post-compacted incinerable waste volume by a factor of 10. The incineration cost used in this study is $5,400/m³. This value, obtained from Reference 5, includes a 13% cost rate increase (Reference 6) to convert to 1998 dollars and a 25% charge for packaging, labeling, and preparation of shipping documents.

- Aqueous liquid wastes, such as aqueous cleaning solutions, are assumed to be solidified with Aquaset®, or other equivalent material, in 208-liter waste drums.

- Miscellaneous material costs and task completion times assumed in this study are presented in Table A.2.

- Costs relevant to the site decommissioning analyses (Chapter 7) are presented in Tables A.3 and A.4.

- Transportation cost estimates for radioactive wastes are taken from Reference 7. Transportation of LLW is by single-purpose tractor-truck that can hold one hundred-twenty 208-liter drums, or 40 drums of supercompacted wastes (based on weight restrictions). Transportation costs of wastes from individual components are estimated by assuming the

[1] "Doc" Dennis, Allied Technology Group, Incorporated, Richland, Washington. February 1966 Personal Communication.

Table A.2 Miscellaneous costs, weights, and rates

Equipment and material costs ($)	
208-liter drum	50
B-25 metal box	645
Commercial vacuum	2,900
Waste compactor	16,400
Weights	
Empty 208-liter drum (kg)	21
Empty B-25 metal box (kg)	270
Surface rates (m^2/h)	
Dry vacuum	60
Dry or wet wiping	30
Painting	30
Concrete scabbling rate	10
Asphalt tile removal	11
Suspended ceiling removal	14
Cutting rate (steel, plastic, or metal, m/hr)	60

Table A.3 Charges for contractor equipment for decommissioning of sites[a,b]

Equipment item	Estimated rental fee ($/week)	Estimated rental fee ($/month)
Tractor, farm type	1,110	3,325
Grader, self-propelled	1,600	4,800
Roller, sheepsfoot, self-propelled	1,920	5,750
Front loader (2-m^3-capacity)	1,410	4,225
Backhoe (2-m^3-capacity)	6,300	18,900
Bulldozer	1,810	5,425
Soil stabilizer, self-propelled	4,200	12,600
Scraper-hauler (20-m^3-capacity)	6,470	19,400
Dump truck (10-m^3-capacity)	1,360	4,075
Lift truck (10-Mg-capacity)	770	2,300
Crane, boom-type (10-Mg-capacity)	1,725	5,175
Light-duty drilling rig	6,535	19,600
Disc-harrow, tractor-drawn	400	1,200
Seeder, tractor-drawn	480	1,440

(a) Rental charges includes equipment depreciation, operating expenses (fuel, lubrication, etc.), decontamination following use, and return on investment Does not include operator's wages.
(b) Adjusted to January 1998 dollars

Table A.4 Unit costs of supplies, materials, and soil analyses for decommissioning of sites

Item	Units	Estimated unit cost[a] ($)
Backfill (topsoil)	m^3	18[b]
Backfill (common borrow)	m^3	4.6[b]
Gravel (graded)	m^3	5.4[b]
Asphalt emulsion	m^3	70
Seed	kg	4.5
Fertilizer	kg	0.34
Straw	bale	2.3
Anti-contamination clothing	per person per week	100
PVC pipe (0.15-m-diameter)	m	20
Chain-link fencing (1.8-m-wide)	m	28
Soil analysis	each	200
Cutie pie detector	each	1,200
G-M probe	each	240
Gamma Scintillation probe (3" x 3" crystal)	each	1,680
Ratemeter (log-lin.)	each	1,440
Phoswhich detector (5" diameter)	each	10,800

(a) Adjusted to January 1998 dollars
(b) Cost shown does not include delivery to site.

wastes to occupy the respective fraction of a truckload of wastes from that component. The waste volume reduction facility (supercompaction or incineration) is assumed to be 350 km from the facility; the LLW disposal facility is assumed to be an additional 800 km from the waste volume reduction facility. Wastes that are not amenable to volume reduction are shipped directly to the LLW disposal facility, assumed to be 800 km away.

- All radioactive wastes resulting from decommissioning, primarily low-level radioactive wastes or low-activity wastes, are assumed to be shipped for disposal to a licensed disposal site. The two major sites are the U.S. Ecology Facility near Richland, Washington, and the Chem-Nuclear Facility near Barnwell, South Carolina. An additional disposal facility is available for low-activity radioactive wastes (LARW), particularly radioactively contaminated soils, at the Envirocare Facility near Clive, Utah. Radioactive wastes from the reference contaminated ground surface site and the tailings pile/evaporation pond site are assumed to be disposed of at the Envirocare Facility. This study uses the burial rate schedule provided by U.S. Ecology, Reference 8, for LLW, exclusive of soils.

- Certain components in some of the non-fuel-cycle facility operations areas are not used for radioactive materials or for uncontaminated sealed radioactive materials. These components include cabinets, refrigerators, freezers, and washing machines. It is assumed in this study, that unless otherwise noted, these components are monitored to ensure they are uncontaminated, then removed and salvaged by the owner as non-radioactive materials.

- The study does not address the removal or disposal of mixed or hazardous wastes from the facility. The costs for such activities are assumed to be operational costs covered by and active Resource Conservation and Recovery (RCRA) permit for the facility. However, the study does include consideration of the constraints that the presence of mixed wastes on-site may impose on decommissioning alternatives and on schedules.

- For purposes of this study, the ultimate cost of disposal of mixed wastes (either liquid or solid) expected to be present on the site of the reference facility at final shutdown are considered to be operational costs, since the majority of such wastes are postulated to be generated during operation of the plant. It should be realized, however, that regardless of when any solid mixed LLW was generated, commercial treatment, storage, and disposal services for the waste do not currently exist for most of the waste. Based on the discussion above, it is assumed further that implementation of waste minimization techniques used during the operating years of the facility will also be used during decommissioning. Therefore, essentially no solid mixed LLW is assumed to be generated during decommissioning of the reference facilities in this report.

- Salvage values of recovered, potentially reusable materials are not considered.

- Property taxes are not considered.

A.1 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. S. M. Short. 1989. *Technology, Safety and Costs of Decommissioning Reference Non-Fuel-Cycle Nuclear Facilities.* NUREG/CR-1754, Addendum 1. U.S. Nuclear Regulatory Commission Report by Pacific Northwest Laboratory, Richland, Washington.

3. *Building Construction Cost Data-1996.* R. S. Means Co., Inc., Kingston, Massachusetts, 1996.

4. *Means Estimating Handbook.* R. S. Means Co., Inc., Kingston, Massachusetts, 1990.

5. "Schedule of Rates for the Period June 1, 1992 through May 31, 1993." Scientific Ecology Group, Oak Ridge, Tennessee, 1992.

6. *Handy-Whitman Index of Public Utility Costs,* Bulletin No. 142, Section E-6. Whitman, Requardt and Associates, 1995.

7. TSMT 4007-C, *Secured Transportation Services, Radioactive Materials Tariff.* Tri-State Motor Transit Co., Joplin, Missouri, December 1995.

8. U.S. Ecology, Inc., Washington Nuclear Center, Radioactive Waste Disposal Schedule A, January 1996.

Appendix B

Process Times Estimating Methodology

Appendix B

Process Times Estimating Methodology

The decommissioning of laboratory components involves several steps: partial surface decontamination and/or fixing of loose surface contaminants, component segmentation, packaging, and loadout. This appendix develops the algorithms used to calculate the time required to perform each of these steps. The labor cost associated with each step is then easily found by multiplying the hourly labor cost of the crew doing the work by the time required to perform the step.

B.1 Surface Decontamination and Removal Times

As discussed in Appendix D, most component surfaces are partially decontaminated and/or painted to reduce or fix surface contamination before the components are cut up for disposal. The time required for performing a surface decontamination procedure is found by dividing the total surface area by the rate (in m^2/hr) appropriate for that procedure. Times required for removing layers of materials are calculated the same way. Surface rates for different procedures are given in Appendix A, Table A.2.

> Examples: Using values from Table A.2, it is found that a 60 m^2 wall requires 60/60 = 1 hour to dry vacuum and 60/30 = 2 hours to paint. Removing asphalt tile from a 60-m^2 floor requires 60/11 = 5.5 hours.

B.2 Cutting Times

In this study it is assumed that components with large surface areas (e.g., glove boxes, fume hoods, cabinets, workbenches, refrigerators, freezers) will be cut into flat, square pieces small enough (0.16 m^2) to fit into a drum. To determine the number of cuts required, suppose that a typical flat surface of area A measures L by W and that it is desired to cut this into small square pieces measuring b by b. Then there will be int(W/b) cuts of length L and int(L/b) cuts of length W, where int(x) is the greatest integer in x. (For example, int(3.6) = 3.) The total length of the cuts is then L x int(W/b) + W x int(L/b). If W and L are relatively large, then int(W/b) and int(L/b) can be approximated by W/b and L/b, without introducing too great an error. With this approximation, the total length of the cuts is LW/b + WL/b = 2A/b. Dividing this by the cutting rate, r, gives the cutting time: t = 2A/(rb).

> Examples: A typical fume hood has a total surface area of about 13 m^2. If the hood is to be cut into squares of about 0.16 m^2, so that the pieces will stack neatly inside a drum, the total cutting length is 2 x 13/0.4, or about 65 meters. Dividing this by the assumed cutting rate of 60 m/hr (Appendix A) gives a cutting time of about one hour. For a refrigerator (assumed to be essentially hollow) with a total surface area for the six sides of about 4.5 m^2, the total cutting length is 2 x 4.5/0.4 = 22 meters. This gives a cutting time of 22/60 = 0.4 hour.

B.3 Packaging and Loadout Times

The time required to collect, bag, and fill a drum with waste is based on times estimated in Reference 1 for hazardous material abatement. Reference 1 estimates that 0 09 hours would be required to collect, bag, and containerize one drum of waste, assuming that three bags of compacted waste will fill a drum. Doubling this time to account for on-site compacting gives the value of 0.18 hours/drum used in this report. Liquid wastes are processed in the drum by the addition of a solidifing agent (Aquaset® or its equivalent) It is assumed that the time required for the addition and mixing of this agent in the drum is 0.25 hours. Once a drum is packaged it is moved to the loadout area. A loadout time of 0 083 hours/drum is assumed for this study.

B.4 References

1. "Building Construction Cost Data 1996." Robert Snow Means Company, Inc., Kingston, Massachusetts.

Appendix C

Details of Decommissioning Facility Components

Appendix C

Details of Decommissioning Facility Components

This appendix provides cost estimates for the DECON of typical facility components. DECON consists of disassembly, packaging, and on-site compaction of the components, followed by further volume reduction, either 1) supercompaction at a centralized facility or 2) supercompaction and incineration at a centralized facility. Following volume reduction, the components are buried at a shallow-land burial ground. Descriptions of the facilities and facility components are given in Appendix A of Reference 1 and in Appendix D of this report. The key assumptions and bases used for estimating manpower requirements and costs are given in Appendix A. The following steps are assumed in the DECON of facility components:

- remove equipment and material and perform initial radiation survey
- remove loose contamination and fix residual contamination
- disconnect service lines as required
- cut component into pieces to efficiently fill the disposal containers (208-liter drums)
- package pieces in plastic and place in drums
- ship drums to central facility for waste reduction treatment: supercompaction (Option 1) or supercompaction and incineration (Option 2)
- ship treated waste to low-level waste (LLW) burial grounds.

A work crew consisting of a foreman and two technicians is assumed to perform the DECON work. When disconnecting or removing components, this crew is assisted as necessary by an electrician or craftsman. Complete descriptions of the DECON operations performed on each facility component are contained in Appendix D.

C.1 Fume Hoods

Estimated costs for decommissioning a radiological fume hood at each facility are shown in Table C.1.a for Option 1 and in Table C.1.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs. Waste management costs include the cost of disposal of the hood only. Roughing and HEPA filters are considered separate components and are discussed in Section C.9.

Table C.1.a Cost ($ thousands) for DECON of a fume hood at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	3.13	3 26	3.37	3.73	3 34	3.17
Equipment & supplies	1.10	1.23	1.48	1.69	1 25	1.00
Waste management						
Packaging	0.13	0.13	0 08	0.13	0.13	0.13
Processing (supercompaction)	0.27	0 28	0.17	0.28	0 28	0.29
Processing (incineration)	–	–	–	–	–	–
Transportation	0 04	0.04	0.02	0.04	0 04	0 04
Disposal	1 36	1.41	0 87	1 40	1.39	1 44
Waste management subtotals	1.80	1.87	1.14	1.85	1 84	1.90
Total	6.03	6 36	5.99	7.27	6 43	6.07
25% Contingency	1.51	1 59	1.50	1.82	1 61	1 52
Totals	7.54	7.95	7 49	9.09	8.03	7.59

Table C.1.b Cost ($ thousands) for DECON of a fume hood at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	3.13	3.26	3.37	3.73	3.34	3.17
Equipment & supplies	1.10	1.23	1.48	1.69	1.25	1.00
Waste management						
Packaging	0.13	0.13	0.08	0.13	0.13	0.13
Processing (supercompaction)	0.22	0.23	0.15	0 23	0.23	0.24
Processing (incineration)	0.50	0.51	0.26	0.51	0.49	0.51
Transportation	0.03	0 04	0.02	0.04	0 04	0 04
Disposal	1 19	1 24	0.78	1.23	1 22	1.27
Waste management subtotals	2.07	2.15	1.28	2.13	2.11	2.18
Total	6.31	6.64	6.14	7.55	6.70	6.35
25% Contingency	1.58	1 66	1.53	1.89	1 67	1.59
Totals	7.88	8.30	7.67	9.44	8.37	7.94

C.2 Glove Boxes

Estimated costs for decommissioning a glove box at each facility are shown in Table C.2.a for Option 1 and in Table C.2.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs. Waste management costs include the cost of disposal of the glove box only. Roughing and HEPA filters are considered separate components and are discussed in Section C.9.

C.3 Small Hot Cell

Estimated costs for decommissioning a small hot cell are shown in Table C.3.a for Option 1 and in Table C.3.b for Option 2. 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 Reference 1. Total costs include manpower, equipment and supplies, and waste management costs. For both Options 1 and 2, hot cell waste (primarily lead bricks) is sent directly to a mixed waste disposal facility; no compaction or incineration is postulated.

Table C.2.a Cost ($ thousands) for DECON of a glove box at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	0.97	1.02	1.04	–	2.71	1.10
Equipment & supplies	0.34	0.38	0.46	–	1.02	0.35
Waste management						
Packaging	0.09	0.09	0.12	–	0.11	0.10
Processing (supercompaction)	0.20	0.20	0.25	–	0.24	0.21
Processing (incineration)	–	–	–	–	–	–
Transportation	0.03	0.03	0.04	–	0.03	0.03
Disposal	1.02	1.03	1.28	–	1.23	1.04
Waste management subtotals	1.35	1.35	1.69	–	1.62	1.37
Total	2.66	2.76	3.19	–	5.35	2.82
25% Contingency	0.67	0.69	0.80	–	1.34	0.70
Totals	3.33	3.45	3.99	–	6.69	3.52

Table C.2.b Cost ($ thousands) for DECON of a glove box at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	0.97	1.02	1.04	–	2.71	1.10
Equipment & supplies	0.34	0.38	0.46	–	1.02	0.35
Waste management						
Packaging	0.09	0.09	0.12	–	0.11	0.10
Processing (supercompaction)	0.18	0.18	0.25	–	0.20	0.18
Processing (incineration)	0.24	0.25	0.03	–	0.42	0.26
Transportation	0.03	0.03	0.04	–	0.03	0.03
Disposal	0.94	0.94	1.27	–	1.08	0.95
Waste management subtotals	1.48	1.49	1.71	–	1.85	1.51
Total	2.80	2.89	3.20	–	5.59	2.96
25% Contingency	0.70	0.72	0.80	–	1.40	0.74
Totals	3.50	3.62	4.01	–	6.98	3.70

Table C.3.a Cost ($ thousands) for DECON of a small hot cell at the ^{137}Cs laboratory–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	–	–	–	5.13	–	–
Equipment & supplies	–	–	–	2.33	–	–
Waste management						
Packaging	–	–	–	0.43	–	–
Processing (supercompaction)	–	–	–	0.10	–	–
Processing (incineration)	–	–	–	–	–	–
Transportation	–	–	–	0.09	–	–
Disposal	–	–	–	13.07	–	–
Waste management subtotals	–	–	–	13.69	–	–
Total	–	–	–	21.16	–	–
25% Contingency	–	–	–	5.29	–	–
Totals	–	–	–	26.45	–	–

Table C.3.b Cost ($ thousands) for DECON of a small hot cell at the ^{137}Cs laboratory–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	–	–	–	5.13	–	–
Equipment & supplies	–	–	–	2.33	–	–
Waste management						
Packaging	–	–	–	0.43	–	–
Processing (supercompaction)	–	–	–	0.06	–	–
Processing (incineration)	–	–	–	0.49	–	–
Transportation	–	–	–	0.08	–	–
Disposal	=	=	=	12.90	=	=
Waste management subtotals	–	–	–	13.96	–	–
Total	–	–	–	21.43	–	–
25% Contingency	=	=	=	5.36	=	=
Total/w contingency	–	–	–	26.78	–	–

C.4 Laboratory Workbenches

Estimated costs for decommissioning a workbench at each facility are shown in Table C.4.a for Option 1 and in Table C.4.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs. The workbenches vary in size and composition, from facility to facility:

^{3}H lab:	Six benches, mild steel construction with plastic laminated top, 20 meters total length
^{14}C lab:	Four benches, painted wood with plastic laminated tops, 15 meters total length
^{125}I lab:	Two benches, mild painted steel with stainless steel tops, 8 meters total length
^{137}Cs lab:	One bench, painted wood with plastic laminated top, four meters long
^{241}Am lab:	One bench, painted mild steel with stainless steel top, 2 meters long
User lab:	Two benches, wood with plastic laminated tops, 24 meters total length

In order to make meaningful comparisons, the costs shown in Tables C.4.a and C.4.b are normalized for a bench 4.9 meters (16 feet) long. (All benches are assumed to be 0.75 m wide.) As can be seen from these tables, there is no obvious relation between the composition of a bench (wood or metal) and its DECON cost.

Table C.4.a Cost ($ thousands) for DECON of a workbench at each of the indicated facilities—supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	1.28	3.81	4.37	4.51	5 38	3.57
Equipment & supplies	0.45	1.43	1.91	2.05	2.02	1.13
Waste management						
Packaging	0.03	0.19	0.05	0.20	0 08	0.19
Processing (supercompaction)	0.06	0 40	0.11	0.43	0 16	0.42
Processing (incineration)	–	–	–	–	–	–
Transportation	0 01	0.06	0.02	0.06	0.02	0.06
Disposal	0 28	2 02	0.53	2.15	0 82	2.10
Waste management subtotals	0.37	2.67	0.70	2.84	1 09	2.77
Total	2.11	7 91	6.99	9 40	8 49	7.46
25% Contingency	0.53	1 98	1.75	2.35	2.12	1 87
Totals	2 63	9.89	8.74	11.75	10 61	9.33

Table C.4.b Cost ($ thousands) for DECON of a workbench at each of the indicated facilities—supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	1.28	3 81	4.37	4.51	5.38	3.57
Equipment & supplies	0.45	1.43	1.91	2.05	2.02	1.13
Waste management						
Packaging	0.03	0.19	0.05	0.20	0 08	0.19
Processing (supercompaction)	0.05	0.05	0 07	0.05	0 14	0.05
Processing (incineration)	0.10	3.64	0.35	3.88	0.28	3.78
Transportation	0 01	0.03	0.01	0.03	0.02	0.03
Disposal	0 25	0.77	0 41	0 82	0 73	0.80
Waste management subtotals	0.43	4.67	0.90	4.98	1.24	4.85
Total	2.16	9.92	7.18	11.54	8 64	9.55
25% Contingency	0.54	2 48	1.80	2.88	2.16	2.39
Totals	2.70	12.40	8.98	14.42	10.80	11.93

C.5 Ventilation Ductwork

Estimated costs for decommissioning ductwork at each facility are shown in Table C.5.a for Option 1 and in Table C.5.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs. The costs in these tables are based on a total ductwork length of 40 meters. About half the length consists of 0.1 m-diameter sheet metal; the remaining length consists of 0.25 by 0.60-m rectangular sheet metal. The exact ratio of cylindrical to rectangular ductwork varies from facility to facility.

C.6 Cabinets

Most of the reference facilities contain one or more wood or metal cabinets as indicated.

^{3}H lab:	Two wood cabinets, 0.76 m x 0.46 m x 1.5 m.
^{14}C lab:	Two wood cabinets, 0.76 m x 0.46 m x 1.5 m.
^{125}I lab:	One steel cabinet, 0.76 m x 0.61 m x 1.5 m with a 1.5 m x 0.5 m x 2.0 m steel shelf unit.
^{137}Cs lab:	None.
^{241}Am lab:	One wood cabinet, 0.76 m x 0.46 x 1.5 m.
User lab:	None.

Estimated costs for decommissioning one cabinet, either wood or metal, at each facility are shown in Table C.6.a for Option 1 and in Table C.6.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs.

Table C.5.a Cost ($ thousands) for DECON of 40 m of ventilation ductwork at each of the indicated facilities–supercompaction option

Cost Item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	7.16	7.25	8.28	8.83	7.87	7.90
Equipment & supplies	2.51	2.72	3.62	4.00	2.94	2.49
Waste Management						
Packaging	0.06	0.06	0.06	0.06	0.09	0.07
Processing (supercompaction)	0.13	0.14	0.12	0.14	0.19	0.15
Processing (incineration)	–	–	–	–	–	–
Transportation	0.02	0.02	0.02	0.02	0.03	0.02
Disposal	0.64	0.69	0.62	0.69	0.96	0.75
Waste management subtotals	0.84	0.91	0.82	0.91	1.27	0.99
Total	10.51	10.89	12.72	13.75	12.08	11.38
25% Contingency	2.63	2.72	3.18	3.44	3.02	2.84
Totals	13.14	13.61	15.90	17.18	15.10	14.22

Table C.5.b Cost ($ thousands) for DECON of 40 m of ventilation ductwork at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	7.16	7.25	8.28	8.83	7.87	7.90
Equipment & supplies	2.51	2.72	3.62	4.00	2.94	2.49
Waste management						
Packaging	0.06	0.06	0.06	0.06	0.09	0.07
Processing (supercompaction)	0.07	0.08	0.07	0.08	0.14	0.09
Processing (incineration)	0.55	0.57	0.54	0.63	0.58	0.61
Transportation	0.01	0.02	0.01	0.01	0.02	0.02
Disposal	0.45	0.50	0.43	0.47	0.77	0.54
Waste management subtotals	1.14	1.22	1.11	1.26	1.59	1.32
Total	10.81	11.20	13.02	14.10	12.40	11.71
25% Contingency	2.70	2.80	3.25	3.52	3.10	2.93
Totals	13.51	14.00	16.27	17.62	15.50	14.64

Table C.6.a Cost ($ thousands) for DECON of a cabinet at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	0.97	0.97	1.16	–	0.97	–
Equipment & supplies	0.34	0.36	0.51	–	0.37	–
Waste management						
Packaging	0.04	0.04	0.01	–	0.04	–
Processing (supercompaction)	0.09	0.09	0.02	–	0.09	–
Processing (incineration)	–	–	–	–	–	–
Transportation	0.01	0.01	0.00	–	0.01	–
Disposal	0.46	0.46	0.10	–	0.44	–
Waste management subtotals	0.60	0.60	0.13	–	0.58	–
Total	1.92	1.94	1.80	–	1.92	–
25% Contingency	0.48	0.48	0.45	–	0.48	–
Totals	2.40	2.42	2.25	–	2.40	–

Table C.6.b Cost ($ thousands) for DECON of a cabinet at each of the indicated facilities–supercompaction w/incineration

Cost Item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	0.97	0.97	1.16	–	0.97	–
Equipment & supplies	0.34	0.36	0.51	–	0.37	–
Waste management						
Packaging	0.04	0.04	0.01	–	0.04	–
Processing (supercompaction)	0.01	0.01	0.01	–	0.01	–
Processing (incineration)	0.83	0.83	0.09	–	0.79	–
Transportation	0.01	0.01	0.00	–	0.01	–
Disposal	0.17	0.17	0.07	–	0.17	–
Waste management subtotals	1.06	1.06	0.17	–	1.01	–
Total	2.38	2.39	1.85	–	2.35	–
25% Contingency	0.59	0.60	0.46	–	0.59	–
Totals	2.97	2.99	2.31	–	2.94	–

C.7 Sinks and Drains

One or more sinks and drains are present in each of the reference laboratories except the laboratory for the manufacture of ^{3}H-labeled compounds and the laboratory for the manufacture of ^{241}Am sealed sources. The sinks are used for personal cleanliness and for washing or rinsing noncontaminated glassware or glassware that has previously been contaminated. Because contaminated liquids are not purposely discharged to the sanitary sewer via these sinks, they are postulated to have low levels of radioactive contamination.

Estimated costs for decommissioning a typical sink and drain at each facility are shown in Table C.7.a for Option 1 and in Table C.7.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs.

C.8 Freezers and Refrigerators

Most facilities contain one or more of each of these appliances. It is assumed in this study that each refrigerator and freezer measures 0.61 m x 0.61 m x 1.52 m and weighs 68 kg. These units are assumed to be only mildly contaminated inside, but exterior contamination levels are assumed to be sufficiently high that it is impractical to attempt to decontaminate them to levels required for unrestricted use. Thus, they are assumed to be disposed of as radioactive LLW with only minimal decontamination.

Estimated costs for decommissioning a typical refrigerator or freezer at each facility are shown in Table C.8.a for Option 1 and in Table C.8.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs.

Table C.7.a Cost ($ thousands) for DECON of a sink or drain at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	–	0.57	0.62	0.67	–	0.57
Equipment & supplies	–	0.22	0.27	0.30	–	0.18
Waste management						
Packaging	–	0.07	0.07	0.07	–	0.07
Processing (supercompaction)	–	0.15	0.15	0.15	–	0.15
Processing (incineration)	–	–	–	–	–	–
Transportation	–	0.02	0.02	0.02	–	0.02
Disposal	=	0.77	0.77	0.77	=	0.77
Waste management subtotals	–	1.01	1.01	1.01	–	1.02
Total	–	1.80	1.90	1.99	–	1.77
25% Contingency	=	0.45	0.47	0.50	=	0.44
Totals	–	2.25	2.37	2.49	–	2.21

Table C.7.b Cost ($ thousands) for DECON of a sink or drain at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	–	0.57	0.62	0.67	–	0.57
Equipment & supplies	–	0.22	0.27	0.30	–	0.18
Waste Management						
Packaging	–	0.07	0.07	0.07	–	0.07
Processing (supercompaction)	–	0.15	0.15	0.15	–	0.15
Processing (incineration)	–	0.02	0.02	0.02	–	0.02
Transportation	–	0.02	0.02	0.02	–	0.02
Disposal	=	0.76	0.76	0.76	=	0.76
Waste management subtotals	–	1.02	1.02	1.02	–	1.03
Total	–	1.81	1.91	2.00	–	1.78
25% Contingency	=	0.45	0.48	0.50	=	0.44
Totals	–	2.26	2.39	2.50	–	2.22

Table C.8.a Cost ($ thousands) for DECON of a freezer or refrigerator at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	1.24	1.27	1.38	–	–	1.25
Equipment & supplies	0.44	0.48	0.61	–	–	0.39
Waste management						
Packaging	0.21	0.21	0.21	–	–	0.21
Processing (supercompaction)	0.46	0.46	0.46	–	–	0.46
Processing (incineration)	–	–	–	–	–	–
Transportation	0.07	0.07	0.07	–	–	0.07
Disposal	2.30	2.30	2.31	–	–	2.31
Waste management subtotals	3.03	3.03	3.05	–	–	3.05
Total	4.70	4.78	5.03	–	–	4.69
25% Contingency	1.18	1.20	1.26	–	–	1.17
Totals	5.88	5.98	6.29	–	–	5.86

Table C.8.b Cost ($ thousands) for DECON of a freezer or refrigerator at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	1.24	1.27	1.38	–	–	1.25
Equipment & supplies	0.44	0.48	0.61	–	–	0.39
Waste management						
Packaging	0.21	0.21	0.21	–	–	0.21
Processing (supercompaction)	0.40	0.40	0.41	–	–	0.41
Processing (incineration)	0.52	0.52	0.52	–	–	0.52
Transportation	0.06	0.06	0.06	–	–	0.06
Disposal	2.12	2.12	2.13	–	–	2.13
Waste management subtotals	3.32	3.32	3.33	–	–	3.33
Total	4.99	5.07	5.32	–	–	4.98
25% Contingency	1.25	1.27	1.33	–	–	1.24
Totals	6.24	6.34	6.65	–	–	6.22

C.9 Filters

The ventilation exhaust systems at each facility include roughing and HEPA filter combinations that serve the glove boxes and fume hoods. Estimated costs for decommissioning a typical filter combination at each facility are shown in Table C.9.a for Option 1 and in Table C.9.b for Option 2. Total costs include manpower, equipment and supplies, and waste management costs.

C.10 Building Surfaces

Facility ceilings, walls, and floors are decontaminated to unrestricted release levels. Contaminated material, such as acoustic ceiling panels, concrete chipped from walls or floors, or floor tiles are packaged and shipped to an LLW burial site.

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 ceiling and floor area of 60 m^2. The surface materials used in each lab are specified in Appendix D. Tables C.10.a, C.11.a, and C.12.a show the estimated costs for decommissioning 60 m^2 of ceilings, walls and floors at the various facilities using Option 1. Costs for Option 2 are shown in Tables C.10.b, C.11.b, and C.12.b. To allow direct comparison with ceiling and wall costs, Tables C.11.a and C.11.b have been adjusted to show DECON costs for 60 m^2 of wall area, even though the total wall area for the reference laboratories is 96 m^2.

Table C.9.a Cost ($ thousands) for DECON of a HEPA or roughing filter at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	0.06	0.07	0.08	0.08	0.07	0.07
Equipment & supplies	0.02	0.03	0.03	0.04	0.03	0.02
Waste management						
Packaging	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Processing (supercompaction)	0.00	0.00	0.01	0.01	0.01	0.00
Processing (incineration)	–	–	–	–	–	–
Transportation	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Disposal	0.02	0.02	0.04	0.04	0.03	0.02
Waste management subtotals	0.03	0.03	0.05	0.05	0.04	0.03
Total	0.11	0.12	0.16	0.17	0.14	0.12
25% Contingency	0.03	0.03	0.04	0.04	0.04	0.03
Totals	0.14	0.15	0.20	0.21	0.18	0.15

Table C.9.b Cost ($ thousands) for DECON or roughing filter at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	0.06	0.07	0.08	0.08	0.07	0.07
Equipment & supplies	0.02	0.03	0.03	0.04	0.03	0.02
Waste management						
Packaging	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Processing (supercompaction)	–	–	–	–	–	–
Processing (incineration)	0.04	0.04	0.07	0.08	0.06	0.04
Transportation	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Disposal	0.01	0.01	0.01	0.01	0.01	0.01
Waste management subtotals	0.05	0.05	0.09	0.10	0.07	0.05
Total	0.14	0.14	0.20	0.21	0.17	0.14
25% Contingency	0.03	0.04	0.05	0.05	0.04	0.04
Totals	0.17	0.18	0.25	0.26	0.22	0.18

Table C.10.a Cost ($ thousands) for DECON of a ceiling (60 m²) at each of the indicated facilities–supercompaction option

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	4.00	4.08	5.49	6.57	5.09	4.68
Equipment & supplies	1.41	1.54	2.42	2.99	1.92	1.48
Waste management						
Packaging	0.28	0.28	0.25	0.64	0.20	0.55
Processing (supercompaction)	0.60	0.59	0.48	1.34	0.38	1.18
Processing (incineration)	–	–	–	–	–	–
Transportation	0.09	0.08	0.07	0.20	0.06	0.17
Disposal	3.03	2.99	3.33	7.41	2.63	5.98
Waste management subtotals	3.99	3.94	4.14	9.59	3.26	7.88
Total	9.40	9.57	12.05	19.15	10.27	14.04
25% Contingency	2.35	2.39	3.01	4.79	2.57	3.51
Totals	11.76	11.96	15.07	23.94	12.84	17.55

Table C.10.b Cost ($ thousands) for DECON of a ceiling (60 m²) at each of the indicated facilities–supercompaction w/incineration

Cost item	³H lab	¹⁴C lab	¹²⁵I lab	¹³⁷Cs lab	²⁴¹Am lab	User lab
Manpower	4.00	4.08	5.49	6.57	5.09	4.68
Equipment & supplies	1.41	1.54	2.42	2.99	1.92	1.48
Waste management						
Packaging	0.28	0.28	0.25	0.64	0.20	0.55
Processing (supercompaction)	0.06	0.06	0.12	0.19	0.09	0.12
Processing (incineration)	5.54	5.47	3.72	11.85	2.92	10.94
Transportation	0.04	0.04	0.05	0.11	0.04	0.09
Disposal	1.12	1.11	2.05	3.33	1.62	2.21
Waste management subtotals	7.04	6.95	6.19	16.12	4.87	13.90
Total	12.45	12.58	14.10	25.67	11.88	20.06
25% Contingency	3.11	3.14	3.53	6.42	2.97	5.01
Totals	15.57	15.72	17.63	32.09	14.85	25.07

Table C.11.a Cost ($ thousands) for DECON of walls (60 m²) at each of the indicated facilities–supercompaction option

Cost item	³H lab	¹⁴C lab	¹²⁵I lab	¹³⁷Cs lab	²⁴¹Am lab	User lab
Manpower	3.65	3.80	5.50	5.46	4.92	6.54
Equipment & supplies	1.29	1.44	2.42	2.49	1.85	2.07
Waste management						
Packaging	0.19	0.19	0.23	0.22	0.15	0.23
Processing (supercompaction)	0.36	0.36	0.43	0.34	0.28	0.44
Processing (incineration)	–	–	–	–	–	–
Transportation	0.06	0.06	0.07	0.06	0.04	0.07
Disposal	2.46	2.63	3.18	3.63	1.93	3.12
Waste management subtotals	3.06	3.25	3.91	4.25	2.41	3.86
Total	7.99	8.48	11.83	12.21	9.18	12.47
25% Contingency	2.00	2.12	2.96	3.05	2.29	3.12
Totals	9.99	10.60	14.79	15.26	11.47	15.59

Table C.11.b Cost ($ thousands) for DECON of walls (60 m²) at each of the indicated facilities–supercompaction w/incineration

Cost item	³H lab	¹⁴C lab	¹²⁵I lab	¹³⁷Cs lab	²⁴¹Am lab	User lab
Manpower	3.65	3.80	5.50	5.46	4.92	6.54
Equipment & supplies	1.29	1.44	2.42	2.49	1.85	2.07
Waste management						
Packaging	0.19	0.19	0.23	0.22	0.15	0.23
Processing (supercompaction)	0.09	0.09	0.17	0.09	0.07	0.11
Processing (incineration)	2.76	2.80	2.64	2.65	2.17	3.38
Transportation	0.03	0.04	0.05	0.04	0.03	0.04
Disposal	1.51	1.67	2.28	2.72	1.19	1.96
Waste management subtotals	4.58	4.79	5.36	5.71	3.60	5.72
Total	9.51	10.02	13.29	13.66	10.37	14.33
25% Contingency	2.38	2.51	3.32	3.42	2.59	3.58
Totals	11.89	12.53	16.61	17.08	12.96	17.91

Table C.12.a Cost ($ thousands) for DECON of a floor (60 m²) at each of the indicated facilities–supercompaction option

Cost item	³H lab	¹⁴C lab	¹²⁵I lab	¹³⁷Cs lab	²⁴¹Am lab	User lab
Manpower	5.25	5.51	5.97	6.53	5.41	5.87
Equipment & supplies	1.85	2.08	2.63	2.98	2.04	1.86
Waste management						
Packaging	0.07	0.09	0.10	0.10	0.20	0.10
Processing (supercompaction)	0.15	0.20	0.21	0.21	0.38	0.23
Processing (incineration)	–	–	–	–	–	–
Transportation	0.02	0.03	0.03	0.03	0.06	0.03
Disposal	0.74	0.99	1.05	1.05	2.63	1.14
Waste management subtotals	0.97	1.30	1.38	1.38	3.26	1.50
Total	8.08	8.89	9.98	10.88	10.71	9.23
25% Contingency	2.02	2.22	2.50	2.72	2.68	2.31
Totals	10.10	11.11	12.48	13.60	13.39	11.54

Table C.12.b Cost ($ thousands) for DECON of a floor (60 m^2) at each of the indicated facilities–supercompaction w/incineration

Cost item	^{3}H lab	^{14}C lab	^{125}I lab	^{137}Cs lab	^{241}Am lab	User lab
Manpower	5.25	5.51	5.97	6.53	5.41	5.87
Equipment & supplies	1.85	2.08	2.63	2.98	2.04	1.86
Waste management						
Packaging	0.07	0.09	0.10	0.10	0.20	0.10
Processing (supercompaction)	0.15	0.16	0.16	0.16	0.09	0.19
Processing (incineration)	–	0.37	0.53	0.53	2.92	0.37
Transportation	0.02	0.03	0.03	0.03	0.04	0.03
Disposal	0.74	0.86	0.86	0.86	1.62	1.01
Waste management subtotals	0.97	1.50	1.67	1.67	4.87	1.70
Total	8.08	9.09	10.28	11.17	12.32	9.43
25% Contingency	2.02	2.27	2.57	2.79	3.08	2.36
Totals	10.10	11.36	12.84	13.97	15.40	11.79

Appendix D

Details of Decommissioning Reference Facilities

Appendix D

Details of Decommissioning Reference Facilities

This appendix provides detailed descriptions (sizes, areas, weights, and volumes) of each potentially contaminated component in the six reference facilities. The methods used to partially decontaminate and remove the components are also described. At the end of each major section, detailed cost and manpower breakdowns for the facility being analyzed are given for the two decommissioning options: (1) DECON with supercompaction and (2) DECON with supercompaction and incineration.

D.1 Reference Laboratory for the Manufacture of ^3H-Labeled Compounds

Detailed physical descriptions and decommissioning procedures for all the components and building surfaces of the ^3H laboratory that are postulated to require removal and/or decontamination are given in Sections D.1.1 through D.1.10. Details of (1) planning and preparation, (2) estimated manpower requirements, (3) waste management, materials, and labor costs, and (4) radiation dosages are presented in Table D.1a for the supercompaction option and in Table D.1b for the supercompaction option with incineration. An overall description of this laboratory is contained in Section 7.1.1 of Reference 1.

D.1.1 Fume Hoods

The ^3H facility contains five fume hoods, each measuring 1.5 m wide x 2.0 m high x 0.945 m deep. Each hood is assumed to be framed externally by mild steel 0.003175 meters thick. Each hood is equipped with an acrylic window 0.00635 m thick. The hood is assumed to rest on an enclosed stainless steel-based cabinet (Fig A.5-1, Reference 1). The support cabinet is assumed to have the same foot print as the fume hood but is only 0.9 m high.

As with essentially all other materials from the various NFC facilities, the fume hoods and the lower cabinets upon which they rest are assumed to be cut up, packaged, and placed in 208-liter drums for disposal as LLW waste. The interior and exterior of the fume hood surfaces are first vacuumed and wet-wiped, then dried and painted to fix contamination. The hoods are then cut to sizes that allow the hood materials to be bagged and placed in 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site.

Amount of Stainless Steel in the Upper Section

Back: 1.5 x 2.0	= 3.00 m^2
Two sides: 2 x 0.945 x 2.0	= 3.78 m^2
Floor and Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 9.615 m^2
Total Volume: 0.003175 x 9.615	= 0.03053 m^3
Total Volume for 5 Hoods	= 0.1526 m^3
Total Weight for 5 Hoods	= 1,221 kg

Table D.1a ^3H Lab summary–supercompaction option; Manpower requirements, radiation doses, and costs for decommissioning the ^3H laboratory–supercompaction option (no incineration)

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech.	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	5.0	--	5.0	--	10.0	--	--	15.0	5.58	5.3
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	30.0	12.5	30.0	--	15.0	--	12.5	70.0	5.58	23.5
Decommissioning										
Fume hoods	6.2	3.1	5.2	1.4	3.1	10.5	--	23.3	34.21	8.7
Glove boxes	2.2	1.1	2.0	0.6	1.1	3.9	--	8.7	3.44	3.2
Workbenches	2.3	1.1	1.7	0.9	1.1	3.4	--	8.3	0.00	3.1
Vent ducts	2.9	1.5	2.2	1.1	1.5	4.4	--	10.6	0.00	4.0
Cabinets	0.8	0.4	0.6	0.3	0.4	1.2	--	2.9	0.00	1.1
Freezer and refrigerators	1.5	0.7	1.2	0.4	0.7	2.5	--	5.5	0.01	2.1
Filters	0.6	0.3	0.6	--	0.3	1.2	--	2.5	0.00	0.9
Ceiling	2.8	1.4	2.8	0.8	1.4	5.6	--	11.9	0.01	4.4
Walls	3.0	1.5	3.0	--	1.5	6.0	--	12.0	0.01	4.4
Floors	3.9	2.0	3.9	--	2.0	7.8	--	15.7	0.00	5.8
Subtotals	26.1	13.1	23.2	5.4	13.1	46.5	--	101.2	37.68	37.7
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	1.1
Laundry	--	--	--	--	--	--	--	--	--	2.6
Subtotals	--	--	--	--	--	--	--	--	--	24.0
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	3.2
Supercompaction	--	--	--	--	--	--	--	--	--	6.9
Incineration	--	--	--	--	--	--	--	--	--	--
Transportation	--	--	--	--	--	--	--	--	--	1.0
Disposal	--	--	--	--	--	--	--	--	--	36.1
Subtotals	--	--	--	--	--	--	--	--	--	47.2
Final radiological survey	5.0	2.5	5.0	--	10.0	--	5.0	22.5	--	6.9
Totals	61.1	28.1	58.2	5.4	38.1	46.5	17.5	193.7	43.26	139.3
25% Cost contingency	--	--	--	--	--	--	--	--	--	34.8
Total cost with contingency	--	--	--	--	--	--	--	--	--	174.1

Table D.1b ^{3}H Lab summary–incineration option; manpower requirements, radiation doses, and costs for decommissioning the ^{3}H laboratory–supercompaction and incineration option

Operation or category	Time (days)	Person-days: Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	5.0	--	5.0	--	10.0	--	--	15.0	5.58	5.3
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	30.0	12.5	30.0	--	15.0	--	12.5	70.0	5.58	23.5
Decommissioning										
Fume hoods	6.2	3.1	5.2	1.4	3.1	10.5	--	23.3	34.21	8.7
Glove boxes	2.2	1.1	2.0	0.6	1.1	3.9	--	8.7	3.44	3.2
Workbenches	2.3	1.1	1.7	0.9	1.1	3.4	--	8.3	0.00	3.1
Vent ducts	2.9	1.5	2.2	1.1	1.5	4.4	--	10.6	0.00	4.0
Cabinets	0.8	0.4	0.6	0.3	0.4	1.2	--	2.9	0.00	1.1
Freezer and refrigerators	1.5	0.7	1.2	0.4	0.7	2.5	--	5.5	0.01	2.1
Filters	0.6	0.3	0.6	--	0.3	1.2	--	2.5	0.00	0.9
Ceiling	2.8	1.4	2.8	0.8	1.4	5.6	--	11.9	0.01	4.4
Walls	3.0	1.5	3.0	--	1.5	6.0	--	12.0	0.01	4.4
Floors	3.9	2.0	3.9	--	2.0	7.8	--	15.7	0.00	5.8
Subtotals	26.1	13.1	23.2	5.4	13.1	46.5	--	101.2	37.68	37.7
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	1.1
Laundry	--	--	--	--	--	--	--	--	--	2.6
Subtotals	--	--	--	--	--	--	--	--	--	24.0
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	3.2
Supercompaction	--	--	--	--	--	--	--	--	--	4.3
Incineration	--	--	--	--	--	--	--	--	--	26.4
Transportation	--	--	--	--	--	--	--	--	--	0.8
Disposal	--	--	--	--	--	--	--	--	--	27.0
Subtotals	--	--	--	--	--	--	--	--	--	61.8
Final radiological survey	5.0	2.5	5.0	--	10.0	--	5.0	22.5	--	6.9
Totals	61.1	28.1	58.2	5.4	38.1	46.5	17.5	193.7	43.26	153.8
25% Cost contingency	--	--	--	--	--	--	--	--	--	38.5
Total cost with contingency	--	--	--	--	--	--	--	--	--	192.3

Amount of Stainless Steel in the Lower Cabinet

Back & Front: 2 x 1.5 x 0.90	= 2.700 m^2
Two Sides: 2 x 0.945 x 0.9	= 1.701 m^2
Bottom & Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 7.236 m^2
Total Volume: 0.003175 x 7.236	= 0.02297 m^3
Total Volume for 5 Hoods	= 0.1149 m^3
Total Weight for 5 Hoods	= 919 kg

Amount of Mild Steel in the Exterior Frame

The frame is assumed to be comprised of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 2.0 m for vertical members and 4 x 1.5 m for horizontal members, for a total length of 14 m. Total mild steel in the fume hood frame is thus 14 m x (0.0508 + 0.04445) x 0.0047626 = 0.006351 m^3.

Total Volume for 5 Hoods	= 0.03176 m^3
Total Weight for 5 Hoods	= 254 kg

Amount of Acrylic Plastic in the Window

The plastic is assumed to be 2.0 m high x 1.5 m wide x 0.00635 m thick, for a total volume of 0.01905 m^3.

Total Volume for 5 Hoods	= 0.09525 m^3
Total Weight for 5 Hoods (specific gravity = 1.2)	= 114 kg

Amount of Processing Equipment

Although difficult to estimate because of the wide variety of processing equipment, an allowance is made for the bulk quantity of materials and equipment in the fume hoods. The following general type of contaminated equipment is postulated to be present in the fume hood. The equipment is bagged and compacted on-site, supercompacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For 5 fume hoods, the total is 10 electric heating units, with a total weight of 70 kg and a total bulk volume of 0.3 m^3.
- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 5 fume hoods, the total is 30 units of processing glassware, with a total weight of 90 kg, and a total bulk volume of 0.6 m^3.
- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 5 fume hoods the total is 20 items, with a total weight of 40 kg, and a total bulk volume of 0.284 m^3.

D.1.2 Glove Boxes

The ^3H facility contains six glove boxes. Each measures 0.9 m wide x 0.6 m high x 0.6 m deep (Reference 1, p. A-33), rests on a workbench (Reference 1, p. 7-8), and is assumed to be framed by mild steel externally, with 0.003175-m-thick stainless steel walls, and 0.00635-m-thick acrylic windows. The glove box has a stainless steel panel across the lower 0.25 m of the front, in which are located two 0.2-m-diameter circular openings for plastic working gloves. Above this panel, the front of the glove box slopes backward at an angle of about 40 degrees, providing an opening for the acrylic plastic viewing window. The viewing window is mounted in a mild steel metal frame which is gasketed to the sloping front of the glove box. At one end of the glove box is a stainless steel airlock for the insertion of equipment and material into the box. Airlock dimensions are 0.3 m high x 0.2 m wide x 0.2 m deep (Reference 1, p. A.33). One acrylic air lock door is accessible from outside the glove box, and one is accessible from inside the box through the use of glove ports. Standard electrical receptacles are located on the inside of the glove box, with power controlled by switches mounted outside on a service panel above the glove box.

Before the glove boxes are dismantled, the interior and exterior surfaces are vacuumed and wet-wiped, and then painted to fix contamination. The glove boxes are then cut to sizes that allow the bagged glove box materials to go into 208-liter drums in such a way that the materials can be reasonably compacted on-site, supercompacted off-site, and then disposed of as LLW. The acrylic plastic, the steel materials, and the equipment inside the glove box are segregated into 208-liter drums, each with one of these categories of materials.

Amount of Stainless Steel in Glove Box and Access Air Lock

Glove Box Proper.	
Back: 0.9 x 0.6	= 0.54 m^2
Bottom: 0.9 x 0.6	= 0.54 m^2
Two sides: 2 x 0.6 x 0.6	= 0.72 m^2
Top: 0.3 x 0.9	= 0.27 m^2
Lower Front Panel: 0.25 x 0.9	= 0.225 m^2
Total Area	= 2.295 m^2
Total Volume: 0.003175 x 2.295	= 0.00729 m^3
Total Volume for 6 Boxes	= 0.0437 m^3
Total Weight for 6 Boxes	= 350 kg
Air Lock.	
Back: 0.3 x 0.2	= 0.06 m^2
Top, Side, Bottom: 3 x 0.2 x 0.2	= 0.12 m^2
Total Area	= 0.18 m^2
Total Volume: 0.003175 x 0.18	= 0.0005715 m^3
Total Volume for 6 Boxes	= 0.00343 m^3
Total Weight for 6 Boxes	= 27 kg
Total Stainless Steel Volume for 6 Boxes	= 0.0472 m^3
Total Stainless Steel Weight for 6 Boxes	= 377 kg

Amount of Mild Steel in the Exterior Frame

The frame is assumed to be comprised of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 0.6 m for vertical members and 4 x 0.9 m for horizontal members, for a total length of 6.9 m. Total mild steel in the frame is thus 6.9 x (0.0508 + 0.04445) x 0.0047626 = 0.00313 m^3.

Total Volume for 6 Boxes	= 0.01878 m^3
Total Weight for 6 Boxes	= 150 kg

Amount of Acrylic Plastic in the Main Window and Air Lock

Main Window. The plastic is assumed to be 0.6 m high x 0.9 m wide x 0.00635 m thick, giving a volume of 0.003429 m^3.

Total Volume for 6 Boxes	= 0.020574 m^3
Total Weight for 6 Boxes (s.g. = 1.2)	= 24.7 kg

Airlock. Each of the two windows is assumed to measure 0.3 m x 0.2 m x 0.00635 m. This gives a total volume of 0.000762 ^{3}.

Total Volume for 6 Boxes	= 0.004572 m^3
Total Weight for 6 Boxes (s.g. = 1.2)	= 5.5 kg

Total Volume of Acrylic for 6 Boxes	= 0.02515
Total Weight of Acrylic for 6 Boxes	= 30 kg

Amount of Processing Equipment

The following general type of contaminated equipment is postulated to be present in the glove boxes. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW:

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For the 6 glove boxes, the total is 12 electric heating units, with a total weight of 84 kg and a total bulk volume of 0.36 m^3.

- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 6 glove boxes, the total is 36 units of processing glassware, with a total weight of 108 kg, and a total bulk volume of 0.72 m^3.

- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 6 glove boxes the total is 24 items, with a total weight of 48 kg, and a total bulk volume of 0.336 m^3.

D.1.3 Workbenches

The six workbenches in the ^3H facility have a total combined length of 20 m (Reference 1, pp 7-8 & 7-9 & p. 9-8). The benches are assumed to be 8 m, 4 m, 3 m, 3 m, 1 m, and 1 m long. The workbenches are made of mild steel and have plastic-laminated tops and are assumed to have no drawers. The benches are 0.75 m wide, 0.9 m high, and are assumed to be open (like tables) and stand on 0.0015875 m-thick mild steel legs that are spaced every 1.5 m. The legs are assumed to be 0.075-m-square box-channels. The workbenches are postulated to have a square U-shaped channel all around the top, and every 0.5 m across the depth for structural support. These channels are postulated to be 0.05 m on each side and 0.0015875 m thick. The top steel surface is assumed to be 0.003175 meters thick. The plastic laminate top cover of the bench is assumed to be 0.0015875-m-thick polycarbonate.

To reduce loose contamination, the workbenches are first vacuumed and wet-wiped. They are then bagged and placed in 208-liter drums. The drums are compacted on-site, supercompacted off-site, and then sent to disposal as LLW. The dimensions and the large number of legs on the benches makes the benches relatively easy to cut into sections for salvage of some of the bench sections, if desirable.

Amount of Mild Steel in the Workbench Tops and Reinforcing

Top: 20 x 0.75 = 15 m^2
U-channels Under Bench Tops: 2 x (8 + 0.75) + 2 x (4 + 0.75) + 4 x (3 + 0.75) + 4 x (1 + 0.75)
= 49 meters (perimeter of all benches)
Area: 49 x 3 x 0.05 = 7.35 m^2
Reinforcing U Channels:
8-m-bench: 15 x 0.75 x 3 x 0.05 = 1.6875 m^2
4-m-bench: 7 x 0.75 x 3 x 0.05 = 0.7875 m^2
Two 3-m-benches: 2 x 5 x 0.75 x 3 x 0.05 = 1.125 m^2
Two 1-m-benches: 2 x 1 x 0.75 x 3 x 0.05 = 0.225 m^2
Total Area = 3.825 m^2
Total Volume: 15 x 0.003175 + (7.35 + 3.825) x 0.0015875 = 0.0654 m^3
Total Weight: 8000 x 0.0654 = 523 kg

Amount of Mild Steel in the Workbench Legs

Number of legs for 8-m-bench: 2 x Int[8/1.5] = 12
Number of legs for 4-m-bench: 2 x Int[4/1.5] = 6
Number of legs for both 3-m-benches: 4 x Int[3/1.5] = 8
Number of legs for both 1-m-benches: = 8
Total Legs = 34
Area: 34 x 0.9 x 4 x 0.075 = 9.18 m^2
Volume: 9.18 x 0.0015875 = 0.01457 m^3
Weight: 8000 x 0.1457 = 116.6 kg

Amount of Polycarbonate on the Surfaces of the Workbenches

Volume: 15 x 0.0015875 = 0.0238 m^3
Weight: 1200 x 0.0283 = 28.6 kg

Amount of Processing Equipment on Each Workbench

This is difficult to estimate because of the wide variety of processing equipment. It is assumed that the workbenches were used for radioactive counting equipment, which had to stay clean; for tools (again, assumed to be free of contamination) for making small new parts for the hoods and glove boxes; for temporary storage of nonradioactive materials; for weighing and overpacking the products (again, expected to be a relatively clean operation); and other similar uses. The following general type of contaminated equipment is postulated to be present on the workbenches.

- various hand tools including a vise, primarily steel, weighing a total estimated 30 kg, with a total gross volume estimated to be 0.02 m^3.

- 6 significant items of processing glassware, each weighing about 3 kg and assumed to take up about 0.02 m^3 of bulk space each. For the 6 glass items, the items would weigh a total of about 18 kg and require 0.12 m^3 of total bulk space.

- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. For these 4 items, the total weight is estimated at 8 kg, with an estimated total volume of 0.008 m^3.

D.1.4 Vent Ducts

The facility contains 20 m of cylindrical ductwork 0.2 m in diameter and 20 m of rectangular ductwork 0.25 m x 0.6 m in cross-section (Reference 1, p. 9-8). The ductwork is assumed to be stainless steel sheet metal 0.0015875 m thick. The ductwork is assumed to be radioactively contaminated internally and externally. The ductwork is vacuumed and wet-wiped where possible to remove the readily-removable contamination, then painted to minimize contamination during subsequent steps. The duct waste is cut into pieces that maximize the amount of material that can fit in 208-liter drums. The waste pieces are placed in plastic bags before being placed in the drums. The waste-filled drums are then compacted on-site and then shipped off-site for supercompaction before disposal as LLW.

Amount of Material in the Ductwork

Cylindrical Ductwork Volume	$= \pi \times 0.2 \times 20 \times 0.0015875 = 0.020\ m^3$
Rectangular Ductwork Volume	$= 2 \times (0.25 + 0.6) \times 20 \times 0.0015875 = 0.054\ m^3$
Total Volume	$= 0.074\ m^3$
Total Weight	= 432 kg

D.1.5 Cabinets

The ^3H facility contains two cabinets, each postulated to be constructed of 0.01905-m-thick latex-painted wood (Reference 1, p. 9-8). The dimensions of each cabinet are assumed to be 0.762 m wide x 0.4572 m deep x 1.524 m high. Each cabinet is assumed to have 2 locking doors, and 3 shelves plus the bottom inside shelf.

Both cabinets are given only mild decontamination by vacuuming and wet-wiping. The material is then painted and sectioned. The sectioned waste is then bagged and placed in 208-liter drums for on-site compaction. The drums are then shipped off-site for supercompaction. If the incineration option is used, the waste is sent off-site for incineration and fixation of the ashes into a monolithic solid. The fixed solid is sent for disposal as LLW.

Amount of Material In Each Cabinet to be Disposed of as Waste

Front and Back: 2 x 0.762 x 1.524 x 0.01905	$= 0.0442\ m^3$
Two Sides: 2 x 0.4572 x 1.524 x 0.01905	$= 0.0265\ m^3$
Top, Bottom, 3 Shelves: 5 x 0.762 x 0.4572 x 0.01905	$= 0.0332\ m^3$
Total Volume	$= 0.1039\ m^3$
Total Volume for 2 Cabinets	$= 0.2078\ m^3$
Total Weight for 2 Cabinets (s.g. = 0.8)	= 166.24 kg

D.1.6 Freezer and Refrigerators

The ^3H facility contains one freezer and two refrigerators, all postulated to be upright units, with the same dimensions of 0.6096 m x 0.6096 m x 1.524 m. The three units are assumed to be only mildly contaminated inside. But outside, the compressor, coils, fan, and other mechanisms are assumed to be sufficiently contaminated that it would not be reasonable to try to decontaminate them to levels required for unrestricted use. Thus, they are assumed to be disposed of as radioactive waste with only minimal decontamination. It is assumed that the freon (not contaminated) will be removed on-site by a subcontractor. The units will then be vacuumed, wiped and painted, and then cut up and bagged into 208-liter drums for on-site compacting. The units will then be shipped off-site for supercompacting before disposal as LLW. Sectioning will be done to effectively use the space in the drums.

Amount of Material in the Three Units

This is based on the gross characteristics of conventional refrigerators and freezers. Each unit will contain the refrigeration cooling system (copper, steel, other metals), some framework (mild steel), plastic inner and outer walls separated by fiber-glass insulation, some plastic trays and glass and mild steel shelves inside. The sectioned and pre-compacted volume of the three units is assumed to be the same as when whole, or 3 x 0.6096 x 0.6096 x 1.524 = 1.699 m^3. The overall weight of each refrigerator or freezer unit is assumed to be 68 kg, for a total weight of 204 kg.

D.1.7 HEPA and Roughing Filters

Each fume hood (5) and glove box (6) in the ^{3}H facility has a HEPA and roughing filter on its ventilation exhaust. The facility uses the 11 HEPA and roughing filters during normal operation (Reference 1, p. 9-8). No other HEPA or roughing filters are in the facility. It is postulated that the facility filters had been replaced at the end of the operating period, and they will last throughout the total decommissioning period. In addition, it is assumed that during the vacuuming activity of the components and the facility, a commercial vacuum unit is leased that uses a roughing filter and a HEPA filter identical to those in the facility, and 2 sets of filters are used during vacuuming, bringing the total to 13 sets. The filter removal is one of the last activities undertaken during decommissioning. Each filter is sealed in a plastic bag during its removal. Each HEPA filter is 0.2 m in diameter and 0.2 m high (Reference 1, p. 9-8). The roughing filters (Reference 1, p. 9-8) are 0.2 m in diameter x 0.1 m high. It is assumed that the filters are comprised of sheet-metal casing with pleated paper as the filter medium. It is postulated that the filters are bagged, placed in 208-liter drums for on-site compaction, followed by shipment off-site for supercompaction before being packaged for disposal as LLW.

Amount of Material in the HEPA and Roughing Filters

The bulk (rectangular) volume of the 13 HEPA filters is 13 x 0.2 x 0.2 x 0.2 = 0.104 m^3. The overall weight of each HEPA filter is assumed to be 5 kg. Thus, the total weight of the 13 HEPA filters is 65 kg.

The bulk (rectangular) volume of the 13 roughing filters is 13 x 0.2 x 0.2 x 0.1 = 0.052 m^3. The overall weight of each roughing filter is assumed to be 2.5 kg. Thus, the total weight of the 13 roughing filters is 32.5 kg.

D.1.8 Facility Ceiling

The ^{3}H facility ceiling consists of 120 m^2 of acoustically-treated fiberboard (Reference 1, p. 9-8) that is suspended (above which some piping and electrical wiring is mounted). The fiberboard is in panels that are typically 0.3 m x 0.3 m, or 0.3 m x 0.6 m. Each panel can be removed separately.

The fiberboard, postulated to be 0.0127 m thick, has a rough surface and many pores, making it impractical to decontaminate. The ceiling panels are first vacuumed and painted to fix the contamination, then are removed for disposal as radioactive waste. The ceiling materials are broken up if necessary and bagged and inserted into 208-liter drums. The waste is then compacted on-site before being transported off-site for supercompaction and disposal as LLW. If the incineration option is used, the resultant ash is fixated into a monolithic solid. The specific gravity (s.g.) of the fiberboard is assumed to be 0.5.

Amount of Material in the Ceiling

Total volume: 120 m^2 x 0.0127 m = 1.524 m^3

The estimated pre-compacted bulk volume is assumed to be twice the actual volume, or about 3.0 m^3. The total weight is 762 kg.

D.1.9 Facility Walls

The 132 m^2 of walls of the ^{3}H facility (Reference 1, p. 9-8) are plasterboard (postulated to be 0.015875 m thick), painted with latex enamel. It is assumed that the walls are decontaminated to unrestricted use levels to maintain the wall surfaces and to keep from contaminating the wall insulation and structural members behind the walls. The walls are first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the walls are wiped with dry rags and allowed to dry completely. For final decontamination, strippable paint is brushed or rolled on, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, or spot-painted again with strippable paint. Only the materials used for decontamination are assumed to become LLW. These are bagged and placed in 208-liter drums.

Amounts of Waste Materials Resulting from Decontaminating the Walls

The estimates developed in Reference 1, p. E-30, for the wash/wipe operations seem reasonable for the decontamination procedures used in that study, but in this study, far less of the liquid decontaminating agent is assumed to be used, with part of the decontamination being done with strippable paint. Thus, the amount of rags, brushes, and liquid wastes here are taken to be 1/3 of those in Reference 1, with adjustments for wall area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 2.67 208-liter drums of wet rags, brushes and contaminated gloves and other clothing (Reference 1). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes before treatment is 50 kg.

- 0.67 208-liter drums of aqueous decontamination solutions (assumed to have small amounts of detergents) and rinse solutions from washing/wiping decontamination, before solidification with an adsorbent material. Estimated weight of the wastes before solidification is 110 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 2 208-liter drums equivalent of removed strippable paint (assumed in this study) to be reduced to one drum after on-site compaction. Estimated weight of the LLW is 50 kg. The waste is compacted on-site, then sent to supercompaction for disposal as LLW.

D.1.10 Facility Floor

The floors of the ^{3}H facility (Reference 1, p. 7-7) consist of 120 m^2 of asphalt tile (postulated to be 0.0015875 m thick) over plywood (postulated to be 0.01905 m thick): The specific gravity of the tiles is assumed to be 1.1.

The floor is postulated to be first vacuumed and then painted to fix the remaining contamination. The tiles are removed manually and packaged in bags and placed in 208-liter drums as LLW. The remaining hot spots in the wood sub-flooring are cleaned by a small amount of scraping or planing. The wood scrapings are bagged and placed in 208-liter drums for on-site compacting, followed by off-site incineration. The final ash content is assumed to be 5 wt%.

Amount of Floor Tile Waste

Total Volume of Floor Tiles:	120 x 0.0015875	= 0.191 m^3
Total Weight of Floor Tiles:	1100 x 0.191	= 210 kg

The floor tiles are compacted on-site, supercompacted off-site, and then sent for disposal as LLW.

Amount of Wood Scraping Waste

The amount of wood scrapings removed as radioactive waste is difficult to estimate. A number of the cracks between the tiles will have contaminated wood that needs to be removed, probably to a depth of about 0.003 m. The total amount of wood scrapings removed as radioactive waste is assumed to be 70 kg, with an assumed bulk specific gravity of 0.4, for a gross volume before compaction of 0.175 m^3.

D.2 Reference Laboratory for the Manufacture of ^{14}C-Labeled Compounds

Detailed physical descriptions and decommissioning procedures for all the components and building surfaces of the ^{14}C laboratory that are postulated to require removal and/or decontamination are given in Sections D.2.1 through D.2.11. Details of (1) planning and preparation, (2) estimated manpower requirements, (3) waste management, materials, and labor costs, and (4) radiation dosages are presented in Table D.2a for the supercompaction option and in Table D.2b for the supercompaction option with incineration. An overall description of this laboratory is contained in Section 7.1.2 of Reference 1.

D.2.1 Fume Hoods

The ^{14}C facility contains four fume hoods, each measuring 1.5 m wide x 2.0 m high x 0.945 m deep. Each hood is assumed to be framed externally by mild steel 0.003175 m thick. Each hood is equipped with an acrylic window 0.00635 m thick. The hood is assumed to rest on an enclosed stainless steel-based cabinet (Fig A.5-1, Reference 1). The support cabinet is assumed to have the same foot print as the fume hood but is only 0.9 m high.

Before dismantling, the interior and exterior of the fume hood surfaces are first vacuumed and wet-wiped, then dried and painted to fix contamination. The hoods are then cut to sizes that allow the hood materials to be bagged and placed in 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site.

Amount of Stainless Steel Upper Section

Back: 1.5 x 2.0	= 3.00 m^2
Two sides: 2 x 0.945 x 2.0	= 3.78 m^2
Floor and Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 9.615 m^2
Total Volume: 0.003175 x 9.615	= 0.03053 m^3
Total Volume for 4 Hoods	= 0.12212 m^3
Total Weight for 4 Hoods	= 977 kg

Amount of Stainless Steel in the Lower Cabinet

Back & Front: 2 x 1.5 x 0.90	= 2.700 m^2
Two Sides: 2 x 0.945 x 0.9	= 1.701 m^2
Bottom & Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 7.236 m^2
Total Volume: 0.003175 x 7.236	= 0.02297 m^3
Total Volume for 4 Hoods	= 0.09188 m^3
Total Weight for 4 Hoods	= 184 kg

Table D.2a ^{14}C Lab summary–supercompaction option; manpower requirements, radiation doses, and costs for decommissioning the ^{14}C laboratory–supercompaction option (no incineration)

Operation or category	Time (days)	Person-days: Supervisor	Foreman	Craftsman	H.P. Tech	Tech.	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	–	–	–	7.5	30.0	–	9.9
Perform radiological survey	3.5	–	3.5	–	7.0	–	–	10.5	0.01	3.7
Develop work plan	10.0	5.0	10.0	–	5.0	–	5.0	25.0	–	8.3
Subtotals	28.5	12.5	28.5	–	12.0	–	12.5	65.5	0.01	21.9
Decommissioning										
Fume hoods	5.0	2.5	4.2	1.1	2.5	8.5	–	18.8	0.03	7.0
Glove boxes	1.5	0.8	1.3	0.4	0.8	2.7	–	5.9	0.00	2.2
Workbenches	5.0	2.5	3.8	1.5	2.5	7.6	–	17.9	0.00	6.7
Vent ducts	2.2	1.1	1.6	0.8	1.1	3.2	–	7.8	0.01	2.9
Cabinets	0.8	0.4	0.6	0.2	0.4	1.2	–	2.8	0.00	1.0
Freezer and refrigerators	1.5	0.7	1.2	0.4	0.7	2.5	–	5.5	0.00	2.1
Filters	0.5	0.2	0.5	–	0.2	1.0	–	2.0	0.00	0.7
Sink and drain	0.2	0.1	0.2	0.1	0.1	0.4	–	0.8	0.00	0.3
Ceiling	1.8	0.9	1.8	0.5	0.9	3.7	–	7.9	0.00	2.9
Walls	2.5	1.2	2.5	–	1.2	5.0	–	9.9	0.00	3.7
Floors	2.7	1.3	2.7	–	1.3	5.3	–	10.6	0.01	3.9
Subtotals	23.6	11.8	20.5	5.0	11.8	40.9	–	90.0	0.06	33.5
Equipment and materials cost										
Commercial vacuum cleaner	–	–	–	–	–	–	–	–	–	3.0
Compactor	–	–	–	–	–	–	–	–	–	17.2
Small tools & materials	–	–	–	–	–	–	–	–	–	1.0
Laundry	–	–	–	–	–	–	–	–	–	2.2
Subtotals	–	–	–	–	–	–	–	–	–	23.5
Waste management costs										
Packaging	–	–	–	–	–	–	–	–	–	3.2
Supercompaction	–	–	–	–	–	–	–	–	–	6.8
Incineration	–	–	–	–	–	–	–	–	–	–
Transportation	–	–	–	–	–	–	–	–	–	1.0
Disposal	–	–	–	–	–	–	–	–	–	35.9
Subtotals	–	–	–	–	–	–	–	–	–	46.9
Final radiological survey	5.0	2.5	5.0	–	10.0	–	5.0	22.5	–	6.9
Totals	57.1	26.8	54.0	5.0	33.8	40.9	17.5	178.0	0.07	132.7
25% Cost contingency	–	–	–	–	–	–	–	–	–	33.2
Total cost with contingency	–	–	–	–	–	–	–	–	–	165.9

Table D.2b ^{14}C Lab summary–incineration option; manpower requirements, radiation doses, and costs for decommissioning the ^{14}C laboratory–supercompaction and incineration option

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech.	Clerk	Total person-days	Person-mrem	Costs ($000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	3.5	--	3.5	--	7.0	--	--	10.5	0.01	3.7
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	28.5	12.5	28.5	--	12.0	--	12.5	65.5	0.01	21.9
Decommissioning										
Fume hoods	5.0	2.5	4.2	1.1	2.5	8.5	--	18.8	0.03	7.0
Glove boxes	1.5	0.8	1.3	0.4	0.8	2.7	--	5.9	0.00	2.2
Workbenches	5.0	2.5	3.8	1.5	2.5	7.6	--	17.9	0.00	6.7
Vent ducts	2.2	1.1	1.6	0.8	1.1	3.2	--	7.8	0.01	2.9
Cabinets	0.8	0.4	0.6	0.2	0.4	1.2	--	2.8	0.00	1.0
Freezer and refrigerators	1.5	0.7	1.2	0.4	0.7	2.5	--	5.5	0.00	2.1
Filters	0.5	0.2	0.5	--	0.2	1.0	--	2.0	0.00	0.7
Sink and drain	0.2	0.1	0.2	0.1	0.1	0.4	--	0.8	0.00	0.3
Ceiling	1.8	0.9	1.8	0.5	0.9	3.7	--	7.9	0.00	2.9
Walls	2.5	1.2	2.5	--	1.2	5.0	--	9.9	0.00	3.7
Floors	2.7	1.3	2.7	--	1.3	5.3	--	10.6	0.01	3.9
Subtotals	23.6	11.8	20.5	5.0	11.8	40.9	--	90.0	0.06	33.5
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	1.0
Laundry	--	--	--	--	--	--	--	--	--	2.2
Subtotals	--	--	--	--	--	--	--	--	--	23.5
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	3.2
Supercompaction	--	--	--	--	--	--	--	--	--	3.7
Incineration	--	--	--	--	--	--	--	--	--	32.2
Transportation	--	--	--	--	--	--	--	--	--	0.7
Disposal	--	--	--	--	--	--	--	--	--	24.8
Subtotals	--	--	--	--	--	--	--	--	--	64.7
Final radiological survey	5.0	2.5	5.0	--	10.0	--	5.0	22.5	--	6.9
Totals	57.1	26.8	54.0	5.0	33.8	40.9	17.5	178.0	0.07	150.5
25% Cost contingency	--	--	--	--	--	--	--	--	--	37.6
Total cost with contingency	--	--	--	--	--	--	--	--	--	188.1

Amount of Mild Steel in the Exterior Frame

The frame is assumed to be made of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 2.0 m for vertical members and 4 x 1.5 m for horizontal members, for a total length of 14 m. Total mild steel in the fume hood frame is thus 14 m x (0.0508 + 0.04445) x 0.0047626 = 0.006351 m^3.

Total Volume for 4 Hoods	= 0.0254 m^3
Total Weight for 4 Hoods	= 203 kg

Amount of Acrylic Plastic in the Window

The plastic is assumed to be 2.0 m high x 1.5 m wide x 0.00635 m thick, for a total volume of 0.01905.

Total Volume for 4 Hoods	= 0.0762 m^3
Total Weight for 4 Hoods (s.g. = 1.2)	= 91.4 kg

Amount of Processing Equipment

An allowance is made for the bulk quantity of materials and equipment in the fume hoods. The following general type of contaminated equipment is postulated to be present in the fume hood. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For 4 fume hoods, the total is 8 electric heating units, with a total weight of 56 kg and a total bulk volume of 0.24.

- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 4 fume hoods, the total is 24 units of processing glassware, with a total weight of 72 kg and a total bulk volume of 0.48.

- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 4 fume hoods the total is 16 items, with a total weight of 32 kg and a total bulk volume of 0.224.

D.2.2 Glove Boxes

Each of the four glove boxes (Reference 1, p. 7-12) in the ^{14}C facility is 0.9 m wide x 0.6 m high x 0.6 m deep. Each glove box is assumed to be framed by mild steel externally, with 0.003175-m-thick stainless steel walls, and 0.00635-m-thick acrylic windows. The glove boxes rest on wood workbenches (discussed in Item 3, below). Each glove box has a stainless steel panel across the lower 0.25 m of the front, in which are located two 0.2-m-diameter circular openings for neoprene working gloves. Above this panel, the front of the glove box slopes backward at an angle of about 40 degrees, providing an opening for the acrylic plastic viewing window. The viewing window is mounted in a mild steel metal frame which is gasketed to the sloping front of the glove box. At one end of two of the glove boxes is assumed to be a stainless steel airlock for the insertion of equipment and material into the box. Airlock dimensions are 0.3 m high x 0.2 m wide x 0.2 m deep (Reference 1, p. A.33). One acrylic air lock door is accessible from outside the glove box, and one is accessible from the inside of the box through the use of glove ports. Standard electrical receptacles are located on the inside of the glove box, with power controlled by switches mounted outside on a service panel above the glove box. Two glove boxes are each sitting on each of two workbenches, discussed in Section D.2.3, below.

Before the glove boxes are dismantled, the interior and exterior surfaces are vacuumed and wet-wiped, and then painted to fix contamination. The glove boxes are then cut to sizes that allow the bagged glove box materials to go into 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site. The acrylic plastic, the steel materials, and the equipment inside the glove box are segregated into 208-liter drums each with one of these categories of materials.

Amount of Stainless Steel in Glove Box and Access Air Lock

Glove Box Proper.

Back: 0.9 x 0.6	= 0.54 m^2
Bottom: 0.9 x 0.6	= 0.54 m^2
Two sides: 2 x 0.6 x 0.6	= 0.72 m^2
Top: 0.3 x 0.9	= 0.27 m^2
Lower Front Panel: 0.25 x 0.9	= 0.225 m^2
Total Area	= 2.295 m^2
Total Volume: 0.003175 x 2.295	= 0.00729 m^3
Total Volume for 4 Boxes	= 0.02916 m^3
Total Weight for 4 Boxes	= 233 kg

Air Lock.

Back: 0.3 x 0.2	= 0.06 m^2
Top, Side, Bottom: 3 x 0.2 x 0.2	= 0.12 m^2
Total Area	= 0.18 m^2
Total Volume: 0.003175 x 0.18	= 0.0005715 m^3
Total Volume for 2 Air Locks	= 0.0011430 m^3
Total Weight for 2 Air Locks	= 9 kg
Total Stainless Steel Volume for 4 Boxes	= 0.0303 m^3
Total Stainless Steel Weight for 4 Boxes	= 342 kg

Amount of Mild Steel in the Exterior Frame

The frame is assumed to be made of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 0.6 m for vertical members and 4 x 0.9 m for horizontal members, for a total length of 6.9 m. Total mild steel in the frame is thus 6.9 x (0.0508 + 0.04445) x 0.0047626 = 0.00313.

Total Volume for 4 Boxes	= 0.01252 m^3
Total Weight for 4 Boxes	= 100 kg

Amount of Acrylic Plastic in the Main Window and Air Lock

Main Window. The plastic is assumed to be 0.6 m high x 0.9 m wide x 0.00635 m thick, giving a volume of 0.003429.

Total Volume for 4 Boxes	= 0.0137 m^3
Total Weight for 4 Boxes (s.g. = 1.2)	= 16.5 kg

Airlock. Each of the two windows is assumed to measure 0.3 x 0.2 x 0.00635. This gives a total volume of 0.000762.

Total Volume for 2 Boxes	= 0.001524 m^3
Total Weight for 2 Boxes (s.g. = 1.2)	= 1.8 kg
Total Volume of Acrylic for 4 Boxes	= 0.01524
Total Weight of Acrylic for 4 Boxes	= 18.3 kg

Amount of Processing Equipment

The following general type of contaminated equipment is postulated to be present in the glove boxes. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For the 4 glove boxes, the total is 8 electric heating units, with a total weight of 56 kg and a total bulk volume of 0.24.
- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 4 glove boxes, the total is 24 units of processing glassware, with a total weight of 72 kg, and a total bulk volume of 0.48.
- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 4 glove boxes the total is 16 items, with a total weight of 32 kg, and a total bulk volume of 0.224.

D.2.3 Workbenches

The four workbenches in the ^{14}C facility have a total combined length of 15 m (Reference 1, pp 7-12). The four benches are assumed to be 5.5 m, 5.5 m, 3 m and 1 m long. Each bench is assumed to be 0.75 m deep (with a top work area of 11.25 m^2) and 0.9 m high. Each bench is constructed of latex-painted wood and has a plastic-laminated top, assumed to be 0.0015875-m-thick polycarbonate. One of the workbenches has a stainless steel sink mounted in it; the two longer workbenches each have two glove boxes setting on them, and the small bench has no permanent component mounted on it. These workbenches are assumed to have one drawer 0.1525 m deep and below that, a shelf a few centimeters above the floor, with two doors. To simplify calculations, it is assumed that each drawer and each set of cabinet doors in the 15-m-length of workbenches is 1 meter wide, and a vertical plywood panel supports the benches every 1 meter (a total of 16 panels).

Because of the proximity of the workbenches to radioactivity-containing components, all of the workbench materials are assumed to be radioactive. The surfaces are first vacuumed, wet-wiped, and then painted to fix surface contamination. The benches are then cut into pieces, bagged, and placed in 208-liter drums. The drums of are compacted on-site, and sent off-site for supercompaction. If the incineration option is used, the waste is sent off-site for incineration, followed by fixation of the resulting ashes into monolithic solids.

Amount of Wood in the Workbenches

Front and Back: 2 x 0.9 x 15 x 0.01905	= 0.51435 m^3
Sides & Support Panels: 16 x 0.75 x 0.9 x 0.01905	= 0.20574 m^3
Bottom & Top: 15 x 3 x 0.75 x 0.01905	= 0.64294 m^3
Sides: 30 x 0.75 x 0.1524 x 0.01905	= 0.06532 m^3
Back: 15 x 0.1524 x 1 x 0.01905	= 0.04355 m^3
Total Volume:	= 1.47190 m^3

Total Weight (s.g. = 0.8)	= 1,178 kg

Amount of Polycarbonate Plastic on the Surfaces of the Workbenches

Volume: 15 x 0.75 x 0.0015875	= 0.01786 m^3
Weight (s.g. = 1.2)	= 21.4 kg.

The plastic laminate is not removed from the workbenches.

Amount of Processing Equipment on the Workbenches

It is assumed that the workbenches were used for radioactive counting equipment, which had to stay reasonably clean; for tools (again, assumed to be free of contamination) for making small new parts for the hoods and glove boxes; for temporary storage of nonradioactive materials; for overpacking the products (again expected to be a relatively clean operation); and other similar uses. The contaminated material below is to be bagged, loaded into 208-liter drums, compacted on-site, and sent off-site for supercompaction before being sent for disposal as LLW. The following general type of equipment is postulated to be present on the workbenches:

- Various hand tools including a vise, primarily steel, weighing a total estimated 12 kg, with a total gross bulk volume estimated to be 0.008.
- 2 significant items of processing glassware, each weighing about 3 kg. For the 2 glass items, the items would weigh about 6 kg and require an estimated 0.04 m^3 of total bulk space.
- 2 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. For the 2 items, the total weight is estimated at 4 kg, with an estimated total bulk volume of 0.004 m^3.

D.2.4 Vent Ducts

The ^{14}C facility contains 16 m of cylindrical ductwork 0.2 m in diameter and 14 m of rectangular ductwork 0.25 m x 0.6 m in cross-section (Reference 1, p. 9-9). The ductwork is assumed to be stainless steel sheet metal 0.0015875 m thick.

The ductwork is assumed to be radioactively contaminated internally and externally. The ductwork is vacuumed and wet-wiped where possible to remove the readily-removable contamination, then painted to minimize contamination during subsequent steps. The duct waste is cut into pieces that maximize the amount of material that can fit in 208-liter drums. The waste pieces are placed in plastic bags before being placed in the drums. The waste-filled drums are then compacted on-site and then shipped off-site for supercompaction before being disposed of as LLW.

Amount of Material in the Ductwork

Cylindrical Ductwork Volume	= π x 0.2 x 16 x 0.0015875 = 0.016 m^3
Rectangular Ductwork Volume	= 2 x (0.25 + 0.6) x 14 x 0.0015875
	= 0.038 m^3
Total Volume	=0.054 m^3
Total Weight	=432 kg

D.2.5 Cabinets

The ^{14}C facility contains two cabinets, each postulated to be constructed of 0.01905 m-thick latex-painted wood. The dimensions of each cabinet are assumed to be 0.762 m wide x 0.4572 m deep x 1.524 m high. Each cabinet is assumed to have two locking doors, and three shelves plus the bottom inside shelf.

Both cabinets are given only mild decontamination by vacuuming and wet-wiping. The material is then painted and sectioned. The sectioned waste is then bagged and placed in 208-liter drums for on-site compaction. The drums are then shipped off-site for supercompaction. If the incineration option is used, the waste is sent off-site for incineration and solidification of the ashes.

Amount of Material in Each Cabinet to be Disposed of as Waste

Front and Back: 2 x 0.762 x 1.524 x 0.01905	= 0.0442 m^3
Two Sides: 2 x 0.4572 x 1.524 x 0.01905	= 0.0265 m^3
Top, Bottom, 3 Shelves: 5 x 0.762 x 0.4572 x 0.01905	= 0.0332 m^3
Total Volume	= 0.1039 m^3
Total Volume for 2 Cabinets:	= 0.2078 m^3
Total Weight for 2 Cabinets (s.g. = 0.8)	=166.24 kg

D.2.6 Freezer and Refrigerators

The ^{14}C facility contains one freezer and two refrigerators, all postulated to be upright units, with the same dimensions of 0.6096 m x 0.6096 m x 1.524 m. The three units are assumed to be only mildly contaminated inside. But outside, the compressor, coils, fan, and other mechanisms are assumed to sufficiently contaminated that it would not be reasonable to try to decontaminate them to levels required for unrestricted use. Thus, they are assumed to be disposed of as radioactive waste with only minimal decontamination. It is assumed that the freon (not contaminated) will be removed on-site by a subcontractor. The units will then be vacuumed, wiped and painted, and then cut up and bagged into 208-liter drums for on-site compacting. The units will then be shipped off-site for supercompacting before disposal as LLW. Sectioning will be done to effectively use the space in the drums.

Amount of Material in the Three Units

This is based on the gross characteristics of conventional refrigerators and freezers. Each unit will contain the refrigeration cooling system (copper, steel, other metals), some framework (mild steel), plastic inner and outer walls separated by fiberglass insulation, some plastic trays and glass and mild steel shelves inside. The sectioned and pre-compacted volume of the three units is assumed to be the same as when whole, or 3 x 0.6096 x 0.6096 x 1.524 = 1.699 m^3. The overall weight of each refrigerator or freezer unit is assumed to be 68 kg, for a total weight of 204 kg.

D.2.7 HEPA and Roughing Filters

The ^{14}C facility uses the eight HEPA and roughing filters during normal operation (Reference 1, p. 9-9), one each at the exhaust of each fume hood and glove box. No other HEPA or roughing filters are in the facility. It is postulated that the facility filters had been replaced at the end of the operating period, and they will last throughout the total decommissioning period. In addition, it is assumed that during the vacuuming activity of the components and the facility, a commercial vacuum unit is leased that uses a roughing filter and a HEPA filter identical to those in the facility, and two sets of filters are used during vacuuming, bringing the total to 10 sets. The filter removal is one of the last activities undertaken during decommissioning. Each filter is sealed in a plastic bag during its removal. Each HEPA filter is 0.2 m in diameter and 0.2 m high (Reference 1, p. 9-9). The roughing filters are 0.2 m in diameter and 0.1 m high (Reference 1, p. 9-9). It is assumed that the filters are comprised of sheet-metal casing with pleated paper as the filter medium. It is postulated that the filters are bagged, placed in 208-liter drums for on-site compaction, followed by shipment off-site for supercompaction before being packaged for disposal as LLW.

Amount of Materials in the Filters

The bulk (rectangular) volume of the 10 HEPA filters is 10 x 0.2 x 0.2 x 0.2 = 0.08 The overall weight of each HEPA filter is assumed to be 5 kg. Thus the total weight of the 10 HEPA filters is 50 kg. The bulk (rectangular) volume of the 10 roughing filters is 10 x 0.2 x 0.2 x 0.1 = 0.04 m^3. The overall weight of each roughing filter is assumed to be 2.5 kg. Thus the total weight of the 10 roughing filters is 25 kg.

D.2.8 Sinks and Drains

There is one single-bowl sink in the ^{14}C facility. The sink is mounted in one of the workbenches. The sink is assumed to be 18-gage stainless steel (0.001214 m thick) with inside dimensions of 0.635 m wide x 0.5588 m long x 0.3048 m deep, with overall dimensions of 0.8382 m wide x 0.5588 m deep to allow for the flanges (Reference 2). The sink is used for hand washing and for rinsing laboratory glassware. Low levels of radioactivity are discharged to the sanitary sewer via the sink (Reference 1, p. 7-12). Contaminated liquids are not purposely discharged to the sanitary sewer via the sink. Thus, it should have low levels of radioactive contamination. The drain pipe is equivalent to a 2-m length of 0.1-m-diameter pipe (Reference 1, p. 9-9).

The sink and its associated water faucet and inside drain pipe are wiped down only, then removed and cut up in a way that uses up space efficiently in the 208-liter drum. The material is then placed in plastic bags by a pipefitter, assisted by a technician. The waste materials are compacted on-site, and supercompacted off-site disposal as LLW.

Amount of Stainless Steel in the Sink

The sink is assumed to weigh about 12 kg and to require a bulk volume of an estimated 0.113 m^3.

Amount of Brass in the Fixture and Connections

The weight of the brass is estimated to be 3 kg, assuming a specific gravity for brass of 8.75. The brass will occupy about 0.0283 m^3 of bulk space.

Amount of Galvanized Steel in the Drain and P Trap

This is equivalent to 2 meters of 0.1-m-diameter pipe (Reference 1, p. 9-9), or an estimated 16.05 kg/m x 2m = 32.1 kg. The bulk volume of the material is estimated to be 0.02 m^3.

D.2.9 Facility Ceiling

The ^{14}C facility ceiling consists of 80 m^2 of acoustically-treated fiberboard (Reference 1, p. 9-8) that is suspended (above which some piping and electrical wiring is mounted). The fiberboard is in panels that are typically 0.3 m x 0.3 m, or 0.3 m x 0.6 m. Each panel can be removed separately.

The fiberboard, postulated to be 0.0127 m thick, has a rough surface and many pores, so is impractical to try to decontaminate. The ceiling panels are first vacuumed and painted to fix the contamination, then are removed for disposal as radioactive waste. The ceiling materials are broken up if necessary and bagged and inserted into 208-liter drums. The waste is then compacted on-site before being transported off-site for supercompaction and disposal as LLW. If the incineration option is used, the resultant ash is fixated into a monolithic solid. The specific gravity of the fiberboard is assumed to be 0.5.

Amount of Material in the Ceiling

Total volume: $80\ m^2 \times 0.0127\ m = 1.016\ m^3$

The estimated pre-compacted bulk volume is assumed to be twice the actual volume, or about 2.0 m^3. The total weight is 508 kg.

D.2.10 Facility Walls

The 108 m^2 of walls of the ^{14}C facility (Reference 1, p. 9-8) are plasterboard (postulated to be 0.015875 m thick) painted with latex enamel. It is assumed that the walls are decontaminated to unrestricted use levels to maintain the wall surfaces and to keep from contaminating the wall insulation and structural members behind the walls. The walls are first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the walls are wiped with dry rags and allowed to dry completely. For final decontamination, strippable paint is applied brushed or rolled on, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, or spot-painted again with strippable paint. Only the materials used for decontamination are assumed to become LLW. These are bagged and placed in 208-liter drums.

Amounts of Waste Materials Resulting from Decontaminating the Walls

The estimates developed in Reference 1, p. E-30, for the wash/wipe operations seem reasonable for the decontamination procedures used in that study, but in this study, far less of the liquid decontaminating agent is assumed to be used, with part of the decontamination being done with strippable paint. Thus, the amount of rags, brushes, and liquid wastes here are taken to be 1/3 of those in Reference 1, with adjustments for wall area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 2 208-liter drums of wet rags, brushes and contaminated gloves and other clothing (Reference 1) assumed to be sent off-site for incineration, resulting in 10 wt% (about one drum) of ashes for fixation into a monolithic solid and disposal as LLW. Estimated weight of these wastes before treatment is 40 kg.

- 0.67 208-liter drums of aqueous decontamination solutions (assumed to have small amounts of detergents) and rinse solutions from washing/wiping decontamination, before solidification with an adsorbent material. Estimated weight of the wastes before solidification is 90 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 2 208-liter drums equivalent of removed strippable paint (assumed in this study) to be reduced to one drum after on-site compaction). Estimated weight of the LLW is 40 kg. The waste is compacted on-site, then sent to supercompaction for disposal as LLW.

D.2.11 Facility Floor

The floors of the ^{14}C facility (Reference 1, p. 9-9) consist of 80 m^2 of asphalt tile (postulated to be 0.0015875 m thick) over plywood (postulated to be 0.01905 m thick). The specific gravity of the tiles is assumed to be 1.1. The floor is postulated to be first vacuumed and then painted to fix the remaining contamination. The tiles are removed manually, packaged in bags, and placed in 208-liter drums as LLW. The remaining hot spots in the wood sub-flooring are cleaned by a small amount of scraping or planing. The wood scrapings are bagged and placed in 208-liter drums for on-site compacting, followed by off-site supercompaction or incineration.

Amount of Floor Tile Waste

Total Volume of Floor Tiles: 80 x 0.0015875	= 0.127 m^3
Total Weight of Floor Tiles: 1100 x 0.127	= 140 kg

The floor tiles are compacted on-site, supercompacted off-site, and then sent for disposal as LLW.

Amount of Wood Scraping Waste

The amount of wood scrapings removed as radioactive waste is difficult to estimate. A number of the cracks between the tiles will have contaminated wood that needs to be removed, probably to a depth of about 0.003 m. The total amount of wood scrapings removed as radioactive waste is assumed to be 50 kg, with an assumed bulk specific gravity of 0.4, for a gross volume before compaction of 0.125 m^3.

D.3 Reference Laboratory for the Manufacture of ^{125}I-Labeled Compounds

Detailed physical descriptions and decommissioning procedures for all the components and building surfaces of the ^{125}I laboratory that are postulated to require removal and/or decontamination are given in Sections D.3.1 through D.3.11. Details of (1) planning and preparation, (2) estimated manpower requirements, (3) waste management, materials, and labor costs, and (4) radiation dosages are presented in Table D.3a for the supercompaction option and in Table D.3b for the supercompaction option with incineration. An overall description of this laboratory is contained in Section 7.1.3 of Reference 1.

D.3.1 Fume Hoods

The ^{125}I facility contains four fume hoods, each measuring 1.5 m wide x 2.0 m high x 0.945 m deep. Each fume hood contains one glove box. Each hood is assumed to be framed externally by mild steel 0.003175 m thick. Each glove box and fume hood is equipped with an activated charcoal filter at its effluent exhaust. At the point where the ventilation air leaves the facility, a roughing filter, a HEPA filter, and a charcoal filter are installed. Each hood is equipped with an acrylic window 0.00635 thick. Inside each fume hood is a specially-designed glove box. Thus, each glove box must be removed before the respective fume hood can be removed. The hood is assumed to rest on an enclosed stainless steel-based cabinet (Fig A.5-1, Reference 1). The support cabinet is assumed to have the same foot print as the fume hood but is only 0.9 m high.

Before the fume hoods are dismantled, the interior and exterior surfaces are first vacuumed and wet-wiped, then dried and painted to fix contamination. The hoods are then cut to sizes that allow the hood materials to be bagged and placed in 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site.

Amount of Stainless Steel Upper Section

Back: 1.5 x 2.0	= 3.00 m^2
Two sides: 2 x 0.945 x 2.0	= 3.78 m^2
Floor and Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 9.615 m^2

Table D.3a ^{125}I Lab summary–supercompaction option; manpower requirements, radiation doses, and costs for decommissioning the ^{125}I laboratory–supercompaction option (no incineration)

Operation or category	Time (days)	Person-days: Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	3.5	--	3.5	--	7.0	--	--	10.5	2.13	3.7
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	28.5	12.5	28.5	--	12.0	--	12.5	65.5	2.13	21.9
Decommissioning										
Fume hoods	4.8	2.4	4.0	1.1	2.4	8.1	--	18.1	0.09	6.7
Glove boxes	1.4	0.7	1.3	0.4	0.7	2.5	--	5.6	13.75	2.1
Workbenches	3.0	1.5	2.1	1.0	1.5	4.1	--	10.1	0.02	3.8
Vent ducts	1.4	0.7	1.0	0.5	0.7	2.1	--	5.0	0.02	1.9
Cabinets	0.9	0.4	0.7	0.2	0.4	1.3	--	3.1	0.03	1.2
Freezer and refrigerators	0.5	0.2	0.4	0.1	0.2	0.8	--	1.8	0.02	0.7
Filters	0.6	0.3	0.6	--	0.3	1.2	--	2.4	0.02	0.9
Sink and drain	0.2	0.1	0.2	0.1	0.1	0.4	--	0.8	0.00	0.3
Ceiling	1.5	0.7	1.5	--	0.7	3.0	--	5.9	0.06	2.2
Walls	2.6	1.3	2.6	--	1.3	5.2	--	10.4	0.10	3.8
Floors	1.6	0.8	1.6	--	0.8	3.2	--	6.4	0.03	2.4
Subtotals	18.4	9.2	15.9	3.4	9.2	31.9	--	69.6	14.15	25.9
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	0.8
Laundry	--	--	--	--	--	--	--	--	--	1.8
Subtotals	--	--	--	--	--	--	--	--	--	22.8
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	1.9
Supercompaction	--	--	--	--	--	--	--	--	--	3.9
Incineration	--	--	--	--	--	--	--	--	--	--
Transportation	--	--	--	--	--	--	--	--	--	0.6
Disposal	--	--	--	--	--	--	--	--	--	21.9
Subtotals	--	--	--	--	--	--	--	--	--	28.3
Final radiological survey	3.0	1.5	3.0	--	6.0	--	3.0	13.5	--	4.2
Totals	49.9	23.2	47.4	3.4	27.2	31.9	15.5	148.6	16.28	103.0
25% Cost contingency	--	--	--	--	--	--	--	--	--	25.8
Total cost with contingency	--	--	--	--	--	--	--	--	--	128.8

Table D.3b ^{125}I Lab summary–incineration option; manpower requirements, radiation doses, and costs for decommissioning the ^{125}I laboratory–supercompaction and incineration option

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	–	–	–	7.5	30.0	–	9.9
Perform radiological survey	3.5	–	3.5	–	7.0	–	–	10.5	2.13	3.7
Develop work plan	10.0	5.0	10.0	–	5.0	–	5.0	25.0	–	8.3
Subtotals	28.5	12.5	28.5	–	12.0	–	12.5	65.5	2.13	21.9
Decommissioning										
Fume hoods	4.8	2.4	4.0	1.1	2.4	8.1	–	18.1	0.09	6.7
Glove boxes	1.4	0.7	1.3	0.4	0.7	2.5	–	5.6	13.75	2.1
Workbenches	3.0	1.5	2.1	1.0	1.5	4.1	–	10.1	0.02	3.8
Vent ducts	1.4	0.7	1.0	0.5	0.7	2.1	–	5.0	0.02	1.9
Cabinets	0.9	0.4	0.7	0.2	0.4	1.3	–	3.1	0.03	1.2
Freezer and refrigerators	0.5	0.2	0.4	0.1	0.2	0.8	–	1.8	0.02	0.7
Filters	0.6	0.3	0.6	–	0.3	1.2	–	2.4	0.02	0.9
Sink and drain	0.2	0.1	0.2	0.1	0.1	0.4	–	0.8	0.00	0.3
Ceiling	1.5	0.7	1.5	–	0.7	3.0	–	5.9	0.06	2.2
Walls	2.6	1.3	2.6	–	1.3	5.2	–	10.4	0.10	3.8
Floors	1.6	0.8	1.6	–	0.8	3.2	–	6.4	0.03	2.4
Subtotals	18.4	9.2	15.9	3.4	9.2	31.9	–	69.6	14.15	25.9
Equipment and materials cost										
Commercial vacuum cleaner	–	–	–	–	–	–	–	–	–	3.0
Compactor	–	–	–	–	–	–	–	–	–	17.2
Small tools and materials	–	–	–	–	–	–	–	–	–	0.8
Laundry	–	–	–	–	–	–	–	–	–	1.8
Subtotals	–	–	–	–	–	–	–	–	–	22.8
Waste management costs										
Packaging	–	–	–	–	–	–	–	–	–	1.9
Supercompaction	–	–	–	–	–	–	–	–	–	2.8
Incineration	–	–	–	–	–	–	–	–	–	11.5
Transportation	–	–	–	–	–	–	–	–	–	0.5
Disposal	–	–	–	–	–	–	–	–	–	17.9
Subtotals	–	–	–	–	–	–	–	–	–	34.6
Final radiological survey	3.0	1.5	3.0	–	6.0	–	3.0	13.5	–	4.2
Totals	49.9	23.2	47.4	3.4	27.2	31.9	15.5	148.6	16.28	109.4
25% Cost contingency	–	–	–	–	–	–	–	–	–	27.3
Total cost with contingency	–	–	–	–	–	–	–	–	–	136.7

Total Volume: 0.003175 x 9.615	= 0.03053 m^3
Total Volume for 4 Hoods	= 0.12212 m^3
Total Weight for 4 Hoods	= 977 kg

Amount of Stainless Steel in the Lower Cabinet

Back & Front: 2 x 1.5 x 0.90	= 2.700 m^2
Two Sides: 2 x 0.945 x 0.9	= 1.701 m^2
Bottom & Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 7.236 m^2
Total Volume: 0.003175 x 7.236	= 0.02297 m^3
Total Volume for 4 Hoods	= 0.09188 m^3
Total Weight for 4 Hoods	= 184 kg

Amount of Mild Steel in the Exterior Frame

The frame is assumed to be made of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 2.0 m for vertical members and 4 x 1.5 m for horizontal members, for a total length of 14 m. Total mild steel in the fume hood frame is thus 14 m x (0.0508 + 0.04445) x 0.0047626 = 0.006351 m^3.

Total Volume for 4 Hoods	= 0.0254 m^3
Total Weight for 4 Hoods	= 203 kg

Amount of Acrylic Plastic in the Window

The plastic is assumed to be 2.0 m high x 1.5 m wide x 0.00635 m thick, for a total volume of 0.01905 m^3.

Total Volume for 4 Hoods	= 0.0762 m^3
Total Weight for 4 Hoods (s.g. = 1.2)	= 91.4 kg

Amount of Processing Equipment

There is very little space inside the fume hood for processing equipment because each fume hood contains a glove box that takes up most of the interior fume hood space. The following general type of contaminated equipment is postulated to be present in the fume hood. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW

- 1 electric heating units, weighing about 7 kg. This is assumed to take up about 0.03 m^3 of space. For 4 fume hoods, the total is 4 electric heating units, with a total weight of 28 kg and a total bulk volume of 0.12 m^3.

- 2 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 4 fume hoods, the total is 8 units of processing glassware, with a total weight of 24 kg and a total bulk volume of 0.16 m^3.

- 1 item of various materials (metals, plastic, ceramic), weighing about 2 kg. This is assumed to take up about 0.014 m^3 of space. For 4 fume hoods the total is 4 items, with a total weight of 8 kg and a total bulk volume of 0.056 m^3.

D.3.2 Glove Boxes

Each glove box in the ^{125}I facility is 1.2 m wide x 0.6 m high x 0.6 m deep (Reference 1, p 7-15). Each glove box is constructed entirely of acrylic plastic, which is assumed to be 0.00635 m thick. Each glove box vents to its respective fume hood through a charcoal filter. As with the glove boxes in the other facilities, in the glove box front are assumed to be two 0.2-m-diameter circular openings for neoprene plastic working gloves, in a vertical panel (acrylic plastic in this facility) that is 0.25 m high. Above this panel, the front of the glove box is assumed to slope backward at an angle of about 40 degrees. At one end of the glove box is assumed to be an acrylic plastic airlock for the insertion of equipment and material into the glove box. Airlock dimensions are 0.3 m high x 0.2 m wide x 0.2 m deep (Reference 1, p. A.33). One acrylic air lock door is accessible from outside the glove box, and one is accessible from the inside of the box through the use of glove ports. Standard electrical receptacles are located on the inside of the glove box, with power controlled by switches mounted outside on a service panel above the glove box. Each glove box is sitting in its respective fume hood, which in turn is sitting on its respective stainless steel cabinet, described above in item 1.

Before the glove boxes are dismantled, the interior and exterior surfaces are vacuumed and wash-wiped, then painted to fix contamination. The glove boxes are then cut to sizes that allow the bagged glove box materials to effectively fill a 208-liter drum for compaction on-site. The drums are then sent off-site for supercompaction and subsequent disposal as LLW. The acrylic plastic and the equipment inside the glove box are segregated into drums, each with one of these categories of materials.

Amount of Acrylic Plastic in the Glove Box and Access Air Lock

Front & Back: 2 x 1.2 x 0.6 x 0.00635	= 0.00914 m^3
2 Sides: 2 x 0.6 x 0.6 x 0.00635	= 0.00457 m^3
Top: 0.9 x 0.3 x 0.00635	= 0.00171 m^3
Lower Front Panel: 0.25 x 0.9 x 0.00635	= 0.00143 m^3
Air Lock (2 x 0.3 x 0.2 + 2 x 0.2 x 0.2) x 0.00635	= 0.00127 m^3
Total Volume	= 0.01813 m^3
Total Volume for 4 Glove Boxes	= 0.07252 m^3
Total Weight for 4 Glove Boxes (s.g. = 1.2):	= 87 kg

Amount of Processing Equipment in each Glove Box

The following general type of contaminated equipment is postulated to be present in the glove box. The material is bagged, compacted on-site, supercompacted off-site, and disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg These are assumed to take up about 0.03 m^3. For 4 glove boxes, the total is 8 electric heating units, with a total weight of 56 kg and a total bulk volume of 0.024 m^3.

- 8 significant items of processing glassware, each weighing about 3 kg. These are assumed to take up about 0.02 m^3, each. For 4 glove boxes, the total is 32 items of processing glassware, with a total weight of 96 kg and a total bulk volume of 0.64 m^3.

- 6 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3, each. For 4 glove boxes, the total is 24 items of various materials, with a total weight of 48 kg and a total bulk volume of 0.34 m^3.

D.3.3 Workbenches

The two workbenches in the ^{125}I facility have a total combined length of 8 m (Reference 1, pp. 7-14 and 7-15). One is assumed to be 5 m long, the other, 3 m long. The workbenches are assumed to be 0.75 m deep and 0.9 m high. The benches are constructed of painted mild steel and have a stainless steel top, assumed to be 0.003175 m thick. The longer bench has a stainless steel sink mounted in it; the small bench has no permanent component mounted on it. These benches are assumed to have one drawer that is 0.1525 m deep and below that, a shelf a few centimeters above the floor, with 2 doors. To simplify calculations, it is assumed that each drawer and each set of cabinet doors in the 8-m-length of workbenches is 1 m wide, and a vertical steel panel supports the benches every 1 m (a total of 16 panels).

Because of the proximity of the workbenches to radioactivity-containing components, all of the workbench materials are assumed to be radioactive. The surfaces are vacuumed and painted before being cut up into pieces sized to effectively fill 208-liter drums. These drums of bagged materials are compacted on-site, and then sent off-site for supercompaction and burial as LLW.

Amount of Painted Mild Steel

Back & Front: 2 x 0.9 x 8	= 14.4 m²
Sides & Support: 9 x 0.75 x 0.9	= 6.075 m²
Bottom, Shelf & Drawer Bottoms: 8 x 3 x 0.75	= 18 m²
Drawer Sides: 8 x 0.75 x 0.1524 x 2	= 1.8288 m²
Backs of 8 Drawers: 8 x 0.1524 x 1	= 1.2192 m²
Total Area	= 41.523 m²
Total Volume (Assuming 0.0015875 m thickness)	= 0.0659 m³
Total Weight	= 527 kg

Amount of Stainless Steel on the Surfaces of the Workbenches

Area = 8 x 0.75 = 6 m². Assuming this material is 0.003175 m thick and has a specific gravity of 8.0, the volume of stainless steel is 0.01905 m³. and the weight is 152 kg.

Amount of Processing Equipment on the Workbenches

It is assumed that the workbenches were used for radioactive counting equipment, which had to stay clean; for tools (again, assumed to be free of contamination) for making small new parts for the hoods and glove boxes; for temporary storage of nonradioactive materials; for overpacking the products (again, expected to be a relatively clean operation); and other similar uses. The following general type of contaminated equipment is postulated to be present on the workbenches:

- Various hand tools, primarily steel, weighing a total estimated 6 kg, with a total gross bulk volume estimated to be 0.004 m³.

- 2 significant items of processing glassware, each weighing about 3 kg. For the 2 glass items, the items would weigh about 6 kg and would require an estimated 0.0400 m³ of total bulk space.

- 2 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. For the 2 various items, the total weight is estimated at 4 kg, with an estimated total bulk volume of 0.004 m³.

D.3.4 Vent Ducts

The ^{125}I facility contains 8 m of cylindrical ductwork 0.2 meters in diameter and 10 m of rectangular ductwork 0.25 m x 0.6 m in cross-section (Reference 1, p. 9-9). The ductwork is assumed to be stainless steel sheet metal 0.0015875 m thick.

The ductwork is assumed to be radioactively contaminated internally and externally. The ductwork is vacuumed and wet-wiped where possible to remove the readily-removable contamination, then painted to minimize contamination during subsequent steps. The duct waste is cut into pieces that maximize the amount of material that can fit in 208-liter drums. The waste pieces are placed in plastic bags before being placed in the drums. The waste-filled drums are then compacted on-site and then shipped off-site for supercompaction before being sent to disposal as LLW.

Amount of Material in the Ductwork

Cylindrical Ductwork Volume = π x 0.2 x 8 x 0.0015875	= 0.00798 m³
Rectangular Ductwork Volume = 2 x (0.25 + 0.6) x 10 x 0.0015875	= 0.027 m³
Total Volume	=0.03498 m³
Total Weight	= 280 kg

D.3.5 Cabinets and Shelf Unit

The cabinet in the ^{125}I facility is steel (assumed to be painted) with a glass panel (Reference 1, p. 9-11). The cabinet is assumed to have two locking doors (each one assumed to have a glass panel) and three shelves plus the bottom inside shelf. The cabinet is assumed to be 0.762 m wide x 0.6096 m deep x 1.524 m high. The glass panel in each door is assumed to be 0.254 m wide x 1.27 m high x 0.00635 m thick. The steel shelves have a total surface area of 4.5 m². There are assumed to be six shelves (including the top) in a book-case type of unit that is 1.5 m wide x 0.5 m deep x 2 m high, with steel that is assumed to be 0.001588 m thick.

The cabinet and shelf unit are given only mild decontamination by vacuuming and wet-wiping. The units are then painted and sectioned. The sectioned waste is then bagged and placed in 208-liter drums for on-site compaction. Following compaction, the drums are shipped off-site for supercompaction before being sent to disposal as LLW.

Amount of Painted Mild Steel in the Cabinet

Front & Back: 2 x 0.762 x 1.524	= 2.3226 m²
Windows: 2 x 0.254 x 1.27	= 0.6452 m²
Front & Back minus Windows	= 1.6774 m²
Top, Bottom, 3 Shelves: 5 x 0.762 x 0.6096	= 2.3226 m²
Total Area	= 4.0000 m²
Total Volume: 4 x 0.001588	= 0.00635 m³
Total Weight	= 50.8 Kg

Amount of Glass in Cabinet Doors

Area (from a, above)	= 0.6452 m²
Volume: 0.6452 x 0.00635	= 0.00410 m³
Weight (s.g. = 2.2)	= 9 kg

Amount of Painted Mild Steel in the Shelf Unit

Sides: 2 x 0.5 x 2	= 2 m^2
Back: 1.5 x 2	= 3 m^2
Shelves & Top: 6 x 1.5 x 0.5	= 4.5 m^2
Total Area	= 9.5 m^2
Total Volume: 9.5 x 0.001588	= 0.01509 m^3
Total Weight	= 120.7 kg

D.3.6 Refrigerator

The ^{125}I facility contains one refrigerator, postulated to be an upright unit, measuring 0.6096 m x 0.6096 m x 1.524 m. The refrigerator is assumed to be only mildly contaminated inside. But outside, the compressor, coils, fan, and other mechanisms are assumed to be sufficiently contaminated that it would not be reasonable to try to decontaminate them to levels required for unrestricted use. Thus, they are assumed to be disposed of as radioactive waste with only minimal decontamination. It is assumed that the freon (not contaminated) will be removed on-site by a subcontractor. The refrigerator will then be vacuumed, wiped and painted, and then cut up and bagged into 208-liter drums for on-site compacting. The refrigerator will then be shipped off-site for supercompacting before disposal as LLW. Sectioning will be done to effectively use the space in the drums.

Amount of Material

This is based on the gross characteristics of a conventional refrigerator. The refrigerator will contain the refrigeration cooling system (copper, steel, other metals), some framework (mild steel), plastic inner and outer walls separated by fiberglass insulation, some plastic trays and glass and mild steel shelves inside. The sectioned and pre-compacted volume of the unit is assumed to be the same as when whole, or 0.6096 x 0.6096 x 1.524 = 0.566 m^3. The weight of the refrigerator is 68 kg.

D.3.7 Filters

The ^{125}I facility has four small, round roughing filters and four small, round HEPA filters at the exhaust of each fume hood (4); one charcoal filter located at the exhaust of each glove box (4) and each fume hood (4); and one larger HEPA, one larger roughing filter, and one larger charcoal filter at the exhaust plenum of the facility. Each glove box vents into its respective fume hood through an activated charcoal filter, and each fume hood vents to the facility exhaust ventilation system through another activated charcoal filter as well as through a HEPA and roughing filter. A bank of a (larger) roughing filter, a (larger) HEPA filter, and another charcoal filter (assumed to also be larger) is located in the ventilation ductwork as it leaves the facility (Reference 1, pp. 7-15, 9-11). The latter set of filters must have about 4 times the capacity of each of the other filters and the smaller round activated charcoal filters, and there is one larger filter to achieve the needed capacity. In addition, two sets of the smaller roughing-HEPA filters are assumed to be used in the vacuuming during the decommissioning of the ^{125}I facility, bringing the number of small, round HEPA-roughing filter sets to 6. (A commercial vacuum unit is leased that uses a roughing filter and a HEPA filter identical to those in the facility for the decommissioning vacuuming.) Thus, the total number of filters from decommissioning this facility is 6 round roughing filters, 6 round HEPA filters, 8 round activated charcoal filters, and 1 larger HEPA, 1 larger roughing, and 1 larger activated charcoal filter. It is postulated that the facility filters had been replaced at the end of the operating period, and they will last throughout the total decommissioning period. The filter removal from the total ventilation system is one of the last activities undertaken during decommissioning.

Each filter is bagged with a plastic bag and sealed during its removal. The dimensions of the round HEPA and charcoal filters (Reference 1, p. 9-11) are 0.2 m in diameter x 0.2 m high. The larger, rectangular filters at the facility exhaust are 0.25 m x 0.6 m x 0.3 m. It is assumed that all the filters are comprised of sheet-metal casing, and the HEPA and roughing filters use pleated paper as the filter medium. It is assumed that the activated charcoal filters are comprised of activated charcoal granules within a stainless steel sheet-metal casing. It is postulated that the charcoal filters are bagged out and placed in 208-liter drums for compacting on-site, followed by direct shipment as LLW to a disposal facility. It is postulated that the HEPA and roughing filters are bagged, placed in drums for on-site compaction, followed by shipment off-site for supercompaction before being packaged for disposal as LLW.

Amount of Materials in the Small, Round HEPA Filters

The overall weight of each HEPA filter is assumed to be 5 kg. The estimated weight of the 6 small, round HEPA filters is thus 30 kg. The bulk (rectangular) volume of the 6 small, round filters is 6 x 0.2 x 0.2 x 0.2, or 0.0.048 m^3.

Amount of Materials in the Large, Rectangular HEPA Filter

The overall weight of the large HEPA filter is assumed to be 12 kg. The bulk volume of the large, rectangular filter is 0.25 x 0.6 x 0.3, or 0.0450 m^3.

Amount of Materials in the Small, Round Roughing Filters

The overall weight of each roughing filter is assumed to be 2.5 kg. The estimated weight of the 6 small, round roughing filters is thus 15 kg. The bulk (rectangular) volume of the 6 small, round filters is 6 x 0.2 x 0.2 x 0.1, or 0.024 m^3.

Amount of Materials in the Large, Rectangular Roughing Filter

The overall weight of the large roughing filter is assumed to be 6 kg. The bulk volume of the large, rectangular filter is 0.25 x 0.6 x 0.15, or 0.0225 m^3.

Amount of Materials in the Small, Round, Charcoal Filters

The volume of activated charcoal per filter is estimated at $\pi/4$ x 0.2 x 0.2 x 0.2, or 0.00628 m^3. At a specific gravity of 480 kg/m^3, the charcoal in one filter weighs 0.00628 x 480, or 3.0 kg. The stainless steel housing, assumed to be 0.001588 meters thick, has a volume of π x 0.2 x 0.2 x 0.001588, or 0.00020 m^3, and weighs an estimated 1.6 kg. The total weight of a small, round charcoal filter is then 3.0 + 1.6, or 4.6 kg. The total weight of 8 small, round activated charcoal filters is 37 kg, and the total (rectangular equivalent) volume is 0.064 m^3.

Amount of Materials in the Large, Rectangular Charcoal Filter

The volume of activated charcoal per filter is estimated at 0.25 x 0.6 x 0.3, or 0.045 m^3. At a specific gravity 480 kg/m^3, the charcoal in one large filter weighs 0.045 x 480, or 21.6 kg. The stainless steel housing, assumed to be 0.001588 meters thick, has an area of 4 x 0.6 x 0.3, or 0.72 m^2, and a volume of 0.72 x 0.001588 or 0.00114 m^3, and weighs an estimated 9.1 kg. The total weight of the large, rectangular charcoal filter is then 21.6 + 9.1, or 30.7 kg.

D.3.8 Sink and Drain

The ^{125}I facility has one sink and in-facility drain line. The sink is mounted in one of the workbenches, near one end. The sink is assumed to be 18-gage stainless steel (0.001214 m thick) with inside dimensions of 0.635 m wide x 0.5588 m high x 0.3048 m deep, with overall dimensions of 0.8382 m wide x 0.5588 m deep to allow for the flanges (Reference 2). The facility sink is used for personal cleanliness and for washing non-radioactive glassware. Liquid effluent is discharged to a tank (assumed to be outside) where it is held for radioactive decay, monitored, and diluted as necessary before discharge to the sanitary sewer (Reference 1, p. 7-15). Contaminated liquids are not purposely discharged to the sanitary sewer via the sink. Operational aqueous waste liquids are not discharged to the laboratory sink system, but are solidified with a setting material and shipped out as LLW during operation. Operational organic waste liquids are absorbed on an absorbent material that meets disposal facility requirements, and are shipped out as a solid LLW during operation (Reference 1, p. 7-26).

The sink, its associated water faucet, and the interior drain piping are wiped down, then removed, cut up to use up space in the 208-liter drum, and bagged out by a pipefitter assisted by a technician. The waste materials are compacted on-site and supercompacted off-site for disposal as LLW.

Amount of Stainless Steel in the Sink

The sink is assumed to weigh about 12 kg and to require a bulk volume of an estimated 0.113 m^3.

Amount of Brass in the Fixture and Connections

The weight of the brass is estimated to be 3 kg, assuming a specific gravity for brass of 8.75. The brass will occupy about 0.0283 m^3 of bulk space.

Amount of Galvanized Steel in the Drain and P Trap

This is equivalent to 5 m of 0.1-m-diameter pipe (Reference 1, p. 2-9), or an estimated 16.05 kg/m x 5 m = 80.3 kg. The bulk volume of the material is estimated to be 0.05 m^3.

D.3.9 Facility Ceiling

The ^{125}I facility's 48 m^2 ceiling is concrete sealed with epoxy paint (Reference 1, p. 7-15). The ceiling is to be decontaminated to unrestricted levels. Because the facility ceiling is a rigid concrete structure, decontamination is done in way to minimize destruction of any significant part of the structure and its highly chemically-resistant ceiling covering of epoxy paint.

The ceiling is first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the ceiling is wiped with dry rags and allowed to dry completely. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contained contamination. Final hot spots are manually wet-wiped then dry-wiped. Only materials used for decontamination are assumed to become LLW. Disposition of each type of waste is identified below.

Amount of Waste Materials Resulting from Decontaminating the Ceiling

The estimates developed in Reference 1, p. E-30 for the wash/wipe operations seem reasonable for the decontamination procedures used in that study, but in this study, much less liquid decontaminating agent is used, and part of the decontamination is done with strippable paint. Thus, the amount of rags and brushes, etc., and liquid wastes here is taken to be 1/3 of that in Reference 1, with adjustments for surface area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 1.33 208-liter drums of wet rags, brushes and contaminated gloves and other clothing (Reference 1). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes before treatment is 29 kg.

- 0.33 208-liter drums of aqueous decontamination solution (assumed to have small amounts of detergents) and rinse solutions from wet/wiping decontamination, before solidification with an adsorbent material. Estimated weight of the waste before solidification is 45 kg. The adsorbed waste is sent directly for LLW disposal.

- 1 208-liter drum equivalent of removed strippable paint (assumed in this study) to be reduced to one-half drum after on-site compaction. Estimated weight of the waste is 20 kg. The waste is sent off-site for supercompaction before being disposed as LLW.

D.3.10 Facility Walls

The ^{125}I facility's walls (84 m^2) are concrete sealed with epoxy paint (Reference 1, p. 9-11). The walls are to be decontaminated to unrestricted levels. Because the facility walls are rigid concrete structures, decontamination is done in ways to minimize destruction of any significant part of the structures and their highly chemically-resistant epoxy paint covering.

The walls are first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the walls are wiped with dry rags and allowed to dry completely. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contained contamination. Final hot spots are manually wet-wiped then dry-wiped. Only materials used for decontamination are assumed to become LLW. Disposition of each type of waste is identified below.

Amount of Waste Materials Resulting from Decontaminating the Walls

The estimates developed in Reference 1, page E-30, for the wash/wipe operations seem reasonable for the decontamination procedures used in that study, but in this study, much less liquid decontaminating agent is used, and part of the decontamination is done with strippable paint. Thus, the amount of rags and brushes, etc., and liquid wastes here is taken to be 1/3 of that in Reference 1, with adjustments for surface area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 2.33 208-liter drums of wet rags, brushes and contaminated gloves and other clothing (Reference 1). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes is 50 kg.

- 0.67 208-liter drums of aqueous decontamination solution (assumed to have small amounts of detergents) and rinse solutions from wet/wiping decontamination, before solidification with an adsorbent material. Estimated weight of the waste before solidification is 90 kg. The adsorbed material is sent directly for disposal as LLW.

- 1.33 208-liter drums removed strippable paint (assumed in this study) to be compacted on-site. Estimated weight of the waste is 40 kg, which is assumed to be compacted on-site, supercompacted off-site, and sent for disposal as LLW.

D.3.11 Facility Floor

The floors of the ^{125}I facility contain 48 m^2 of asphalt tile (postulated to be 0.001588 m thick) over concrete (Reference 1, p. 9-11). The floor is postulated to be first vacuumed and then painted to fix the remaining contamination. All tiles are postulated to be removed manually and packaged in plastic bags, then compacted on-site, supercompacted off-site, and disposed of as LLW. The remaining hot spots in the concrete flooring are postulated to be cleaned by a small amount of scabbling, followed by re-vacuuming the entire floor surface.

Amount of Waste Materials Resulting from Removing Floor Tiles

The total volume of floor tiles = 48 x 0.001588 = 0.0762 m^3. Assuming a specific gravity of 1.1, the asphalt tiles would weigh an estimated 84 kg. The floor tiles are compacted on-site, supercompacted off-site, and then sent for disposal as LLW.

Amount of Concrete Flooring Removed

It is postulated that about 10% of the concrete area below the asphalt tiles will have become contaminated to a depth of 0.0127 m. The total amount of concrete rubble and dust removed as radioactive waste is thus 48 x 0.1 x 0.0127 = 0.061 m^3. Assuming the effective density of the dust is 60% of the theoretical specific gravity of concrete (2.5), the volume is 0.061/0.6 = 0.102 m^3. The weight is estimated to be 2500 x 0.061 = 153 kg. The concrete rubble and dust are postulated to be bagged and drummed for efficient use of the drum space, followed by on-site compaction before being sent for disposal as LLW.

D.4 Reference Laboratory for the Manufacture of ^{137}Cs Sealed Sources

Detailed physical descriptions and decommissioning procedures for all the components and building surfaces of the ^{137}Cs laboratory that are postulated to require removal and/or decontamination are given in Sections D.4.1 through D.4.11. Details of (1) planning and preparation, (2) estimated manpower requirements, (3) waste management, materials, and labor costs, and (4) radiation dosages are presented in Table D.4a for the supercompaction option and in Table D.4b for the supercompaction option with incineration. An overall description of this laboratory is contained in Section 7.1.4 of Reference 1.

D.4.1 Fume Hoods

The ^{137}Cs facility contains two fume hoods, each 1.5 m wide x 2.0 m high x 0.945 m deep. Each hood is assumed to be framed externally by mild steel 0.003175 m thick and is equipped with an acrylic window 0.00635 m thick. Each hood is immediately adjacent to a small hot cell, and one side of the hood has an opening to accommodate the sliding-door opening in the hot cell to the hood. The hood is assumed to rest on an enclosed stainless steel-based cabinet (Reference 1, p. A-30). The support cabinet is assumed to have the same foot print as the fume hood but is only 0.9 m high.

Before the fume hoods are dismantled, the interior and exterior surfaces are vacuumed and wet-wiped, and then painted to fix contamination. The hoods are then cut to sizes that allow the hood materials to be bagged and go into 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site.

Table D.4a ^{137}Cs Lab summary–supercompaction option; manpower requirements, radiation doses, and costs for decommissioning the ^{137}C laboratory–supercompaction option (no incineration)

Operation or category	Time (days)	Person-days: Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	2.5	--	2.5	--	5.0	--	--	7.5	428.46	2.7
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	27.5	12.5	27.5	--	10.0	--	12.5	62.5	428.46	20.8
Decommissioning										
Fume hoods	2.8	1.4	2.1	0.8	1.4	4.2	--	10.0	191.93	3.7
Hot cells	3.3	1.6	3.1	1.1	1.6	6.3	--	13.8	2795.65	5.1
Manipulators	1.4	0.7	0.7	1.1	0.7	1.3	--	4.5	828.90	1.7
Workbenches	1.5	0.7	1.1	0.4	0.7	2.3	--	5.3	0.03	2.0
Vent ducts	1.9	0.9	1.4	0.7	0.9	2.8	--	6.8	1.31	2.5
Filters	0.3	0.2	0.3	--	0.2	0.6	--	1.2	0.02	0.5
Sink and drain	0.2	0.1	0.2	0.1	0.1	0.4	--	0.9	0.01	0.3
Ceiling	1.8	0.9	1.8	--	0.9	3.5	--	7.1	0.11	2.6
Walls	2.6	1.3	2.6	--	1.3	5.1	--	10.3	0.15	3.8
Floors	1.8	0.9	1.8	--	0.9	3.5	--	7.0	0.14	2.6
Subtotals	17.5	8.7	15.0	4.3	8.7	30.1	--	66.8	3818.24	24.9
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	0.7
Laundry	--	--	--	--	--	--	--	--	--	1.6
Subtotals	--	--	--	--	--	--	--	--	--	22.7
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	2.4
Supercompaction	--	--	--	--	--	--	--	--	--	3.4
Incineration	--	--	--	--	--	--	--	--	--	--
Transportation	--	--	--	--	--	--	--	--	--	0.6
Disposal	--	--	--	--	--	--	--	--	--	45.3
Subtotals	--	--	--	--	--	--	--	--	--	51.8
Final radiological survey	3.0	1.5	3.0	--	6.0	--	3.0	13.5	--	4.2
Totals	48.0	22.7	45.5	4.3	24.7	30.1	15.5	142.8	4246.70	124.3
25% Cost contingency	--	--	--	--	--	--	--	--	--	31.1
Total cost with contingency	--	--	--	--	--	--	--	--	--	155.4

Table D.4b ^{137}Cs Lab summary–incineration option; manpower requirements, radiation doses, and costs for decommissioning the ^{137}C laboratory–supercompaction and incineration option

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	2.5	--	2.5	--	5 0	--	--	7.5	428.46	2.7
Develop work plan	10 0	5.0	10 0	--	5 0	--	5.0	25 0	--	8.3
Subtotals	27.5	12.5	27.5	--	10.0	--	12.5	62.5	428.46	20.8
Decommissioning										
Fume hoods	2 8	1.4	2.1	0 8	1.4	4.2	--	10 0	191.93	3.7
Hot cells	3 3	1.6	3.1	1.1	1.6	6.3	--	13.8	2795 65	5.1
Manipulators	1.4	0.7	0 7	1.1	0.7	1.3	--	4.5	828.90	1.7
Workbenches	1.5	0.7	1.1	0 4	0.7	2 3	--	5.3	0 03	2.0
Vent ducts	1.9	0.9	1.4	0.7	0.9	2.8	--	6.8	1.31	2.5
Filters	0 3	0.2	0.3	--	0 2	0.6	--	1.2	0 02	0 5
Silk and drain	0 2	0.1	0 2	0.1	0.1	0.4	--	0 9	0 01	0 3
Ceiling	1 8	0.9	1 8	--	0 9	3.5	--	7.1	0 11	2 6
Walls	2 6	1.3	2.6	--	1.3	5.1	--	10.3	0.15	3 8
Floors	1.8	0.9	1.8	--	0.9	3.5	--	7.0	0.14	2.6
Subtotals	17.5	8.7	15.0	4.3	8.7	30.1	--	66.8	3818.24	24.9
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3 0
Compactor	--	--	--	--	--	--	--	--	--	17 2
Small tools & materials	--	--	--	--	--	--	--	--	--	0.7
Laundry	--	--	--	--	--	--	--	--	--	1.6
Subtotals	--	--	--	--	--	--	--	--	--	22.7
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	2.4
Supercompaction	--	--	--	--	--	--	--	--	--	1.4
Incineration	--	--	--	--	--	--	--	--	--	20 4
Transportation	--	--	--	--	--	--	--	--	--	0 5
Disposal	--	--	--	--	--	--	--	--	--	38 3
Subtotals	--	--	--	--	--	--	--	--	--	63.0
Final radiological survey	3.0	1.5	3.0	--	6.0	--	3.0	13.5	--	4.2
Totals	48.0	22.7	45.5	4.3	24.7	30.1	15.5	142.8	4246.70	135.5
25% Cost contingency	--	--	--	--	--	--	--	--	--	33.9
Total cost with contingency	--	--	--	--	--	--	--	--	--	169.4

Amount of Stainless Steel Upper Section

Back: 1.5 x 2.0	= 3.00 m^2
Two sides: 2 x 0.945 x 2.0	= 3.78 m^2
Floor and Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 9.615 m^2
Total Volume: 0.003175 x 9.615	= 0.03053 m^3
Total Volume for 2 Hoods	= 0.06106 m^3
Total Weight for 2 Hoods	= 488 kg

Amount of Stainless Steel in the Lower Cabinet

Back & Front: 2 x 1.5 x 0.90	= 2.700 m^2
Two Sides: 2 x 0.945 x 0.9	= 1.701 m^2
Bottom & Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 7.236 m^2
Total Volume: 0.003175 x 7.236	= 0.02297 m^3
Total Volume for 2 Hoods	= 0.04594 m^3
Total Weight for 2 Hoods	= 368 kg

Amount of Mild Steel in the Exterior Frame

This is assumed to be comprised of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 2.0 m for vertical members and 4 x 1.5 m for horizontal members, for a total length of 14 m. Total mild steel in the fume hood frame is thus 14 m x (0.0508 + 0.04445) x 0.0047626 = 0.006351 m^3.

Total Volume for 2 Hoods	= 0.01270 m^3
Total Weight for 2 Hoods	= 102 kg

Amount of Acrylic Plastic in the Window

The plastic is assumed to be 2.0 m high x 1.5 m wide x 0.00635 m thick, for a total volume of 0.01905 m^3.

Total Volume for 2 Hoods	= 0.0381 m^3
Total Weight for 2 Hoods (s.g. = 1.2)	= 46 kg

Amount of Processing Equipment

The following general type of contaminated equipment is postulated to be present in the fume hoods. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For 2 fume hoods, the total is 4 electric heating units, with a total weight of 28 kg and a total bulk volume of 0.12 m^3.

- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 2 fume hoods, the total is 12 units of processing glassware, with a total weight of 36 kg and a total bulk volume of 0.24 m^3.

- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 2 fume hoods, the total is 8 items, with a total weight of 16 kg and a total bulk volume of 0.112 m^3.

D.4.2 Hot Cells

The ^{137}Cs facility contains two small hot cells constructed of interlocking lead bricks as the walls and a layer of lead bricks on each of the top and bottom of the hot cell (Reference 1, p. A-34-5). The inside dimensions of the hot cells are the same as a 1.2-m cube, with a wall thickness of 0.1 m. The top and bottom shielding of the cells is assumed to also be 0.1 m of lead bricks. The top shielding is supported by a steel plate (assumed to be equivalent to 0.025-m-thick). Two holes in the top steel plate and the bricks there are used to insert one each of the vertical arms of master-slave manipulators. The front of the hot cell has a viewing window 0.6 m x 0.6 m x 0.141 m thick (thickness equivalent to the lead wall thickness in gamma shielding effectiveness). The viewing window is made of lead glass that has the same gamma shielding power as steel. (Thus, it is assumed that the shielding window thickness is 1.41 times that of the lead brick, or 0.141 m.) The working surface floor inside the hot cell is lined with stainless steel (assumed to be 0.001588 m thick), which extends integrally up to a height of 0.1 m along each wall. The walls and ceiling of the hot cells are lined with plastic laminate (assumed to be polycarbonate, 0.001588 m thick). Equipment and material are transferred between each hot cell and its adjacent fume hood through a sliding door on one side that reveals an opening to the fume hood. The sliding door, a rectangular steel box filled with lead, is assumed to be 0.4 m x 0.5 m x 0.1 m thick. Each hot cell is supported by a concrete pedestal that is 0.76 m high and 1.4 m on each side.

Decommissioning of each hot cell involves removal of the equipment inside. (If the equipment needs to be cut, it is done before removing the master-slave manipulators and disassembling the hot cell.) The interior wall and floor and window and door surfaces of the hot cell are vacuumed and wet-wiped with an aqueous solution that contains a small amount of detergent. The master-slave manipulators are removed (see next section), then the hot cell is disassembled. The lead bricks are disassembled from the hot cell, brick-by-brick, vacuumed, wet-wiped, and allowed to dry. The dried lead bricks and the lead-filled door in the hot cell are bagged and placed in 208-liter drums that are sent directly to radioactive-hazardous mixed waste for encapsulation, then to disposal. The lead-glass window is vacuumed, wet-wiped and dried, and removed and bagged and placed in a 208-liter drum (the window may be placed with other, lighter materials from the facility), then sent directly to LLW disposal. The door to the fume hood is removed and bagged and placed in a drum. (The door may be placed with lead bricks from the hot cells.) The internal plastic laminate liner is removed, vacuumed, wet-wiped, painted and cut up to fit efficiently in a drum after bagging, for on-site compaction and off-site supercompaction before sending to LLW disposal. The concrete pedestal for the hot cell is vacuumed, wet-wiped, and painted with strippable decontamination paint. Hot spots are removed by additional spot decontamination with strippable paint. Wet-wiping is done using rags and brushes and a dilute aqueous solution with a small amount of detergent in a way that minimizes run-off or puddling.

Amount of Lead in the Hot Cell

This is equal to that in the 6 sides minus that for the shielding window and the 2 manipulator holes. The volume of lead in the hot cell is 1.4 x 1.4 x 1.4 (outside cube) - 1.2 x 1.2 x 1.2 (inside cavity). From this, we subtract the lead from the window space (0.1 x 0.6 x 0.6) and the 2 holes for the manipulators (assumed to be 0.3048 m in diameter), or 2 x 0.1 x (π/4) x 0.3048 x 0.3048. The volumes become:

2.744 m^3 (outside cube)
minus 1.728 (inside cavity)
Sum = 1.016 gross
minus 0.036 (window hole)
minus 0.0146 (manipulator holes), or,
Net 0.9654 m^3 of lead in hot cell.

For 2 hot cells, the total volume is 1.9308 m^3. The net weight is 10,900 kg, assuming a specific gravity of 11.3. The lead is bagged and placed in 208-liter drums, then sent directly to radioactive-hazardous mixed waste for encapsulation, and then to disposal.

Amount of Lead and Stainless Steel in the Hot Cell Door

Volume: 0.4 x 0.5 x 0.1	= 0.020 m^3
Total Volume for 2 Doors	= 0.040 m^3
Total Weight	= 452 kg

The small amounts of lead in the steel-boxed lead are not differentiated here.

Amount of Stainless Steel in the Hot Cell

This is the inner liner of the bottom, and the 4 sides up 0.1 m high.

Volume: 1.2 x 1.2 x 0.001588 + 1.2 x 0.1 x 4 x 0.001588	= 0.00305 m^3
Total Volume for 2 Hot Cells	= 0.00610 m^3
Total Weight	= 48.8 kg

Amount of Plastic Laminate in the Hot Cell

Volume: 4 x 1.1 x 1.1 x 0.001588	= 0.00769 m^3
Total Volume for 2 Hot Cells	= 0.01537 m^3
Total Weight	= 23 kg

Amount of Leaded Glass in the Hot Cell

Volume: 0.141 x 0.6 x 0.6	
	= 0.0508 m^3
Total Volume for 2 Hot Cells	= 0.1016 m^3
Total Weight	= 813 kg

Amount of Mild Steel in the Hot Cell

This is assumed to come from the 0.025-m-thick plate equivalent that supports the bricks on the top of the hot cell.

Volume: 1.4 x 1.4 x 0.0254	= 0.0498 m^3
Total Volume for 2 Hot Cells	= 0.0996 m^3
Total Weight	= 797 kg

Amount of Materials from Cleaning the Pedestal for the Hot Cell

This is based on the quantities identified in Reference 1, p. 7-15; these are used here, with adjustment for the amount of surface area involved. The surface area of the pedestal is 1.4 x 1.4 (top) + 4 x 1.4 x 0.76 (4 sides) = 6.216 m^2. Ratioing twice this area (for 2 hot cells) to the 48 m^2 in the ceiling of the ^{137}Cs facility results in the following amounts of wastes:

- 1 208-liter drum of wet rags, brushes and contaminated gloves and other clothing (Reference 1, p. E-30). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. It is assumed that other waste materials could be added to the drum with these materials. Estimated weight of these wastes for 2 hot cells before treatment is 19 kg.

- 0.26 208-liter drums of aqueous decontamination solution (assumed to have small amounts of detergents) and rinse solutions from washing/wiping decontamination, before solidification with an adsorbent material. It is assumed that other waste materials could be added to the drum with these materials. Estimated weight of the waste for 2 hot cells before solidification is 41 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 0.26 208-liter drum equivalent of removed strippable paint (assumed in this study) to be compacted on-site. It is assumed that other waste materials could be added to the drum with these materials and the drum could be recompacted. Estimated weight of the waste for 2 hot cells is 6.3 kg. The waste is compacted on-site, supercompacted off-site, and then sent for disposal as LLW.

D.4.3 Master-Slave Manipulators

Two pair of master-slave manipulators are used in each of the two hot cells in the ^{137}Cs facility, for a total of four. The slave sections insert vertically through holes in the hot cell, with shielding assumed to be around or within the manipulator. The master (operator) sections are also vertical, and the mechanisms between the master and the slave sections are in horizontal tubes. It is assumed for that the master and slave sections are each about 2 m long, and the horizontal section is about 1 m long. The average diameter of each section is assumed to be about 0.127 m.

The manipulators would be very difficult to decontaminate at best, even with careful operational procedures and booting of the slave ends. Thus, it is assumed that the manipulators are removed, sectioned, bagged, and placed in 208-liter drums for compacting on-site, and supercompacting off-site before disposal as LLW.

Amount of Material in Manipulators

Volume (π/4) x 0.127 x 0.127 x 5	= 0.0633 m^3
Total Volume for 4 Manipulators	= 0.2533
Total Weight for 4 Manipulators	= 160 kg

D.4.4 Workbenches

The ^{137}Cs facility's single workbench is assumed to be 0.75 m deep, 0.9 m high, and 4 m long (Reference 1, p. 9-13). It is constructed of latex-enamel-painted wood (0.01905 m thick), and has a plastic-laminated top, assumed to be 0.001588-m polycarbonate. The workbench has a stainless steel sink mounted in it at one end (Reference 1, p. 7-17). The workbench is assumed to have one drawer 0.1524 m deep, and below that a shelf a few centimeters above the floor, with 2 doors for every meter of length. To simplify calculations, it is assumed that each drawer and each set of cabinet doors in the 4-m-length of workbench is 1 m wide, and a vertical plywood panel supports the benches every 1 m (a total of five panels).

Because of the proximity of the workbenches to radioactivity-containing components, all of the workbench materials are assumed to be radioactive. The surfaces will be vacuumed and painted before cutting up into pieces sized to effectively fill 208-liter drums. These drums of materials will be sent off-site for supercompaction or incineration (if that option is used), followed by fixation of the resulting ashes.

Amount of Wood in the Workbench

Area:

Front & Back: 2 x 0.9 x 4	= 7.2 m^2
Sides & Support Panels: 5 x 0.75 x 0.9	= 3.375 m^2
Bottom & Top: 4 x 3 x 0.75	= 9 m^2
Sides & Back of 4 Drawers: 4 x 0.1524 x 1 + 8 x 0.1524 x 0.75	

		$= 1.524\ m^2$
Total Area		$= 21.099\ m^2$
Total Volume:	21.099 x 0.01905	$= 0.402\ m^3$,
Total weight (s.g. = 0.8)		= 322 kg

Amount of Polycarbonate on Workbench Surfaces

Volume:	4 x 0.75 x 0.001588	$= 0.0048\ m^3$
Weight (s.g. = 1.5)		= 7.2 kg

Amount of Processing Equipment on the Workbench not used to Support the Hot Cells

It is assumed that the workbenches were used for radioactive counting equipment, which had to stay clean, for tools (again, assumed to be free of contamination) for making small new parts for the hot cells; for temporary storage of nonradioactive materials; for overpacking the products (again expected to be a relatively clean operation); and other similar uses. The contaminated material below is to be bagged, loaded into 208-liter drums, compacted on-site, and sent off-site for supercompaction before being sent for disposal as LLW. The following general type of equipment is postulated to be present on the workbench:

- various hand tools, primarily steel, weighing a total estimated 3 kg, with a total gross bulk volume estimated to be $0.002\ m^3$.
- 1 significant item of processing glassware, weighing about 3 kg. This item would weigh about 3 kg and would require an estimated $0.020\ m^3$ of total bulk space.
- 1 item of various materials (metals, plastic, ceramic), weighing about 2 kg. The estimated weight for this item is 2.0 kg, with an estimated total bulk volume of $0.002\ m^3$.

D.4.5 Vent Ducts

The ^{137}Cs facility contains 8 m of cylindrical ductwork 0.2 m in diameter and 15 m of rectangular ductwork 0.25 m x 0.6 m in cross-section (Reference 1, p. 9-13). The ductwork is assumed to be stainless steel sheet metal 0.0015875 m thick.

The ductwork is assumed to be radioactively contaminated internally and externally. The ductwork is vacuumed and wet-wiped where possible to remove the readily-removable contamination, then painted to minimize contamination during the next step of cutting into pieces and bagging and packaging as LLW. The duct waste is cut into pieces that maximize the amount of material that can fit in 208-liter drums. The waste pieces are placed in plastic bags before being placed in the drums. The waste-filled drums are then compacted on-site and then shipped off-site for supercompaction before disposal as LLW.

Amount of Material in the Ductwork

Cylindrical Ductwork Volume = π x 0.2 x 8 x 0.0015875	$= 0.008\ m^3$
Rectangular Ductwork Volume = 2 x (0.25 + 0.6) x 15 x 0.0015875	
	$= 0.040\ m^3$
Total Volume	$= 0.048\ m^3$
Total weight	= 384 kg

D.4.6 Filters

In the ^{137}Cs facility, each fume hood (2) and hot cell (2) has a small, round HEPA and roughing filter at its respective air outlet, and there is one larger HEPA and roughing filter on the facility's ventilation exhaust (Reference 1, pp. 7-19, 9-13) where the exhaust enters the facility exhaust plenum. The round HEPA filters are 0.2 m diameter x 0.2 m high; the round roughing filters are 0.2 m diameter x 0.1 m high; the large, rectangular HEPA filter is 0.25 m x 0.6 m x 0.3 m; and the large, rectangular roughing filter is 0.25 m x 0.6 m x 0.15 m. It is postulated that the facility filters had been replaced at the end of the operating period, and they will last through-out the total decommissioning period. In addition, it is assumed that during the vacuuming activity of the components and the facility, a commercial vacuum unit is leased that uses a set of round roughing and HEPA filters identical to those in the facility components, and 2 sets of filters are used during vacuuming, making the total 6 sets. The filter removal is one of the last activities undertaken during decommissioning.

Each filter is wrapped in a plastic bag and sealed during its removal. It is assumed that the filters are made of sheet-metal casing with pleated paper as the filter medium. It is postulated that the HEPA filters are bagged, placed in 208-liter drums for on-site compaction, followed by shipment off-site for supercompaction before being packaged for disposal as LLW.

Amount of Materials in the HEPA Filters

The bulk (rectangular) volume of the 6 filters is 6 x 0.2 x 0.2 x 0.2 = 0.048 m^3. The rectangular volume of the large HEPA filter is 0.25 x 0.6 x 0.3 = 0.045 m^3. The total volume of all HEPA filters is thus 0.093 m^3. The overall weight of each small HEPA filter is assumed to be 5 kg; the large HEPA is assumed to weigh 12 kg. Thus the total weight of all HEPA filters is 42 kg.

Amount of Materials in the Roughing Filters

The bulk (rectangular) volume of the 6 filters is 6 x 0.2 x 0.2 x 0.1 = 0.024 m^3. The rectangular volume of the large roughing filter is 0.25 x 0.6 x 0.15 = 0.0225 m^3. The total volume of all the roughing filters is thus 0.0465 m^3. The overall weight of each small filter is assumed to be 2.5 kg; the large roughing filter is assumed to weigh 6 kg. Thus the total weight of all roughing filters is 21 kg.

D.4.7 Sink and Drain

There is one single-bowl sink in the ^{137}Cs facility. The sink is mounted near one end of the workbench. The sink is assumed to be 18-gage stainless steel (0.001214 m thick) with inside dimensions of 0.635 m wide x 0.5588 m long x 0.3048 m deep, with overall dimensions of 0.8382 m wide x 0.5588 m deep to allow for the flanges (Reference 2). The facility sink is used for personal cleanliness. Liquid effluent is discharged to a tank (assumed to be outside) where it is held for monitoring before discharge to the sanitary sewer (Reference 1, p. 7-19). Contaminated liquids are not purposely discharged to the sanitary sewer via the sink. Operational aqueous waste liquids are not discharged to the laboratory sink system, but are solidified with a setting material and shipped out as LLW during operation. Operational organic waste liquids are absorbed on an absorbent material that meets disposal facility requirements, and are shipped out as a solid LLW during operation (Reference 1, p. 7-26). The sink and its associated water faucet, and the drain piping to the facility wall are wiped down, removed, cut up to efficiently use space in the 208-liter drum, and wrapped in plastic bags by a pipefitter, assisted by a technician. The waste materials are compacted on-site, and supercompacted off-site before disposal as LLW.

Amount of Stainless Steel in the Sink

The sink is assumed to weigh about 12 kg and to require a bulk volume of an estimated 0.113 m^3.

Amount of Brass in the Fixture and Connections

The weight of the brass is estimated to be 3 kg, assuming a specific gravity for brass of 8.75. The brass will occupy about 0.0283 m^3 of bulk space.

Amount of Galvanized Steel in the Drain and P Trap

This is equivalent to 5 m of 0.1-m-diameter pipe (Reference 1, p. 2-9), or an estimated 16.05 kg/m x 4 m = 64.2 kg. The bulk volume of the material is estimated to be 0.05 m^3.

D.4.8 Facility Ceiling

The ^{137}Cs facility contains 48 m^2 of latex enamel painted concrete ceiling (Reference 1, p. 7-19). The ceiling is decontaminated to unrestricted levels. Because the facility ceiling is a rigid concrete structure, decontamination is done in ways to minimize destruction of any significant part of the structure and its enamel paint (although some of the enamel paint may be removed by the decontamination). The ceiling is first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the ceiling is wiped with dry rags and allowed to dry completely. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, then dry-wiped, or possibly spotted with additional strippable paint. Only materials used for decontamination are assumed to become LLW.

Amounts of Waste Materials Resulting from Decontaminating the Ceiling

The estimates developed in Reference 1, p. E-30, for the wash/wipe operations seem reasonable for the decontamination procedures used in that study, but in this study, much less liquid decontaminating agent is used, with part of the decontamination being done with strippable paint. Thus, the amount of rags, brushes, and liquid wastes is taken to be 1/3 of that in Reference 1, with adjustments for wall area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 1 208-liter drum of wet rags, brushes and contaminated gloves and other clothing. These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes before treatment is 18 kg.

- 0.25 208-liter drums of aqueous decontamination solutions (assumed to contain small amounts of detergents) and rinse solutions from wet/wiping decontamination activities, before solidification on-site with an adsorbent material. It is assumed that the drum can be filled with similar solutions from decontamination of other components to fully use the drum space. The estimated weight of the wastes before solidification is 40 kg.

- 0.73 208-liter drums equivalent of removed strippable paint (assumed in this study) to be reduced to a smaller volume after on-site compaction). It is assumed that the drum can be filled with other strippable paint from decommissioning other components of the facility to fully use the drum space. The waste is compacted on-site and sent off-site for supercompaction before being disposed of as LLW. Estimated weight of the LLW is 18 kg.

D.4.9 Facility Walls

The ^{137}Cs facility contains 84 m^2 of latex-enamel-painted concrete walls (Reference 1, p. 7-19). The walls are decontaminated to unrestricted levels. Because the facility walls are rigid concrete structures, decontamination is done in ways to minimize destruction of any significant part of the structure and its enamel paint (although some of the enamel paint may be removed by the decontamination).

The walls are first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the walls are wiped with dry rags and allowed to dry completely. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, then dry-wiped, or spotted with another coat of strippable paint. Only materials used for decontamination are assumed to become LLW. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

Amount of Waste Materials Resulting from Decontaminating the Walls

The estimates developed in Reference 1, p E-30, for the wash/wipe operations seem reasonable for the decontamination procedures used in that study, but in this study, we are assuming much less usage of liquid decontaminating agent, with part of the decontamination being done with strippable paint. Thus, the amount of rags, brushes, and liquid wastes is taken to be 1/3 of that in Reference 1, with adjustments for surface area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 1.67 208-liter drums of wet rags, brushes and contaminated gloves and other clothing. These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. The estimated weight of these wastes before treatment is 32 kg.

- 1.27 208-liter drums of aqueous decontamination solutions (assumed to contain small amounts of detergents) and rinse solutions from wet/wiping decontamination, before solidification with an adsorbent material. The estimated weight of the wastes before solidification is 70 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 1.27 208-liter drums equivalent of removed strippable paint (assumed in this study) to be combined with other strippable paint waste from decommissioning of this facility to efficiently use drum space). The estimated weight of the LLW is 32 kg. The waste is compacted on-site, supercompacted off-site, and sent for disposal as LLW.

D.4.10 Facility Floor

The ^{137}Cs facility floor contains 48 m^2 of asphalt tile (postulated to be 0.0015875 m thick) over concrete (Reference 1, p. 7-19). The floor is postulated to be first vacuumed and then painted to fix the remaining contamination. The tiles are manually removed and packaged in plastic bags in 208-liter drums as LLW. The remaining hot spots in the concrete flooring are cleaned by a small amount of scabbling of the hot spots, followed by re-vacuuming the entire floor surface. The concrete rubble and dust are then bagged and efficiently packed in drums. The drums are compacted on-site, then sealed and sent for disposal as LLW.

Amount of Waste Materials Resulting from Removing Floor Tiles

The total volume of floor tiles = 48 x 0.0015875 = 0.0762 m^3. Assuming a specific gravity of 1.1, the asphalt tiles would weigh an estimated 85 kg. The floor tiles are compacted on-site, supercompacted off-site, and then sent for disposal as LLW.

Amount of Concrete Flooring Removed as Radioactive Waste

A number of the cracks between the tiles (assumed here to be 10% of the floor area) will have contaminated concrete that needs to be removed, assumed to a depth of 0.0127 m. The total amount of concrete rubble and dust removed as radioactive waste is 48 x 0.1 x 0.0127 = 0.061 m^3 of concrete as rubble and dust. Assuming the specific gravity is 60% of theoretical, the volume is 0.102 m^3 before compaction. The weight is estimated at 153 kg, assuming a specific gravity of 2.5. The concrete rubble and dust are postulated to be bagged and drummed, then compacted on-site before disposal as LLW.

D.5 Reference Laboratory for the Manufacture of ^{241}Am Sealed Sources

Detailed physical descriptions and decommissioning procedures for all the components and building surfaces of the ^{241}Am laboratory that are postulated to require removal and/or decontamination are given in Sections D.5.1 through D.5.11. Details of (1) planning and preparation, (2) estimated manpower requirements, (3) waste management, materials, and labor costs, and (4) radiation dosages are presented in Table D.5a for the supercompaction option and in Table D.5b for the supercompaction option with incineration. An overall description of this laboratory is contained in Section 7.1.5 of Reference 1.

D.5.1 Fume Hoods

Each of the ^{241}Am facility's two fume hoods is 1.5 m wide x 2.0 m high x 0.945 m deep. Each fume hood is assumed to be framed externally by mild steel 0.003175 m thick and to contain acrylic windows 0.00635 m thick. Each hood is assumed to rest on an enclosed stainless steel-based cabinet (Fig A.5-1, p. A-30, Reference 1.) The support cabinet is assumed to have the same foot print as the fume hood but is only 0.9 m high.

Before the fume hoods are dismantled, the interior and exterior surfaces are vacuumed and wet-wiped, then dried and painted to fix contamination. The hoods are then cut to sizes that allow the hood materials to be bagged and placed into 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site.

Amount of Stainless Steel Upper Section

Back: 1.5 x 2.0	= 3.00 m^2
Two sides: 2 x 0.945 x 2.0	= 3.78 m^2
Floor and Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 9.615 m^2
Total Volume: 0.003175 x 9.615	= 0.03053 m^3
Total Volume for 2 Hoods	= 0.06106 m^3
Total Weight for 2 Hoods	= 488 kg

Table D.5a ^{241}Am Lab summary–supercompaction option; manpower requirements, radiation doses, and costs for decommissioning the ^{241}Am laboratory–supercompaction option (no incineration)

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	4.5	--	4.5	--	9.0	--	--	13.5	1798.23	4.8
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	29.5	12.5	29.5	--	14.0	--	12.5	68.5	1798.23	22.9
Decommissioning										
Fume hoods	2.5	1.2	2.1	0.6	1.2	4.2	--	9.3	91.61	3.5
Glove boxes	7.5	3.7	5.7	2.1	3.7	11.3	--	26.6	11473.31	9.9
Workbenches	0.9	0.4	0.7	0.4	0.4	1.4	--	3.3	1.60	1.2
Vent ducts	2.9	1.4	2.2	1.1	1.4	4.3	--	10.4	10.09	3.9
Cabinets	0.4	0.2	0.3	0.1	0.2	0.6	--	1.4	2.61	0.5
Filters	0.6	0.3	0.6	--	0.3	1.2	--	2.5	4.99	0.9
Ceiling	1.8	0.9	1.8	--	0.9	3.6	--	7.2	14.33	2.7
Walls	4.8	2.4	4.8	--	2.4	9.7	--	19.4	38.74	7.2
Floors	1.9	1.0	1.9	--	1.0	3.8	--	7.6	38.08	2.8
Subtotals	23.2	11.6	20.1	4.2	11.6	40.1	--	87.7	11675.38	32.6
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools & materials	--	--	--	--	--	--	--	--	--	1.0
Laundry	--	--	--	--	--	--	--	--	--	2.2
Subtotals	--	--	--	--	--	--	--	--	--	23.5
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	2.1
Supercompaction	--	--	--	--	--	--	--	--	--	4.3
Incineration	--	--	--	--	--	--	--	--	--	--
Transportation	--	--	--	--	--	--	--	--	--	0.6
Disposal	--	--	--	--	--	--	--	--	--	24.5
Subtotals	--	--	--	--	--	--	--	--	--	31.5
Final radiological survey	5.0	2.5	5.0	--	10.0	--	5.0	22.5	--	6.9
Totals	57.7	26.6	54.6	4.2	35.6	40.1	17.5	178.7	13473.61	117.5
25% Cost contingency	--	--	--	--	--	--	--	--	--	29.4
Total cost with contingency	--	--	--	--	--	--	--	--	--	146.8

Table D.5b ^{241}Am Lab summary–incineration option; manpower requirements, radiation doses, and costs for decommissioning the ^{241}Am laboratory–supercompaction and incineration option

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	4.5	--	4.5	--	9.0	--	--	13.5	1798.23	4.8
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	29.5	12.5	29.5	--	14.0	--	12.5	68.5	1798.23	22.9
Decommissioning										
Fume hoods	2.5	1.2	2.1	0.6	1.2	4.2	--	9.3	91.61	3.5
Glove boxes	7.5	3.7	5.7	2.1	3.7	11.3	--	26.6	11473.31	9.9
Workbenches	0.9	0.4	0.7	0.4	0.4	1.4	--	3.3	1.60	1.2
Vent ducts	2.9	1.4	2.2	1.1	1.4	4.3	--	10.4	10.09	3.9
Cabinets	0.4	0.2	0.3	0.1	0.2	0.6	--	1.4	2.61	0.5
Filters	0.6	0.3	0.6	--	0.3	1.2	--	2.5	4.99	0.9
Ceiling	1.8	0.9	1.8	--	0.9	3.6	--	7.2	14.33	2.7
Walls	4.8	2.4	4.8	--	2.4	9.7	--	19.4	38.74	7.2
Floors	1.9	1.0	1.9	--	1.0	3.8	--	7.6	38.08	2.8
Subtotals	23.2	11.6	20.1	4.2	11.6	40.1	--	87.7	11675.38	32.6
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools & materials	--	--	--	--	--	--	--	--	--	1.0
Laundry	--	--	--	--	--	--	--	--	--	2.2
Subtotals	--	--	--	--	--	--	--	--	--	23.5
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	2.1
Supercompaction	--	--	--	--	--	--	--	--	--	2.5
Incineration	--	--	--	--	--	--	--	--	--	18.7
Transportation	--	--	--	--	--	--	--	--	--	0.5
Disposal	--	--	--	--	--	--	--	--	--	18.0
Subtotals	--	--	--	--	--	--	--	--	--	41.8
Final radiological survey	5.0	2.5	5.0	--	10.0	--	5.0	22.5	--	6.9
Totals	57.7	26.6	54.6	4.2	35.6	40.1	17.5	178.7	13473.61	127.8
25% Cost contingency	--	--	--	--	--	--	--	--	--	31.9
Total cost with contingency	--	--	--	--	--	--	--	--	--	159.7

Amount of Stainless Steel in the Lower Cabinet

Back & Front: 2 x 1.5 x 0.90	= 2.700 m^2
Two Sides: 2 x 0.945 x 0.9	= 1.701 m^2
Bottom & Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 7.236 m^2
Total Volume: 0.003175 x 7.236	= 0.02297 m^3
Total Volume for 2 Hoods	= 0.04594 m^3
Total Weight for 2 Hoods	= 368 kg

Amount of Mild Steel in the Exterior Frame

This is assumed to be comprised of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 2.0 m for vertical members and 4 x 1.5 m for horizontal members, for a total length of 14 m. Total mild steel in the fume hood frame is thus 14 m x (0.0508 + 0.04445) x 0.0047626 = 0.006351 m^3.

Total Volume for 2 Hoods	= 0.0127 m^3
Total Weight for 2 Hoods	= 102 kg

Amount of Acrylic Plastic in the Window

The plastic is assumed to be 2.0 m high x 1.5 m wide x 0.00635 m thick, for a total volume of 0.01905 m^3.

Total Volume for 2 Hoods	= 0.0381 m^3
Total Weight for 2 Hoods (s.g. = 1.2)	= 46 kg

Amount of Processing Equipment

There is very little space inside the fume hood for processing equipment because each fume hood contains a glove box that takes up most of the interior fume hood space. The following general type of contaminated equipment is postulated to be present in the fume hood. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. This is assumed to take up about 0.03 m^3 of space. For 2 fume hoods, the total is 4 electric heating units, with a total weight of 28 kg and a total bulk volume of 0.12 m^3.

- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 2 fume hoods, the total is 12 units of processing glassware, with a total weight of 36 kg and a total bulk volume of 0.24 m^3.

- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. This is assumed to take up about 0.014 m^3 of space. For 2 fume hoods the total is 8 items, with a total weight of 16 kg and a total bulk volume of 0.112 m^3.

D.5.2 Glove Boxes

The ^{241}Am facility contains seven glove boxes. Each glove box measures 1.2 m wide x 0.6 m high x 0.6 deep (Reference 1, p. 7-22). Each glove box is assumed to be framed externally by mild steel 0.003175 m thick and to contain a 0.00635 m-athick acrylic window. Each box is postulated to rest on an enclosed stainless steel-based cabinet, similar to that for the fume hood, above, but with differing foot print dimensions: The cabinet is assumed to have the same foot print as the glove box but is only 0.9 m high. The glove box is assumed to have a stainless steel panel across the lower 0.25 m of the front, in which are located two 0.2-m-diameter circular openings for neoprene working gloves. Above this panel, the front of the glove box slopes backward at an angle of about 40 degrees, providing an opening for the acrylic plastic viewing window (assumed to be 0.00635-m-thick). The acrylic plastic viewing window is mounted in a mild steel metal frame which is gasketed to the sloping front of the glove box. Six of the 7 glove boxes are in a row and each is connected to the adjacent one(s) through a stainless steel transfer tunnel. The transfer tunnel cross-section is 0.45 m x 0.45 m, and the stainless steel there is assumed to be 0.003175 m thick. The total number of transfer tunnels is 5 and the total length of the tunnels is 4 m (Reference 1, p. 9-15), with an acrylic plastic door assumed to be located at the entrance and exit from each of the in-line glove boxes. The 7th glove box, located independently, is also assumed to rest on its own mild steel cabinet. At one end of the independent glove box and each of the two end glove boxes that are in a row is a stainless steel airlock for the insertion of equipment and material into the box. Dimensions of the three airlocks are 0.3 m high x 0.2 m wide x 0.2 m deep (Reference 1, p. A.33). One acrylic air lock door of each air lock is accessible from outside the glove box, and one is accessible from the inside of the box through the use of glove ports. An acrylic door is assumed to be located in the 5 transfer tunnels on each of the 6 connected glove boxes. Construction materials of the transfer tunnels is stainless steel, with no framework. Standard electrical receptacles are located on the inside of each glove box, with power controlled by switches mounted outside on a service panel above the glove box.

Before dismantlement of the glove boxes, the interior and exterior box surfaces (as well as the air lock and transfer tunnel surfaces) are vacuumed and wet-wiped, and then are painted to fix contamination. The glove boxes are then cut to sizes that allow the bagged glove box materials to go into 208-liter drums in such a way that the materials can be reasonably compacted on-site, supercompacted off-site, and then disposed of as LLW. The acrylic plastic, the steel materials, and the equipment inside the glove box are segregated into drums, each with one of these categories of materials.

Amount of Stainless Steel

Area:	
Back: 1.2 x 0.6	= 0.72 m^2
Bottom: 1.2 x 0.6	= 0.72 m^2
2 sides: 2 x 0.6 x 0.6	= 0.72 m^2
Top: 1.2 x 0.3	= 0.36 m^2
Front Panel: 0.25 x 1.2	= 0.30 m^2
Total Area	= 2.82 m^2
Total Volume: 2.82 x 0.003175	= 0.0089535 m^2
Total Volume for 7 Glove Boxes	= 0.0626745 m^3
Total Weight for 7 Glove Boxes	= 501 kg

Amount of Stainless Steel in the Air Locks

Area:	
Back: 0.3 x 0.2	= 0.06 m^2
Top, Side, Bottom: 3 x 0.2 x 0.2	= 0.12 m^2
Total Area	= 0.18 m^2
Total Volume: 0.18 x 0.003175	= 0.0005715 m^2
Total Volume for 3 Air Locks	= 0.0017145 m^3
Total Weight	= 13.7 kg

Amount of Stainless Steel in the Transfer Tunnels

Volume: 4 x 4 x 0.45 x 0.003175	= 0.02286 m^3
Total Volume for 5 Transfer tunnels	= 0.1143 m^3
Total weight for 5 Transfer Tunnels	= 914 kg

Amount of Stainless Steel in the Lower Cabinet Section Below the Glove Box

Area:	
Back and Front: 2 x 1.2 x 0.9	= 2.16 m^2
Two Sides: 2 x 0.6 x 0.6	= 0.72 m^2
Bottom and Top: 2 x 1.2 x 0.6	= 1.44 m^2
Total Area	= 4.32 m^2
Total Volume: 4.32 x 0.003175	= 0.0137 m^3
Total Volume for 7 cabinets	= 0.0960 m^3
Total Weight for 7 cabinets	= 768 kg

Amount of Mild Steel in the Exterior Frame of the Glove Box

This is postulated to be from angle iron, 0.0508 m wide x 0.0047625 m thick. The amount of mild steel is 4 x 0.6 high (for vertical members) + 5 x 1.2 m wide (for horizontal members), or 8.4 linear meters, total.

Volume: 8.4 x (0.0508 + 0.04445) x 0.0047625	= 0.003810 m^3
Volume for 7 Glove Boxes: 7 x 0.003810	= 0.02667 m^3
Weight for 7 Glove Boxes: 8000 x 0.02667	= 30.5 kg.

Amount of Acrylic Plastic in the Main Window of a Glove Box

Volume: 0.6 x 1.2 x 0.00635	= 0.00457 m^3
Volume for 7 Glove Boxes	= 0.032 m^3
Weight for 7 Glove Boxes: 1200 x 0.032	= 38.4 kg

Amount of Acrylic Plastic in Each Airlock Window of a Glove Box

Volume: 0.3 x 0.2 x 0.00635	= 0.000381 m^3
Volume for 3 Glove Box Airlocks or Transfer Tunnels	= 0.0011 m^3
Weight for 3 Glove Box Airlocks or Transfer Tunnels	= 1.37 kg

Amount of Acrylic Plastic in each Transfer Tunnel Door of a Glove Box

Volume: 0.45 x 0.45 x 0.00635	= 0.0013 m^3
Volume for 10 Transfer Tunnel Doors	= 0.013 m^3
Weight for 10 Transfer Tunnel Doors	= 15.6 kg

Amount of Processing Equipment in Each Glove Box

The following general type of contaminated equipment, to be disposed of as LLW, is postulated to be present in the glove boxes:

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.0283 m^3 of space, each. For 7 glove boxes, the total is 14 electric heating units, with a total weight of 98 kg and a total bulk volume of 0.1981 m^3.
- 6 significant items of processing glassware, each weighing about 3 kg. These are assumed to take up about 0.02 m^3 of space, each. For 7 glove boxes, the total is 42 units of processing glassware, with a total weight of 126 kg and a total bulk volume of 0.84 m^3.
- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 7 glove boxes, the total is 28 items, with a total weight of 56 kg and a total bulk volume of 0.39 m^3.

D.5.3 Workbench

The single workbench in the ^{241}Am facility has a total top surface area of 1.5 m^2 (Reference 1, p. 9-15). Assuming the workbench has the same width as those for the other facilities in this study, or 0.75 m, then the length of the bench is 2 m. The bench is assumed to be 0.9 m high. The workbench is made of painted mild steel (assumed to be 0.0015875 m thick) and has a top of stainless steel, assumed to be 0.003175 m thick. The workbench is assumed to have two side-by-side drawers (below the surface) that are 0.1524 m deep, and below that, a shelf a few centimeters above the floor, with 2 doors for each meter of workbench length. To simplify calculations, it is assumed that each drawer and each set of cabinet doors in the workbench is 1 m wide, and that a vertical steel panel supports the bench every 1 m (a total of 1 panel plus the two ends).

Because of the proximity of the workbench to radioactivity-containing components, all of the workbench materials are assumed to be radioactive. For decommissioning, the surfaces are vacuumed, wet-wiped, and painted before the bench is cut into pieces. The pieces are bagged and sized to effectively fill 208-liter drums. These drums of materials are compacted on-site and sent off-site for supercompaction prior to being overpacked for shipment and disposal as LLW.

Amount of Painted Mild Steel in the Workbench

Areas:	
Front & Back: 2 x 0.9 x 2	= 3.6 m^2
Sides & Support Panels: 3 x 0.75 x 0.9	= 2.025 m^2
Bottom, Shelf & Drawer Bottoms: 2 X 2 X 0.75	= 3.0 m^2
Drawer Sides: 2 x 2 x 0.75 x 0.1524	= 0.4572 m^2
Backs of 2 Drawers: 2 x 1 x 0.1524	= 0.3048 m^2
Total Area	= 9.387 m^2
Total Volume: 0.0015875 x 9.387	= 0.0149 m^3
Total Weight: 8000 x 0.0149	= 119 kg

Amount of Stainless Steel on the Surfaces of the Workbench

Volume: 2 x 0.75 x 0.003175	= 0.00476 m^3
Weight: 8000 x 0.00476	= 38 kg

Amount of Processing Equipment on the Workbench

It is assumed that the workbench was used for radioactive counting equipment that had to stay clean; for tools (again, assumed to be free of contamination) for making small new parts for the hoods and glove boxes; for temporary storage of nonradioactive materials; for weighing and overpacking the products (again, expected to be a relatively clean operation); and other similar uses. The following general type of contaminated equipment is to be disposed of as LLW (with compacting on-site, and supercompacting off-site):

- Various hand tools, primarily steel, weighing a total estimated 8 kg, with a total gross volume estimated to be 0.005 m^3
- 2 significant items of processing glassware, each weighing about 3 kg and each occupying about 0.02 m^3 of space. For the 2 glass items, the items would weigh a total of about 6 kg and require 0.040 m^3 of total bulk space.
- 1 additional item that could be made of various materials (metals, plastic, ceramic), weighing about 2 kg and occupying a volume of about 0.002 m^3.

D.5.4 Vent Ducts

The ^{241}Am facility contains 38 linear meters of polyvinyl chloride pipe (Reference 1, p. 7-23, 9-15). There are exhaust ducts from each of the two fume hoods and from each of the 7 glove boxes. The ductwork is composed of 18 m of 0.2-m-diameter PVC pipe and 20 m of rectangular pipe (0.25 m x 0.6 m). All pipe is assumed to be 0.003175 m thick.

The ductwork is assumed to be contaminated internally and externally. The ductwork is vacuumed and wet-wiped where possible to remove the readily-removable contamination, then painted to minimize contamination. The duct waste is cut into pieces and put into plastic bags. The pieces are cut so as to maximize the amount of material that can fit in 208-liter waste drums. The waste-filled drums are compacted on-site and then shipped off-site for supercompaction before being disposed of as LLW.

Amount of PVC Material in the Round Ductwork

Volume: π x 0.2 x 18 x 0.003175	= 0.0359 m^3
Weight: 1400 x 0.0359	= 50 kg

Amount of PVC Material in the Rectangular Ductwork

Volume: 20 x (2 x 0.25 + 2 x 0.6) x 0.003175	= 0.108 m^3
Weight: 1400 x 0.108	= 151 kg

D.5.5 Cabinets and Shelf Unit

The ^{241}Am facility has one cabinet (Reference 1, p. 7-22) for storing nonradioactive supplies. The cabinet is postulated to be constructed of painted wood 0.01905 m thick. The dimensions are assumed to be 0.762 m wide x 0.4572 m deep x 1.524 m high. The cabinet is postulated to have two locking doors and three shelves, plus the bottom inside shelf.

The cabinet is given only mild decontamination by vacuuming and wet-wiping. It is then painted, sectioned, bagged, and placed in 208-gallon drums which are compacted on-site. The sectioning is done in a way that efficiently uses the space in the drums. The drums are then shipped off-site for supercompaction. If the incineration option is used, the waste is sent off-site for incineration and fixation of the ashes into a monolithic solid. The fixed solid is sent for disposal as LLW.

Amount of Material in the Cabinet

Area:	
Front & Back: 2 x 0.762 x 1.524	= 2.3226 m^2
Two Sides: 2 x 0.4572 x 1.524	= 1.3935 m^2
Top, Bottom, 3 Shelves: 5 x 0.762 x 0.4572	= 1.742 m^2
Total Area	= 5.4581 m^2
Volume: 5.4581 x 0.01905	= 0.104 m^3
Weight: 800 x 0.104	= 83 kg

D.5.6 Filters

The exhaust ducts from each of the two fume hoods and from each of the seven glove boxes in the ^{241}Am facility include a roughing filter and a HEPA filter, for a total of nine sets of roughing and HEPA filters at the exhaust from each component. The HEPA filters are 0.2 m in diameter and 0.2 m high; the roughing filters are 0.2 m in diameter and 0.1 m high (Reference 1, p. 9-15). The filters are assumed to have frames of stainless steel and use pleated paper as the filter medium. At the point where the component exhaust air meets the facility exhaust plenum, another bank of larger roughing/HEPA filters is used. These filters are larger and rectangular, with the HEPA filters measuring 0.25 m x 0.6 m x 0.3 m, and the roughing filters measuring 0.25 m x 0.6 m x 0.15 m. It is postulated that the facility filters had been replaced at the end of the operating period, and that they will last throughout the total decommissioning period. In addition, it is assumed that during the vacuuming activity of the components and the facility, a commercial vacuum unit is leased that uses a round roughing filter and a round HEPA filter identical to those in the facility. Two sets of these filters are used during vacuuming, bringing the total number of small, round HEPA/roughing filter sets to 11. The filter removal is one of the last activities undertaken during decommissioning.

It is assumed that the filters are comprised of sheet-metal casings with pleated paper as the filter medium. It is postulated that the HEPA filters are bagged, placed in 208-liter drums for on-site compaction, followed by shipment off-site for super-compaction, before being packaged for disposal as LLW.

Amount of Materials in the Small, Round HEPA Filters

The overall weight of each small, round HEPA filter is assumed to be 5 kg. The estimated weight of the 11 small, round HEPA filters is thus 55 kg. The bulk (rectangular) volume of the 11 filters is 11 x 0.2 x 0.2 x 0.2 = 0.088 m^3.

Amount of Materials in the Large, Rectangular HEPA Filters

The overall weight of each large, rectangular HEPA filter is assumed to be 12 kg. The volume of each large, rectangular HEPA filter is 0.25 x 0.6 x 0.3 = 0.0450 m^3.

Amount of Materials in the Small, Round Roughing Filters

The overall weight of each roughing filter is assumed to be 2.5 kg. The estimated weight of the 11 roughing filters is thus 27.5 kg. The bulk (rectangular) volume of the 11 filters is 11 x 0.2 x 0.2 x 0.1 = 0.044 m^3.

Amount of Materials in the Larger, Rectangular Roughing Filter

The overall weight of the rectangular roughing filter is assumed to be 6 kg. The bulk volume of the rectangular roughing filter is 0.25 x 0.6 x 0.15 = 0.0225 m^3.

D.5.7 Facility Ceiling

The ^{241}Am facility contains 60 m^2 of concrete ceiling that is all painted and sealed with acrylic paint (Reference 1, p. 9-15). The ceiling is decontaminated to unrestricted levels. Because the facility ceiling is a rigid concrete structure, decontamination is done in ways to minimize destruction of any significant part of the structure and its paint (although some of the paint may be removed by the decontamination). The ceiling is first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the ceiling is wiped with dry rags and allowed to dry completely. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, then dry-wiped, or spotted with strippable paint. Only materials used for decontamination are assumed to become LLW.

Amounts of Waste Materials Resulting from Decontaminating the Ceiling

The estimates developed in Reference 1 for the wash/wipe operations are reasonable for the decontamination procedures used in the original study, but in this study, considerably less liquid decontaminating agent is used, and part of the decontamination is done with strippable paint. Thus, the amount of rags and brushes, and liquid wastes here is taken to be 1/3 of that in Reference 1, with adjustments for surface area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 1.33 208-liter drums of wet rags, brushes, and contaminated gloves and other clothing (Reference 1, p. E-30). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes before treatment is 24 kg.

- 0.33 208-liter drums of aqueous decontamination solutions (assumed to contain small amounts of detergents) and rinse solutions from wet/wiping decontamination, before solidification with an adsorbent material. It is assumed that the drum can be filled more fully with similar solutions from decontamination of other components to fully use the drum space. Estimated weight of the wastes before solidification is 53 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 0.97 208-liter drums equivalent of removed strippable paint (assumed in this study) to be reduced to a smaller volume after on-site compaction). It is assumed that the drum can be filled with other strippable paint from decommissioning other components of the facility to fully use the drum space. The removed strippable paint is compacted on-site, supercompacted off-site, and then sent for disposal as LLW. Estimated weight of the LLW is 24 kg.

D.5.8 Facility Walls

The ^{241}Am facility contains 168 m^2 of concrete walls painted with acrylic paint (Reference 1, p. 9-15). The walls are decontaminated to unrestricted levels. Because the facility walls are rigid concrete structures, decontamination is done in ways to minimize destruction of any significant part of the structure, and its acrylic paint (although some of the acrylic paint may be removed by the decontamination). The walls are first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the walls are wiped with dry rags and allowed to dry completely. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, then dry-wiped, or spotted with another coat of strippable paint. Only materials used for decontamination are assumed to become LLW.

Amount of Waste Materials Resulting from Decontaminating the Walls

The estimates developed in Reference 1 for the wash/wipe operations seem reasonable for the decontamination procedures used in the original study, but in this study, considerably less liquid decontaminating agent is used, and part of the decontamination being done with strippable paint. Thus, the amount of rags and brushes, and liquid wastes here are taken to be 1/3 of those in Reference 1, with adjustments for wall area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 2.67 208-liter drums of wet rags, brushes and contaminated gloves and other clothing (Reference 1, p. E-30). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes before treatment is 51 kg.

- 0.67 208-liter drums of aqueous decontamination solutions (assumed to contain small amounts of detergents) and rinse solutions from wet/wiping decontamination, before solidification with an adsorbent material. Estimated weight of the wastes before solidification is 112 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 2.0 208-liter drums equivalent of removed strippable paint (assumed in this study) to be combined with other strippable paint waste from decommissioning of this facility to efficiently use drum space). Estimated weight of the LLW is 51 kg. The removed strippable paint is compacted on-site, supercompacted off-site, and then sent for disposal as LLW.

D.5.9 Facility Floor

The facility contains 60 m^2 of concrete covered with linoleum postulated to be 0.0015875 m thick. All the linoleum joints are heat-sealed. The linoleum is turned up at the walls to form 0.15-m cove corners with the walls (Reference 1 p. 7-22). The floor is postulated to be decontaminated to unrestricted use levels. The floor is first vacuumed and then wet-wiped down with rags and brushes that minimize use of liquid decontaminating agents and keep the decontaminating agents from puddling. The wash-wipe decontaminating agent is a dilute aqueous detergent. After the wet-wipe, the floors are then dry-wiped, and allowed to dry completely in the room air. Final decontamination is by use of a strippable paint that is applied with brushes or rollers, allowed to dry, then stripped off with the contamination. Final hot spots are manually wet-wiped, then dry-wiped, or spot decontamination with another coat of strippable paint. If this final decontamination of hot spots does not remove the remaining floor contamination, the hot spots will be carved out of the linoleum. The removed linoleum is bagged and placed in the LLW drums. Removal of concrete floor material is not considered to be necessary. The solid materials used for floor decontamination are assumed to be bagged into 208-liter drums and set for disposal as LLW.

Amounts of Waste Materials Resulting from Decontaminating the Floor

The estimates developed in Reference 1 for the wash/wipe operations seem reasonable for the decontamination procedures used in the original study, but in this study, considerably less liquid decontaminating agent is used, and part of the decontamination is done with strippable paint. Thus, the amount of rags and brushes, and liquid wastes here are taken to be 1/3 of those in Reference 1, with adjustments for wall area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 1.33 208-liter drums of wet rags, brushes and contaminated gloves and other clothing (Reference 1, p. E-30). These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid, and disposed of as LLW. Estimated weight of these wastes before treatment is 24 kg.

- 0.33 208-liter drums of aqueous decontamination solutions (assumed to contain small amounts of detergents) and rinse solutions from wet/wiping decontamination, before solidification with an adsorbent material. It is assumed that the drum can be filled more fully with similar solutions from decontamination of other components to fully use the drum space. Estimated weight of the wastes before solidification is 53 kg. The adsorbed wastes are sent directly to disposal as LLW.

- 0.97 208-liter drums equivalent of removed strippable paint (assumed in this study) to be reduced to a smaller volume after on-site compaction). It is assumed that the drum can be filled with other strippable paint from decommissioning other components of the facility to fully use the drum space. The waste is compacted on-site and sent for supercompaction off-site before being disposed of as LLW. Estimated weight of the LLW is 24 kg.

D.6 Reference Laboratory for the Reference Institutional User Facility

Detailed physical descriptions and decommissioning procedures for all the components and building surfaces of the user facility that are postulated to require removal and/or decontamination are given in Sections D.6.1 through D.6.12. Details of (1) planning and preparation, (2) estimated manpower requirements, (3) waste management, materials, and labor costs, and (4) radiation dosages are presented in Table D.6a for the supercompaction option and in Table D.6b for the supercompaction option with incineration.

As shown in Reference 1, p. 7-27, the user facility occupies two rooms that comprise one-half of a wing in a building, where the other half is separated by a hallway (i.e., two walls). The radioactive half of the facility is also divided into two rooms with a connecting door; these rooms are the main laboratory facility and the animal laboratory facility (the latter is about one-third of the radioactive half). Although some parts of the facility in the non-radioactive half of the building contain radioactivity (e.g., counting areas, an equipment room where sealed radioactive waste containers are interim-stored, a freezer for contaminated animal carcasses), these areas are not considered to be part of the User facility for decommissioning purposes.

D.6.1 Fume Hoods

The user facility contains three fume hoods in the radioisotope room and two in the animal laboratory, for a total of five. Each fume hood is 1.5 m wide x 2.0 m high x 0.945 m deep. Each hood is assumed to be framed by mild steel externally, with 0.003175-m-thick floor and walls. The floor of the hood is stainless steel, and the walls are assumed to be 0.003175-m-thick steel with plastic laminate covering (assumed to be 0.0015875 m thick). Each hood is equipped with an acrylic window 0.00635 m thick. Each hood is assumed to rest on an enclosed stainless steel-based cabinet (Reference 1, Figure A.5-1, p. A30). The support cabinet is assumed to have the same foot print as the fume hood but is only 0.9 m high.

Before the fume hoods are dismantled, the interior and exterior surfaces are vacuumed and wet-wiped, and then dried and painted to fix contamination. The hoods are then cut to sizes that allow the hood materials to be bagged and placed in 208-liter drums in such a way that the materials can be reasonably compacted on-site, then supercompacted off-site.

Table D.6a User lab summary–supercompaction option; manpower requirements, radiation doses, and costs for decommissioning the institutional isotope user facility–supercompaction option (no incineration)

Operation or category	Time (days)	Person-days: Supervisor	Foreman	Craftsman	H.P. Tech	Tech.	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	5.0	--	5.0	--	10.0	--	--	15.0	4.88	5.3
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	30.0	12.5	30.0	--	15.0	--	12.5	70.0	4.88	23.5
Decommissioning										
Fume hoods	6.2	3.1	5.3	1.4	3.1	10.6	--	23.5	34.50	8.7
Glove boxes	0.4	0.2	0.4	0.1	0.2	0.7	--	1.6	0.65	0.6
Workbenches	7.8	3.9	5.9	2.1	3.9	11.8	--	27.5	0.00	10.3
Vent ducts	2.6	1.3	1.9	0.9	1.3	3.9	--	9.3	0.00	3.5
Refrigerator	0.5	0.2	0.4	0.1	0.2	0.8	--	1.8	0.00	0.7
Washington machine	0.3	0.2	0.3	0.1	0.2	0.6	--	1.3	0.00	0.5
Filters	0.4	0.2	0.4	--	0.2	0.8	--	1.6	0.00	0.6
Sink and drain	0.6	0.3	0.5	0.2	0.3	1.1	--	2.5	0.00	0.9
Ceiling	2.2	1.1	2.2	0.5	1.1	4.4	--	9.3	0.01	3.4
Walls	4.4	2.2	4.4	--	2.2	8.8	--	17.5	0.02	6.5
Floors	2.9	1.5	2.9	--	1.5	5.8	--	11.6	0.00	4.3
Animal cages	0.5	0.3	0.3	0.3	0.3	0.7	--	1.8	0.00	0.7
Lead vault	1.2	0.6	1.2	--	0.6	2.5	--	4.9	1.97	1.8
Subtotals	30.1	15.0	26.2	5.8	15.0	52.3	--	114.3	37.16	42.6
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	1.3
Laundry	--	--	--	--	--	--	--	--	--	2.9
Subtotals	--	--	--	--	--	--	--	--	--	24.4
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	4.0
Supercompaction	--	--	--	--	--	--	--	--	--	7.9
Incineration	--	--	--	--	--	--	--	--	--	--
Transportation	--	--	--	--	--	--	--	--	--	1.2
Disposal	--	--	--	--	--	--	--	--	--	49.3
Subtotals	--	--	--	--	--	--	--	--	--	62.3
Final radiological survey	8.0	4.0	8.0	--	16.0	--	8.0	36.0	--	11.1
Totals	68.1	31.5	64.2	5.8	46.0	52.3	20.5	220.3	42.04	163.8
25% Cost contingency	--	--	--	--	--	--	--	--	--	41.0
Total cost with contingency	--	--	--	--	--	--	--	--	--	204.8

Table D.6b User lab summary–incineration option; manpower requirements, radiation doses, and costs for decommissioning the institutional isotope user facility–supercompaction and incineration option

Operation or category	Time (days)	Person-days Supervisor	Foreman	Craftsman	H.P. Tech	Tech.	Clerk	Total person-days	Person-mrem	Costs ($ 000)
Planning & preparation										
Prepare documentation	15.0	7.5	15.0	--	--	--	7.5	30.0	--	9.9
Perform radiological survey	5.0	--	5.0	--	10.0	--	--	15.0	4.88	5.3
Develop work plan	10.0	5.0	10.0	--	5.0	--	5.0	25.0	--	8.3
Subtotals	30.0	12.5	30.0	--	15.0	--	12.5	70.0	4.88	23.5
Decommissioning										
Fume hoods	6.2	3.1	5.3	1.4	3.1	10.6	--	23.5	34.50	8.7
Glove boxes	0.4	0.2	0.4	0.1	0.2	0.7	--	1.6	0.65	0.6
Workbenches	7.8	3.9	5.9	2.1	3.9	11.8	--	27.5	0.00	10.3
Vent ducts	2.6	1.3	1.9	0.9	1.3	3.9	--	9.3	0.00	3.5
Refrigerator	0.5	0.2	0.4	0.1	0.2	0.8	--	1.8	0.00	0.7
Washing machine	0.3	0.2	0.3	0.1	0.2	0.6	--	1.3	0.00	0.5
Filters	0.4	0.2	0.4	--	0.2	0.8	--	1.6	0.00	0.6
Sink and drain	0.6	0.3	0.5	0.2	0.3	1.1	--	2.5	0.00	0.9
Ceiling	2.2	1.1	2.2	0.5	1.1	4.4	--	9.3	0.01	3.4
Walls	4.4	2.2	4.4	--	2.2	8.8	--	17.5	0.02	6.5
Floors	2.9	1.5	2.9	--	1.5	5.8	--	11.6	0.00	4.3
Animal cages	0.5	0.3	0.3	0.3	0.3	0.7	--	1.8	0.00	0.7
Lead vault	1.2	0.6	1.2	--	0.6	2.5	--	4.9	1.97	1.8
Subtotals	30.1	15.0	26.2	5.8	15.0	52.3	--	114.3	37.16	42.6
Equipment and materials cost										
Commercial vacuum cleaner	--	--	--	--	--	--	--	--	--	3.0
Compactor	--	--	--	--	--	--	--	--	--	17.2
Small tools and materials	--	--	--	--	--	--	--	--	--	1.3
Laundry	--	--	--	--	--	--	--	--	--	2.9
Subtotals	--	--	--	--	--	--	--	--	--	24.4
Waste management costs										
Packaging	--	--	--	--	--	--	--	--	--	4.0
Supercompaction	--	--	--	--	--	--	--	--	--	3.4
Incineration	--	--	--	--	--	--	--	--	--	46.1
Transportation	--	--	--	--	--	--	--	--	--	0.8
Disposal	--	--	--	--	--	--	--	--	--	33.4
Subtotals	--	--	--	--	--	--	--	--	--	87.6
Final radiological survey	8.0	4.0	8.0	--	16.0	--	8.0	36.0	--	11.1
Totals	68.1	31.5	64.2	5.8	46.0	52.3	20.5	220.3	42.04	189.2
25% Cost contingency	--	--	--	--	--	--	--	--	--	47.3
Total cost with contingency	--	--	--	--	--	--	--	--	--	236.5

Amount of Stainless Steel Upper Section

Back: 0	= 0.0 m^2
Two sides: 0	= 0.0 m^2
Floor and Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 2.835 m^2
Total Volume: 0.003175 x 2.835	= 0.009 m^3
Total Volume for 5 Hoods	= 0.045 m^3
Total Weight for 5 Hoods	= 360 kg

Amount of Stainless Steel in the Lower Cabinet

Back & Front: 2 x 1.5 x 0.90	= 2.700 m^2
Two Sides: 2 x 0.945 x 0.9	= 1.701 m^2
Bottom & Top: 2 x 1.5 x 0.945	= 2.835 m^2
Total Area	= 7.236 m^2
Total Volume: 0.003175 x 7.236	= 0.02297 m^3
Total Volume for 5 Hoods	= 0.1149 m^3
Total Weight for 5 Hoods	= 919 kg

Amount of Mild Steel in the Exterior Frame

The exterior frame is assumed to be comprised of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 2.0 m for vertical members and 4 x 1.5 m for horizontal members, for a total length of 14 m. Total mild steel in the fume hood frame is thus 14 m x (0.0508 + 0.04445) x 0.0047626 = 0.006351 m^3.

Total Volume for 5 Hoods	= 0.03176 m^3
Total Weight for 5 Hoods	= 254 kg

Amount of Mild Steel in the Walls

Back: 1.5 x 2	= 3.0 m^2
Two Sides 2 x 0.945 x 2	= 3.78 m^2
Total Area	= 6.78 m^2
Total Volume: 6.78 x 0.003175	= 0.02153 m^2
Total Volume for 5 Fume Hoods	= 0.1076
Total weight for 5 Fume Hoods	= 861 kg

Amount of Plastic Laminate on Walls

Same area as in d.	= 6.78 m^2
Volume: 6.78 x 0.0015875	= 0.01076 m^3
Volume for 5 Hoods	= 0.0538 m^3
Weight: 1500 x 0.0538	= 81 kg

Amount of Acrylic Plastic in the Window

The plastic is assumed to be 2.0 m high x 1.5 m wide x 0.00635 m thick, for a total volume of 0.01905 m^3.

Total Volume for 5 Hoods = 0.09525 m^3
Total Weight for 5 Hoods (s.g. = 1.2) = 114 kg

Amount of Processing Equipment

The following general type of contaminated equipment is postulated to be present in the fume hood. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For 5 fume hoods, the total is 10 electric heating units, with a total weight of 70 kg and a total bulk volume of 0.3 m^3.
- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For 5 fume hoods, the total is 30 units of processing glassware, with a total weight of 90 kg and a total bulk volume of 0.6 m^3.
- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For 5 fume hoods, the total is 20 items, with a total weight of 40 kg and a total bulk volume of 0.284 m^3.

D.6.2 Glove Boxes

The user facility contains one glove box in the radioisotope room. The box is 0.9 m wide x 0.6 m high x 0.6 m deep (Reference 1, p. A.33), rests on one of the workbenches and is assumed to be framed by mild steel externally, with 0.003175-m-thick stainless steel walls, and 0.00635-m-thick acrylic windows. The glove box has a stainless steel panel across the lower 0.25 m of the front, in which are located two 0.2-m-diameter circular openings for plastic working gloves. Above this panel, the front of the glove box slopes backward at an angle of about 40 degrees, providing an opening for the acrylic plastic viewing window. The viewing window is mounted in a mild steel metal frame which is gasketed to the sloping front of the glove box. At one end of the glove box is a stainless steel airlock for the insertion of equipment and material into the box. Airlock dimensions are 0.3 m high x 0.2 m wide x 0.2 m deep (Reference 1, p. A.33). One acrylic air lock door is accessible from outside the glove box, and one is accessible from the inside of the box through the use of glove ports. Standard electrical receptacles are located on the inside of the glove box, with power controlled by switches mounted outside on a service panel above the glove box.

Before the glove box is dismantled, the interior and exterior surfaces are vacuumed and wet-wiped, and then painted to fix contamination. The glove box is then cut into pieces that allow the bagged glove box materials to go into 208-liter drums in such a way that the materials can be reasonably compacted on-site, supercompacted off-site, and then disposed of as LLW. The acrylic plastic, the steel materials, and the equipment inside the glove box are segregated into 208-liter drums, each with one of these categories of materials.

Amount of Stainless Steel in Glove Box and Access Air Lock

Glove Box Proper.

Back: 0.9 x 0.6 = 0.54 m^2
Bottom: 0.9 x 0.6 = 0.54 m^2
Two sides: 2 x 0.6 x 0.6 = 0.72 m^2
Top: 0.3 x 0.9 = 0.27 m^2

Lower Front Panel: 0.25 x 0.9	= 0.225 m^2
Total Area	= 2.295 m^2
Total Volume: 0.003175 x 2.295	= 0.00729 m^3

Air Lock.

Back: 0.3 x 0.2	= 0.06 m^2
Top, Side, Bottom: 3 x 0.2 x 0.2	= 0.12 m^2
Total Area	= 0.18 m^2
Total Volume: 0.003175 x 0.18	= 0.0005715 m^3

Total Stainless Steel Volume	= 0.00786 m^3
Total Stainless Steel Weight	= 63 kg

Amount of Mild Steel in the Exterior Frame

The exterior frame is assumed to be comprised of angle iron (0.0508 m by 0.04445 m by 0.0047625 m thick). The amount of mild steel is 4 x 0.6 m for vertical members and 4 x 0.9 m for horizontal members, for a total length of 6.9 m. Total mild steel in the frame is thus 6.9 x (0.0508 + 0.04445) x 0.0047626 = 0.00313 m^3.

Total Volume	= 0.00313 m^3
Total Weight	= 25 kg

Amount of Acrylic Plastic in the Main Window and Air Lock

Main Window. The plastic is assumed to be 0.6 m high x 0.9 m wide x 0.00635 m thick, giving a volume of 0.003429 m^3.

Airlock. Each of the two windows is assumed to measure 0.3 x 0.2 x 0.00635. This gives a total volume of 0.000762 m^3.

Total Volume of Acrylic: 0.003429 + 0.000762	= 0.004191 m^3
Total Weight of Acrylic: 1200 x 0.004191	= 5 kg

Amount of Processing Equipment

The following general type of contaminated equipment is postulated to be present in the glove boxes. The equipment is bagged and compacted on-site, super-compacted off-site, and then disposed of as LLW.

- 2 electric heating units, each weighing about 7 kg. These are assumed to take up about 0.03 m^3 of space, each. For the one glove box, the total is 2 electric heating units, with a total weight of 14 kg and a total bulk volume of 0.06 m^3.
- 6 significant items of processing glassware, each weighing about 3 kg and taking up about 0.02 m^3 of space. For the one glove box, the total is 6 units of processing glassware, with a total weight of 18 kg and a total bulk volume of 0.12 m^3.
- 4 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. These are assumed to take up about 0.014 m^3 of space, each. For the one glove box, the total is 4 items, with a total weight of 8 kg and a total bulk volume of 0.056 m^3.

D.6.3 Workbenches

The user facility has two separate workbenches. The first is a long one with three "L's" from it to form the letter "E". The second is in the shape of an "L" (Reference 1, p. 7-27, and 9-18). The workbenches are 0.9 m high and assumed to be 0.75 m wide. The total length of the two benches is 24 m. The workbenches are constructed of wood (assumed to be 0.01905 meters thick), and have a plastic-laminated top (assumed to be 0.0015875 m thick polycarbonate); the other wood surfaces are painted with latex enamel. Three workbench locations contain a stainless steel sink; at a fourth location rests a glove box. These workbenches are assumed to have one drawer that is 0.1524 m deep and below that, a shelf a few centimeters above the floor, with two doors, for every linear meter of workbench. To simplify calculations, it is assumed that each drawer and each set of cabinet doors in the 24-m-length of workbenches is 1 m wide, and a vertical plywood panel supports the benches every 1 m (a total of 29 panels).

Because of the proximity of the workbenches to radioactivity-containing components, all of the workbench materials are assumed to be radioactive. The surfaces are to be vacuumed, wet-wiped, and painted before cutting up into pieces sized to effectively fill 208-liter drums. These drums of materials are compacted on-site, and sent off-site for supercompaction or incineration (if that option is used), followed by fixation of the resulting ashes.

Amount of Wood in the Workbenches

Back & Front: 2 x 0.9 x 24	= 43.2 m^2
Sides & Support Panel: 29 x 0.75 x 0.9	= 19.575 m^2
Bottom & Top: 24 x 3 x 0.75 x 1	= 54 m^2
Sides & Back of 24 Drawers 24 x 0.1524 x (0.75+0.75+1)	= 9.144 m^2
Total Area	= 125.919 m^2
Total Volume: 125.919 x 0.01905	= 2.40 m^3
Total weight: 800 x 2.40	= 1,920 kg

It is assumed that the incinerated wood yields an ash content of 5 wt% before incorporation into monolithic solids for disposal as LLW.

Amount of Polycarbonate on the Surfaces of the Workbenches

Volume: 24 x 0.75 x 0.0015875	= 0.028575 m^3
Weight: 1500 x 0.028575	= 42.9 kg

Amount of Processing Equipment on the Workbenches Not Used to Support Glove Boxes

It is assumed that the workbenches were used for radioactive counting equipment, which had to stay clean; for tools (again, assumed to be free of contamination) for making small new parts for the hoods and glove boxes; for temporary storage of nonradioactive materials; for overpacking the products (again, expected to be a relatively clean operation); and other similar uses. The contaminated equipment and material below are to be bagged, loaded into 208-liter drums, compacted on-site, and supercompacted off-site before being disposed of as LLW.

- Various hand tools including a vise, primarily steel, weighing a total estimated 12 kg, with a total gross bulk volume estimated to be 0.008 m^3.

- 2 significant items of processing glassware, each weighing about 3 kg. For the 2 glass items, the items would weigh about 6 kg and would require an estimated 0.0400 m^3 of total bulk space.

- 2 items of various materials (metals, plastic, ceramic), each weighing about 2 kg. For these items, the total weight is estimated at 4 kg, with an estimated total bulk volume of 0.004 m^3 m.

D.6.4 Vent Ducts

The user facility contains 12 m of cylindrical ductwork 0.2 m in diameter and 20 m of rectangular ductwork 0.25 m x 0.6 m in cross-section (Reference 1, p. 9-18). The ductwork is assumed to be stainless steel sheet metal 0.0015875 m thick.

The ductwork is assumed to be radioactively contaminated internally and externally. The ductwork is vacuumed and wet-wiped where possible to remove the readily-removable contamination, then painted to minimize contamination during subsequent steps. After painting, the duct waste is cut into pieces that maximize the amount of material that can fit in 208-liter drums. The waste pieces are placed in plastic bags before being placed in the drums. The waste-filled drums are then compacted on-site and then shipped off-site for supercompaction before being sent to LLW disposal.

Amount of Material in the Ductwork

Cylindrical Ductwork Volume	$= \pi \times 0.2 \times 12 \times 0.0015875 = 0.012\ m^3$
Rectangular Ductwork Volume	$= 2 \times (0.25 + 0.6) \times 20 \times 0.0015875$ $= 0.054\ m^3$
Total Volume	$= 0.066\ m^3$
Total weight	=528 kg

D.6.5 Sinks and Drains

The user facility contains three sinks. Two sinks are in the radioisotope room, and one is in the animal laboratory. Associated with the sinks are 15 linear m of 0.1-m-diameter drain pipe (Reference 1, p. 9-18). Each sink is assumed to be 18-gage stainless steel (0.001214 m thick) with inside dimensions of 0.635 m wide x 0.5588 m high x 0.3048 m deep, and with overall dimensions of 0.8382 m wide x 0.5588 m deep to allow for the flanges (Reference 2, p. 1049). One sink (on the north wall of the radioisotope room) is reserved for washing contaminated dishes and for discarding substances that have low specific radioactivity. The other two sinks do not receive any radioactivity except through accidental contamination. Drains for the sinks are carried above the floor line to simplify maintenance. The drains from the three sinks are connected in common at the northwest corner of the building. A common drain line penetrates the building floor at this point and goes underground to a 2,000-liter stainless steel holding tank buried outside the building. In the holding tank, the liquid effluent is held for radioactive decay, monitored, and diluted as necessary before discharge to the sanitary sewer. Water from a spray fixture in the tank may be used to flush the wastes to the sewer. The decommissioning of the outside drain line and holding tank are not included in this section, but is covered elsewhere.

The sinks and inside drains are all assumed to be contaminated. The sinks and their associated water faucets and the drain piping to the facility junction point are wiped down only, removed, cut up in a way that uses space efficiently in the 208-liter drum, and then put in plastic by a pipefitter and a technician. The waste materials are compacted on-site, and supercompacted off-site before transport to LLW disposal.

Amount of Stainless Steel in the Sink

Each sink is assumed to weigh about 12 kg and to require a bulk volume of an estimated 0.113 m^3.

Total Volume for 3 Sinks	$= 0.339\ m^3$
Total Weight for 3 Sinks	= 36 kg

Amount of Brass in the Fixture and Connections

The weight of the brass is estimated to be 3 kg, assuming a specific gravity for brass of 8.75. The brass will occupy about 0.0283 m^3 of bulk space.

Total Volume for 3 Sinks	= 0.849 m^3
Total Weight for 3 Sinks	= 9 kg

Amount of Galvanized Steel in the Drain and P Trap

This is equivalent to 5 m of 0.1-m-diameter pipe (Reference 1, p. 2-9), or an estimated 16.05 kg/m x 5 m = 80.3 kg. The bulk volume of the material is estimated to be 0.05 m^3.

Total Volume for 3 Sinks	= 0.15 m^3
Total Weight for 3 Sinks	= 241 kg

D.6.6 Lead Vault

The lead vault, located in the radioisotope room within the user facility, is used for the storage of radioactive chemicals. These chemicals are usually contained in acid or saline solutions, and are packaged in glass vials and bottles (Reference 1, p. 7-31). The lead vault is assumed to be contaminated throughout, and is removed as mixed waste. The lead vault is comprised of interlocking lead bricks (Reference 1, p. 9-18) and is assumed to be 1.0 m deep x 1.5 m wide x 1.0 m high, outside dimensions, with a wall thickness assumed to be 0.1 m. This makes the inside dimensions 0.8 m deep x 1.3 m wide x 0.8 m high. The lead vault is disassembled, brick-by-brick. As the vault is disassembled, each brick is wet-wiped and allowed to dry. The dried lead bricks are bagged and placed in 208-liter drums that are sent directly to radioactive hazardous mixed waste for encapsulation and disposal. Wet-wiping is done using rags and brushes and a dilute aqueous solution with a small amount of detergent.

Amount of Lead in the Vault

Volume: 1 x 1.5 x 1 - 0.8 x 1.3 x 0.8	= 0.668 m^3
Weight: 0.668 m^3 x 11,300	= 7,548 kg

D.6.7 Animal Cages

The user facility has one animal cage that is assumed to be comprised of multiple-animal cages for study of animals that have been injected with radionuclides (Reference 1, p. 7-31). The overall cage dimensions are assumed to be 1 m deep x 3 m wide x 1 m high. The cage is assumed to be divided into 2 cages high, 2 cages deep, 6 cages wide (total of 24 separated compartments), with tops that open above each upper-row cage. The cage is assumed to be made of galvanized steel wire 0.003175 m in diameter on 0.0195-m centers (52 wires/m) in a square pattern.

The cage is cut up into pieces, bagged, and placed efficiently into 208-gallon drums for compaction on-site, then supercompaction off-site, followed by sending to a disposal facility as LLW.

Amount of Galvanized Steel in the Animal Cages

Front, Middle, Back Walls: 3 x 1.0 m x 3.0 m	= 9 m^2
Top, Middle, Bottom Walls: 3 x 1.0 m x 3.0 m	= 9 m^2
Side Panels for all sub-cages: 7 1.0 m x 1.0 m	= 7 m^2

Total Mesh Area: $= 25\ m^2$

There are 52 wires for each meter of length, thus:

Total Length of Wire: 2 x 25 x 52 = 2600 m
Volume (π/4) x 0.003175 x 0.003175 x 2600 = 0.0206 m^3
Weight: 8000 x 0.0206 = 165 kg

D.6.8 Refrigerator

The single refrigerator in the user facility is used for storage of small quantities of labeled hydrocarbons to reduce chemical deterioration of the compounds (Reference 1, p. 7-31). The refrigerator is postulated to be 0.6096 m wide x 0.6096 m deep x 1.524 m high.

The unit is assumed to be only mildly contaminated inside. But outside, the compressor, coils, fan, and other mechanisms are assumed to be contaminated to such a degree that it would not be reasonable to try to decontaminate it to levels required for unrestricted use. Thus, the refrigerator is assumed to be disposed of as radioactive LLW with only minimal decontamination. It is assumed that a subcontractor will remove the freon on-site, after which the refrigerator will be vacuumed, wiped and painted. It will then be cut up and bagged into 208-liter drums for on-site compacting, then shipped off-site for supercompacting before disposal as LLW. Sectioning and bagging will be done to effectively use the space in the drums.

Amount of Material in the Refrigerator

These calculations are based on gross characteristics of conventional refrigerators. The unit contains the refrigeration cooling system (copper, steel, other metals), some framework (mild steel), plastic inner and outer walls separated by fiberglass insulation, with some plastic trays, glass and mild steel shelves inside. The overall weight of the refrigerator unit is assumed to be 68 kg. The sectioned and pre-compacted volume of the unit is assumed to be the same as when whole, or 0.6096 x 0.6096 x 1.524 = 0.5663 m^3.

D.6.9 Filters

In the user facility, one set of HEPA-plus-roughing filters is located at the exhaust of each of the five fume hoods and the one glove box during normal operation, for a total of six sets. No other HEPA or roughing filters are used in the facility (Reference 1, p. 7-29 and p. 9-18). It is postulated that the filters had been replaced at the end of the operating period, and that they will last throughout the total decommissioning period. In addition, it is assumed that during the vacuuming activity of the components and the facility, a commercial vacuum unit is leased that uses a roughing filter and a HEPA filter identical to those in the facility, and 2 sets of filters are used during vacuuming, bringing the total to 8 sets. The filter removal is one of the last activities undertaken during decommissioning.

Each filter is bagged with a plastic bag and sealed during its removal. The dimensions of the HEPA filters (Reference 1, p. 9-18) are 0.2 m in diameter x 0.2 m high; the roughing filters are 0.2 m in diameter x 0.1 m high. It is assumed that the filters are comprised of sheet-metal casing with pleated paper as the filter medium. It is postulated that the HEPA filters are bagged, placed in 208-liter drums for on-site compaction, followed by shipment off-site for supercompaction, before being packaged for disposal as LLW.

Amount of Materials in the HEPA Filters

The overall weight of each of the small, round HEPA filters is assumed to be 5 kg. The estimated weight of the 8 HEPA filters is thus 40 kg. The bulk (rectangular) volume of the 8 filters is 8 x 0.2 x 0.2 x 0.2 = 0.064 m^3.

Amount of Materials in the Roughing Filters

The overall weight of each roughing filter is assumed to be 2.5 kg. The estimated weight of the 8 roughing filters is thus 20 kg. The bulk (rectangular) volume of the 8 roughing filters is 8 x 0.2 x 0.2 x 0.1 = 0.032 m^3.

D.6.10 Washing Machine

The user facility has one automatic washing machine in the animal laboratory. The machine is used for some washing of laboratory clothing (Reference 1, p. 7-31). The washing machine is postulated to be a conventional, home-use type, with dimensions of 0.65 m deep x 0.65 m wide x 1 m high.

It is assumed that the washing machine is contaminated (internally from contaminated clothing, and externally in the mechanical parts from slightly contaminated dust and oil in the room) and is to be disposed of as radioactive waste. The readily-accessible surfaces of the washing machine are vacuumed and wet-wiped, and allowed to dry. The machine is cut up and/or partially disassembled into pieces that fit efficiently into 208-liter drums. The waste is bagged before being placed in drums. The drummed waste is compacted on-site, and then sent off-site for supercompaction before being shipped to a disposal facility as LLW.

Amount of Material in the Washing Machine

This is based on the gross characteristics of conventional washing machines. The machine will be comprised of the outer shell, the wash tub, the electric motor, a water pump and the rest of the mechanical system, solenoid valves, electronic controls, and electrical equipment and wiring. The overall weight of the machine is assumed to be 68 kg. The sectioned and pre-compacted volume of the machine is assumed to be 2/3 of the original volume when whole, or 2/3 x (0.65 x 0.65 x 1.0) = 0.282 m^3.

D.6.11 Facility Ceiling

The ceiling in the user facility consists of 80 m^2 of suspended acoustically-treated fiberboard (Reference 1, p. 9-18), above which some piping and electrical wiring are mounted. The fiberboard comes in panels that are typically 0.3 x 0.3 m or 0.3 m x .6 m. Each panel can be removed separately.

The fiberboard, postulated to be 0.0127 m thick, has a rough surface and many pores, which makes decontamination impractical. The ceiling panels are first vacuumed and painted to fix the contamination, then are removed for disposal as radioactive waste. The ceiling materials are broken up if necessary and bagged and inserted into 208-liter drums. The waste is then compacted on-site before being transported off-site for supercompaction and disposal as LLW. If the incineration option is used, the resultant ash is processed into a monolithic solid. The specific gravity of the fiberboard is assumed to be 0.5.

Amount of Material in the Ceiling

Volume: 80 x 0.0127	= 1.016 m^3
Precompacted Volume: 2 x Volume	= 2.0 m^3
Weight: 500 x Volume	= 508 kg

D.6.12 Facility Walls

There are 150 m^2 of plasterboard (postulated to be 0.015875 m thick) in the user facility. The plasterboard is painted with latex enamel. It is assumed that the walls are to be decontaminated to unrestricted levels to maintain the wall surfaces and to keep from contaminating the wall insulation and structural members behind the walls.

The walls are first vacuumed, then wiped with wet rags and brushes. The decontaminating solution, a dilute aqueous detergent, is applied sparingly to minimize dripping. After wet-wiping, the walls are wiped with dry rags and allowed to dry completely. Finally, strippable paint is brushed or rolled on, allowed to dry in the room air, and then stripped off with the entrained contamination. Final hot spots are wet-wiped, or possibly spot-painted with strippable paint. Only materials used for decontamination are assumed to be bagged into 208-liter drums and disposed of as LLW.

Amount of Waste Materials Resulting from Decontaminating the Walls

The estimates developed in Reference 1, p. E-30, for the wash/wipe operations seem reasonable for the decontamination procedures used in the original study, but in this study, much less liquid decontaminating agent is used, and part of the decontamination is done with strippable paint. Thus, the amount of rags, brushes, and liquid wastes here is taken to be 1/3 of that in the original study, with adjustments for surface area. The estimates of waste materials from decontamination and the subsequent waste treatment are given below. Disposition of the final wastes is discussed in each of the three subsets of waste categories below.

- 3 drums of wet rags, brushes, contaminated gloves and other clothing. These are assumed to be compacted on-site, sent off-site for supercompaction and LLW disposal. If the incineration option is used, the waste is incinerated off-site, with the ashes fixed into a monolithic solid and disposed of as LLW. Estimated weight of these wastes is 150 kg.

- 0.76 drums of aqueous decontamination solutions (assumed to contain small amounts of detergents) and rinse solutions from wet-wiping, before solidification with an adsorbent material. Estimated weight of the waste before solidification is 125 kg. The adsorbed wastes are sent directly for disposal as LLW.

- 2 drums equivalent of removed strippable paint (assumed in this study). Estimated weight of the waste is 50 kg. The waste is compacted on-site, then sent to supercompacting off-site for disposal as LLW.

D.6.13 Facility Floors

The floors of the User facility consist of 80 m^2 of asphalt tile (postulated to be 0.0015875 m thick) over concrete (Reference 1, p. 7-29, p. 9-18). The floor is postulated to be first vacuumed and then painted to fix the remaining contamination. All tiles are postulated to be removed manually and packaged in plastic bags in 208-liter drums compacted on-site, supercompacted off-site, and then disposed of as LLW. The remaining hot spots in the concrete flooring are postulated to be cleaned by a small amount of scabbling, followed by re-vacuuming the entire floor surface. The concrete rubble and dust are postulated to be bagged and drummed for efficient use of the drum space. The concrete rubble waste is compacted on-site, and the drums are sealed and disposed of as LLW.

Amount of Radioactive Waste Materials Resulting from Removing the Floor Tiles

Volume: 80 x 0.0015875	= 0.127 m^3.
Weight: 1100 x 0.127	= 140 kg

Amount of Concrete Flooring Removed as Radioactive Waste

It is assumed that some contamination will have penetrated through the cracks in the floor tile to the extent that 10% of the underlying concrete will be contaminated to a depth of 0.0127 m. The total amount of concrete rubble and dust removed as radioactive waste is thus 80 x 0.1 x 0.0127 = 0.102 m^3. Assuming the specific gravity is 60% of theoretical, the effective volume is 0.170 m^3. Assuming a specific gravity of 2.5, the weight of concrete dust and rubble is estimated at 255 kg.

D.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.

2. "McMaster-Carr Supply Company, Catalog 98." 1992. McMaster-Carr Supply Company, Los Angeles, California.

Appendix E

Details of Decommissioning Reference Sites

Appendix E

Details of Decommissioning 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 labor 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 labor 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 1998 dollars.

For ease in evaluating time and labor 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 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.

E.1 Details of Decommissioning a Contaminated Underground Drain Line

Time and labor 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 labor requirements for removing a contaminated drain line and hold-up tank are presented in Table E.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.

Cost details for removing a contaminated drain line and hold-up tank are presented in Table E.2. The total costs of decommissioning the site is estimated to be about $126,000. A contractor's fee is included in the total costs 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 208-liter drums to contain the exhumed material and contaminated soil.

Table E.1 Details of estimated time and labor requirements for removal of a contaminated drain line and hold-up tank

Operation	Time (days)[a]	Labor requirements (person-days): Supervisor[b]	Foreman	Equipment operator	Craftsman	Technician	Health physics technician	Clerk	Total labor (person-days)	Labor costs ($ 000)[c,d]
Planning & preparation	5	5	5	--	--	--	4	1	15	5.64
Prep documentation										
Perform rad survey										
Develop work plan										
Decommissioning	10	5	9	10	5.5	14	7	--	50.5	27.38
Mobilize/demobilize	2	1	2	2	--	2	--	--	7	4.04
Remove overburden	1.5	0.75	1.5	1.5	--	--	1.5	--	5.25	2.72
Exhume and package	5.5	2.75	5.5	5.5	5.5	11	5.5	--	35.75	19.18
Backfill and restore	1	0.5	--	1	--	1	--	--	2.5	1.44
Final site survey	2	1	2	--	--	--	4	--	7	2.59
Labor totals	17	11	16	10	5.5	14	15	1	72.5	35.61

(a) 50% ancillary time is included in estimate.
(b) Charged half-time to project.
(c) Costs are in January 1998 dollars. Number of cost figures is for computational accuracy only.
(d) 25% contingency not included.

Table E.2 Cost details for the removal of a contaminated drain line and hold-up tank

Cost item	Cost ($ 000)[a]
Labor	35.61
Equipment	15.75
Materials	4.77
Soil analyses	8.00
Contractor's fee[b]	3.68
Waste management	
Packaging	1.72
Transportation	0.32
Disposal	30.90
Subtotal	100.74
25% Contingency	25.18
Total	125.92

(a) Costs are in January 1998 dollars. Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for labor, equipment, materials, and packaging.

Only about 31% 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.

E.2 Details of Decommissioning a Contaminated Ground Surface

Time and labor 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 that same document.

Details of estimated time and labor requirements for removing a contaminated ground surface are presented in Table E.3. 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 E.4. The total costs of decommissioning the site is estimated to be about $1,396,000. A contractor's fee is included in the total costs as described in Section D.1 of NUREG/CR-1754.[1]

Approximately 12% of the total decommissioning cost is related to the initial and final site surveys. More than 74% 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 E.3, the number of soil samples and the cost of sample analyses would decrease by a factor of 4.

Most of the total decommissioning cost (approximately 77% of the total) is related to the packaging, transportation, and disposal of the exhumed material. Packaging cost could be substantially reduced if the soil were transported to the shallow-land burial ground (LARW Envirocare facility) in plastic-lined dump trucks instead of being packaged in B-25 metal containers. 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 47% of the total decommissioning cost. No savings through volume reduction is possible since soil is not compactible or combustible.

E.3 Details of Decommissioning a Tailings Pile/Evaporation Pond

Time and labor 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 labor requirements for decommissioning the pile/pond are presented in Table E.5. Cost details are presented in Table E.6.

E.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 assume rate of 50 liters/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.

Table E.3 Details of estimated time and labor requirements for removal of a contaminated ground surface

Operation	Time (days)[a]	Labor requirements (person-days) Supervisor[b]	Foreman	Equipment operator	Health physics technician	Truck driver	Laborer	Clerk	Total labor (person-days)	Labor costs ($ 000)[c,d]
Planning & preparation Prep documentation Perform rad survey Develop Work Plan	20	20	20	--	30	--	--	5	75	27.44
Decommissioning	17	8.5	17	34	12	9	31	--	111.5	56.37
Mobilize/demobilize	2	1	2	4	--	--	4	--	11	5.82
Exhume and package	12	6	12	24	12	--	24	--	78	39.02
Backfill and restore	3	1.5	3	6	--	9	3	--	22.5	11.53
Final site survey	5	2.5	5	--	15	--	--	--	22.5	8.18
Labor totals	42	31	42	34	57	9	31	5	209	91.99

(a) 50% ancillary time is included in estimate.
(b) Charged half-time to project.
(c) Costs are in January 1998 dollars. Number of cost figures is for computational accuracy only
(d) 25% contingency not included

Table E.4 Cost details for the removal of a contaminated ground surface

Cost Item	Cost ($ 000)[a]
Labor	91.99
Equipment	31.79
Materials	15.51
Soil analyses	96.00
Contractor's fee[b]	26.14
Waste management	
Packaging	237.13
Transportation	88.46
Disposal	530.00
Subtotal	1,117.02
25% Contingency	279.26
Total	1,396.28

(a) Costs are in January 1998 dollars Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for labor, equipment, materials, and packaging.

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 $237,000. About 35% of this cost is for the asphalt and the soil used to establish cover over the tailings pile.

The total annual cost of long-term care is estimated to be about $17,000. Labor costs represent almost 66% of this cost.

E.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 B-25

Table E.5 Details of estimated time and labor requirements for decommissioning a tailings pile/evaporation pond

Operation	Time (days)[a]	Labor requirements (person-days)							Total labor (person-days)	Labor costs ($ 000)[c,d]
		Supervisor[b]	Foreman	Equipment operator	Health physics technician	Truck driver	Laborer	Clerk		
Site stabilization option										
Planning & preparation	20	20	20	--	10	--	--	20	70	21.98
Mobilize/demobilize	2	1	2	4	--	--	4	--	11	5.82
Place asphalt	2	1	2	4	2	--	4	--	13	6.50
Place soil cap	6	3	6	12	2	40	12	--	75	36.40
Revegetate	2	1	--	2	--	--	2	--	5	2.65
Labor totals	32	26	30	22	14	40	22	20	174	73.35
Long-term care (annual values)										
Administration	2	2	--	--	--	--	--	2	4	1.08
Site maintenance	3	--	3	3	--	--	3	--	9	3.11
Environmental Surveillance	1	--	--	--	2	--	--	--	2	0.68
Vegetation management	4	--	4	--	--	--	8	--	12	3.86
Labor totals	10	2	7	3	2	--	11	2	27	8.73
Removal option										
Planning & preparation	20	20	20	--	10	--	--	20	70	21.98
Mobilize/demobilize	4	2	4	24	--	--	24	--	54	27.69
Exhume and package	90	45	90	540	90	--	540	--	1,305	653.83
Backfill and restore	20	10	20	40	--	100	40	--	210	103.85
Final site survey	5	2.5	5	--	10	--	--	--	17.5	6.47
Labor totals	139	79.5	139	604	110	100	604	20	1,656.5	813.82

(a) 50% ancillary time is included in estimate.
(b) Charged half-time to project.
(c) Costs are in January 1998 dollars. Number of cost figures is for computational accuracy only.
(d) 25% contingency not included.

Table E.6 Cost details for the decommissioning of a tailings pile/evaporation pond

Cost item	Cost ($ 000)[a] Site stabilization	Long-term care (annual costs)	Pile removal
Labor	73.35	8.73	813.8
Equipment	21.25	1.80	98.9
Materials	74.50	0.75	179.2
Soil analyses	10.00	2.00	96.0
Contractor's fee[b]	10.86	–	452.0
Waste management			
Packaging	–	–	4,600.4
Transportation	–	–	1,716.0
Disposal	–	–	10,282.0
Subtotal	189.95	13.28	18,238.3
25% Contingency	47.49	3.32	4,559.6
Total	237.44	16.60	22,797.9

(a) Costs are in January 1998 dollars. Number of figures shown is for computational accuracy only.
(b) Based on 8% of the sum of contractor's charges for labor, equipment, materials, and packaging.

metal boxes (2.72-m^3) for shipment to the shallow-land burial ground (LARW Envirocare facility). Approximately 7,100 boxes are required for the 19,400 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 five boxes per flat-bed trailer. Therefore, 1,426 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 $23 million. Most of this cost (approximately 91%) is associated with the waste management costs for disposal of the exhumed material. The waste management cost could be reduced by about $4.0 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 B-25 metal boxes. No savings through volume reduction is possible since soil is not compactible or combustible.

E.4 References

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

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C. W. Prichard, NRC Project Manager

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The objective of this study is to provide a current compendium of relevant information on the technology and costs for decommissioning non-fuel-cycle nuclear facilities. The report is a revised analysis of the original reports on the same subject (NUREG/CR-1754 and Addendum 1 thereto). The information presented will be used by the NRC in the development of financial assurance rulemakings for by-product, source, and special nuclear materials licensees. This report may also be useful to the licensees planning for the decommissioning of their facilities.

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