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Technology, Safety, and Costs of Decommissioning a Reference Large Irradiator and Reference Sealed Sources

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Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

This report contains the results of a study sponsored by the U.S. Nuclear Regulatory Commission (NRC) to examine the decommissioning of large radioactive irradiators and their respective facilities, and a broad spectrum of sealed radioactive sources and their respective devices. Conceptual decommissioning activities are identified, and the technology, safety, and costs (in early 1993 dollars) associated with decommissioning the reference large irradiator and sealed source facilities are evaluated. The study provides bases and background data for possible future NRC rulemaking regarding decommissioning, for evaluation of the reasonableness of planned decommissioning actions, and for determining if adequate funds are reserved by the licensees for decommissioning of their large irradiator or sealed source facilities. Another purpose of this study is to provide background and information to assist licensees in planning and carrying out the decommissioning of their sealed radioactive sources and respective facilities.

Contents

Figures

Tables

Foreword

The Nuclear Regulatory Commission (NRC) has issued its regulations specifying radiation safety requirements and licensing requirements for the use of licensed radioactive materials in large irradiators and small sealed sources. Included in these requirements is the recognition of the need for licensees to decommission these facilities, thereby allowing termination of their licenses at the end of their useful lives.

The results presented in this report include information on the technology, safety, and estimated costs to decommission the postulated set of reference facilities that utilize sealed sources.

Normally, decommissioning of these types of facilities is relatively simple, because there would be no radioactive contamination present in the facilities. However, if leakage of the sources did occur, contamination could be present. The required monitoring and sampling at a facility should allow early detection of leakage before large amounts of radioactive material have been released, and a leaking source could be identified and isolated before significant contamination of the facility has occurred. Thus, designing and operating a facility in accordance with established regulations and guidelines should facilitate decommissioning of that facility.

This report is not a substitute for NRC regulations, and compliance is not required. The approaches and/or methods described in this NUREG/CR are provided for information only. Publication of this report does not necessarily constitute NRC approval or agreement with the information contained herein.

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The many individuals who contributed information that subsequently led to the completeness of this study are greatly appreciated. A full listing of individuals who contributed to this report is provided in Appendix C for the large irradiator decommissioning analysis and in Appendix F for the sealed source decommissioning analysis.

Summary of Study Results

The majority of the large irradiator and sealed source licensees have facilities and devices that do not require any major decommissioning effort. For most licensees, the transfer or disposal of the radioactive sealed sources, a radiation survey of the facility, and a letter to the regulatory agency certifying that all sources have been transferred or disposed of in accordance with applicable regulations may constitute the necessary decommissioning actions.

Large Irradiator Decommissioning

Large irradiators use intense gamma radiation to irradiate products to change their characteristics in some way. Irradiators usually use radioactive materials, such as cobalt-60 contained in sealed sources or capsules, to produce very high radiation dose levels.

The major conclusions of the large irradiator decommissioning analysis are summarized below.

- Decommissioning costs for a clean reference large irradiator facility vary over a wide range from $289,000, if the sources are returned to the supplier, to $3.0 million (both in 1993 dollars with a 25% contingency added) with the major factor being the cost for disposal of the sealed sources as low-level radioactive waste. Cleanup of a contaminated facility would add an additional $115,000 for the medium contamination scenario.

- Decommissioning of a reference large irradiator facility, whether clean or contaminated, can be accomplished with minimal radiation exposure to decommissioning workers, ranging from 0.075 person-rem to 1.203 person-rem, and with no significant impact to the general public.

- Decommissioning of large irradiator facilities can be accomplished using currently available technology.

Sealed Source Decommissioning

Small sealed sources are employed in a wide variety of applications from estimating the thickness of asphalt during road construction to irradiating specific cells in the human body for medical purposes. The more frequent uses of sealed sources are in gauges and in medical applications.

The major conclusions of the sealed source decommissioning analysis are summarized below.

- Decommissioning costs for the reference small sealed sources, and the devices housing the sources, vary from $2,000 up to $7,500, depending on the decommissioning option chosen. Cleanup costs for leaking sources account for about $2,800 to $3,200 of the total decommissioning costs. All costs are in 1993 dollars with a 25% contingency added.

- Decommissioning of the reference small sealed sources, and the devices housing the sources, can be accomplished with minimal radiation exposure to decommissioning workers, ranging from negligible ($<3 \times 10^{-10}$ person-rem) to 2×10^{-5} person-rem, and with no significant impact to the general public.

- Decommissioning of the reference small sealed sources, and the devices housing the sources, can be accomplished using currently available technology.

1 Introduction

This report contains the results of a study sponsored by the U.S. Nuclear Regulatory Commission (NRC) to examine the decommissioning of large radioactive irradiators and their respective facilities, and a broad spectrum of sealed radioactive sources and their respective devices. Conceptual decommissioning activities are identified, and the technology, safety, and costs (in early 1993 dollars) associated with decommissioning the reference large irradiator and sealed source facilities are evaluated. The study provides bases and background data for possible future NRC rulemaking regarding decommissioning, for evaluating the reasonableness of planned decommissioning actions, and for determining if adequate funds are reserved by the licensees for decommissioning. Another purpose of this study is to provide background and information to assist licensees in planning and carrying out the decommissioning of their sources and respective facilities/devices.

Earlier studies of this type have been carried out for nuclear power reactors, nuclear fuel cycle facilities, and non-fuel-cycle facilities for manufacturing of radioactive products. This is the first study of its type for the NRC where decommissioning of large irradiator facilities and sealed sources has been reviewed in the manner described above.

"Decommissioning" as defined by the NRC (10 CFR 30.4) means to remove (as a facility) safely from service and reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of the license.

While several courses of action are feasible, only three decommissioning scenarios are generally considered for decommissioning a facility (U.S. Federal Register, "General Requirements for Decommissioning Nuclear Facilities," NRC Rule, June 27, 1988, pp. 24018-24056):

- **DECON** - A decommissioning alternative in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or decontaminated shortly after cessation of operations to a level that permits the property to be released for unrestricted use;

- **SAFSTOR** - A decommissioning alternative in which the nuclear facility is placed into and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use;

- **ENTOMB** - A decommissioning alternative in which radioactive contaminants are encased in a structurally long-lived material, such as concrete; the entombed structure is appropriately maintained and continued surveillance is carried out until the contained radioactivity decays to a level permitting unrestricted use of the property.

It has been determined that the SAFSTOR and ENTOMB alternatives are not appropriate for the facilities/devices covered in this study. Thus, DECON is the only alternative considered for the user licensee. Cases in which a licensed broker, radionuclide supplier, or other contractor takes possession of a sealed source for interim storage or re-use are covered for the original owner/user, but not for the second or subsequent owner/user.

Conceptual decommissioning activities and sequences are identified, and estimates are made of work and work categories, work schedules, labor needs by type, material and equipment needs, transportation needs, disposal needs, occupational radiation doses, and costs for all decommissioning activities, including administrative activities. A contingency of 25% is applied to all costs to provide for unforeseeable cost elements likely to occur. Decommissioning techniques are postulated which represent current technology and experience and are consistent with current regulatory requirements.

The reference large irradiator facility described in this report is a composite of existing facilities. The decommissioning cases examined are comprised of a facility with: 1) no leaking irradiation sources (decontamination of the facility is not required), and 2) with a leaking irradiation source (requires facility decontamination). Disposition of the irradiation source is postulated to be accomplished by transfer to the manufacturer or another user, or by disposal as low-level radioactive waste.

A total of five sealed sources were selected to represent the spectrum of smaller sealed sources used in industry. The sources examined are utilized in fixed and portable gauges and have radionuclide contents ranging from Fe-55 (1 μCi to 5 Ci), Ni-63 (1 μCi to 25 mCi) to Cs-137 (10 mCi to 10 Ci), Am-241 (50 mCi to 5 Ci), and I-125 (0.1 mCi to 70 mCi). Leaking and non-leaking sources are examined. Final disposition of the sources is postulated to be accomplished by transfer to the manufacturer or another user, or by disposal as low-level radioactive wastes or greater-than-class C waste.

The report takes account of the current status of regulations in the U.S. and includes consideration of the impacts of those regulations on decommissioning activities. Decommissioning may include generation and management of mixed radioactive and other hazardous wastes, and of radioactive wastes that are considered to be in the low-level or greater-than-class C categories.

Many aspects of decommissioning (e.g., plans, decommissioning methods, safety, and costs) may be sensitive to variations in facility location, specific facility shutdown conditions, and residual contamination levels. The bases and assumptions used in this study must be carefully examined before the results can be applied to a different facility.

The report is presented in a series of chapters and appendices, with each divided in such a way that the analyses of large irradiators and sealed sources are presented separately and in parallel. Following the Summary of Study Results and this introductory chapter, Chapter 2 presents the study approach and key study bases. Chapter 3 contains descriptions of the reference facilities and sites. Chapter 4 contains descriptions of the decommissioning activities, presents the estimated labor requirements, and provides the estimated costs and radiation doses for each major decommissioning step and alternative. Chapter 5 contains a discussion of the results and overall study conclusions. Chapter 6 contains a glossary of key terms and abbreviations used in the report. These chapters are followed by appendices that provide background information or details on cost estimating bases; a review of related decommissioning information, experience and technologies; details of decommissioning activities of the reference facilities; and a listing of study contacts.

2 Study Approach and Bases

This chapter contains a description of the study approach, bases, and assumptions used in this study of decommissioning large irradiator facilities and sealed sources. Section 2.1 discusses the study approach and assumptions used for the postulated decommissioning of the reference large irradiator facility. Section 2.2 addresses the postulated decommissioning of the set of reference sealed sources.

2.1 Approach and Bases for Large Irradiator Facility

Large irradiators use gamma radiation to irradiate products to change their characteristics in some way. Irradiators use either radioactive materials or electronic machines (x-ray machines or accelerators) to produce very high radiation dose levels. The NRC and Agreement States regulate irradiators using radioactive byproduct materials. The radioactive materials, generally cobalt-60 or cesium-137, are contained in sealed sources or capsules made of stainless steel to prevent the spread of radioactive materials. This study focuses primarily on large commercial irradiators, which are classified as Category IV—Panoramic, Wet-Source Storage Irradiators.

The regulatory considerations for decommissioning of large irradiators are summarized in Section 2.1.1. The types of large irradiators considered are discussed in Section 2.1.2. The decommissioning alternatives are described in Section 2.1.3, the technical approach to the study is provided in Section 2.1.4, and the decommissioning processes are considered in Section 2.1.5. Finally, the key study bases and assumptions are listed in Section 2.1.6.

2.1.1 Regulatory Considerations for Decommissioning Large Irradiators

The Nuclear Regulatory Commission (NRC) has established regulations and guidelines in 10 CFR Part 36 that specify radiation safety requirements and licensing requirements for the use of licensed radioactive materials in large irradiators.

The decommissioning aspects of large irradiator facilities are addressed in 10 CFR Part 30.35, Financial Assurance and Recordkeeping for Decommissioning, and in 10 CFR Part 30.36, Expiration and Termination of Licenses and Decommissioning of Sites and Separate Buildings or Outdoor Areas.

Normally, decommissioning is relatively simple, because there would be no radioactive contamination present in the facility. However, contamination could be present if leakage of the sources did occur. If leakage from sources did occur, the required monitoring and sampling of the pool water should allow early detection of leakage before large amounts of radioactive material have been released. With early detection of leakage, a leaking source could be identified and isolated and pool cleanup would purify the water, removing the contamination from the water. In addition, the pool walls and the required pool liner would prevent contamination from leaking out of the pool if contamination occurred. Thus, an irradiator facility designed, licensed, and operated in accordance with established guidelines in 10 CFR Part 36 should facilitate decommissioning.

Transfer of licensed byproduct material, the sealed irradiation sources, to another authorized licensee is allowed, provided that necessary verification and approval is obtained, as specified in 10 CFR Part 30.41, Transfer of Byproduct Material.

Near-surface disposal regulations do not specifically limit the cobalt-60 concentration; however, practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations of these wastes.

2.1.2 Types of Large Irradiator Facilities Considered

A panoramic, wet-source storage irradiator (American National Standards Institute ANSI N43.10, Category IV) is a "controlled human access irradiator in which the sealed source is contained in a storage pool (usually containing water). The sealed source is fully shielded when not in use, and the sealed source is exposed within a radiation volume that is maintained inaccessible during use by an entry control system."

At present, there are about 45 commercial large irradiators (see Table B.1, Appendix B) operating in the United States and nine irradiators either shut down or decommissioned. Five of these facilities used or were licensed to use cesium-137 irradiation sources in cesium chloride (CsCl) form [Waste Encapsulation Storage Facility (WESF) capsules supplied by the Department of Energy (DOE)] beginning in 1985. However, following a loss of encapsulation integrity and subsequent cesium-137 leakage and associated contamination at the Radiation Sterilizers, Inc. (RSI) facility at Decatur, Georgia, all WESF capsules in use in irradiator facilities have been removed and returned to the DOE or are being returned to DOE. Due to the above-described problem of using cesium-137 (CsCl is highly soluble in water) in a wet-storage irradiator, it is questionable that cesium-137 will be used in the wet-storage configuration in large irradiators. Although cesium-137 irradiation sources can be used in a dry configuration, decommissioning of cesium-137 large irradiators is not addressed in this study.

The remaining large irradiator facilities utilize cobalt-60 capsules. Data were obtained from a set of licensees and regulators (limited to less than 10 organizations) on quantities of cobalt-60 possessed and in use at operating large irradiator facilities. The distribution of source strengths at those facilities is indicated by the following table:

Source Strength	No. of Facilities
< 1 MCi[a]	1
1-3 MCi	12
3-5 MCi	3
> 5 MCI	1

(a) MCi = 1 megacurie = one million curies.

Using the average of the above source strengths weighted by the number of operating facilities suggests a value of 2.0 MCi as the source strength for the reference large irradiator to be evaluated in this study.

2.1.3 Decommissioning Alternatives Considered

For most large irradiator facilities that include structures and equipment, the basic decommissioning alternative considered is DECON [immediate decontamination (if necessary) and release for unrestricted use]. Normally, return of the sealed sources to the supplier or transfer to another licensed user is the most practical decommissioning alternative. In certain situations involving disposal of large inventories of cobalt-60 with limited access to licensed disposal sites (currently only two licensed disposal sites with limited access exist in the U.S.), interim storage of the sealed sources, either onsite in the existing storage pool or by a licensed broker for radioactive materials, may be an acceptable alternative. Access to currently licensed disposal sites is limited as follows: 1) the U.S. Ecology site at Richland, Washington, only accepts waste generated in states of the Northwest and Rocky Mountain Compact and 2) the Chem-Nuclear facility at Barnwell, South Carolina, accepts waste generated in all other states except North Carolina. With the relatively short half-life (5.27 year) of cobalt-60, the curie level would decrease during interim storage with the potential for significantly reduced disposal costs (assuming the current curie surcharges at disposal facilities) and likewise other disposal requirements, such as shielding.

2.1.4 Technical Approach to Study

The first phase of this study was to examine the characteristics of the large irradiator facilities, which are primarily commercial facilities. From this information base, the key characteristics needed to establish a generic reference large irradiator were identified. Facilities were characterized in sufficient depth to permit an engineering analysis of their decommissioning. This required identifying facility components, describing operations performed, and assessing radioactive contamination prior to decommissioning.

A composite reference large irradiator was then defined that would have characteristics typical of the majority of large irradiator facilities currently operating and licensed by the NRC and Agreement States. The characteristics chosen lend themselves to the use of the unit cost factor method, which is used throughout the analysis.

Direct costs of decommissioning are estimated, including labor, materials, equipment, and, where applicable, packaging, transportation, and disposal of radioactive wastes. Cost ranges are defined to estimate the sensitivity of the total decommissioning cost to variations in selected key cost elements. These key cost elements include the sealed source inventory in possession at the time of facility decommissioning, levels of radioactive contamination caused by postulated sealed source leakage, and access to available disposal sites.

Likewise, safety assessments, expressed in radiation exposure doses, are developed in much the same fashion to estimate the radiological hazards to the decommissioning workers and to the public.

2.1.5 Decommissioning Processes Considered

In the normal situation, when a licensee of a commercial irradiator facility desires to terminate operation of the irradiator, possibly due to obsolescence, reduced product demand, or increased operating costs that have affected its economic competitiveness, the licensee would request that the supplier of the radioactive sealed sources remove and take possession of the remaining sealed sources. Part of the process of removing the sealed sources from the facility is to assure that no site contamination from leaking radioactive sources has occurred by performing a thorough radiological site survey of the facility. This is the most likely decommissioning scenario, and would eliminate the need for disposal of the remaining sealed sources by the licensee at a low-level radioactive waste (LLW) disposal facility.

If the supplier does not agree to accept the sealed sources, the supplier is not in existence, or another interested licensee cannot be identified, the licensee may need to resort to sealed source disposal at an approved LLW burial site as the only alternative. To conform with disposal requirements at specific sites, certain packaging requirements must also be met.

In certain rare instances, the cobalt-60 source material in the doubly-encapsulated sealed sources may have leaked into the storage pool water and throughout the water treatment system. In most cases where early leak detection occurs and contamination is minimal, the water treatment system of the facility can remove the contamination with ion exchange resin columns and filters, provided the leaking source has been identified and isolated in an appropriate container. Higher contamination levels may justify mobilizing a portable water treatment system with larger capacity. Contamination adhering to the pool walls, source racks, and other equipment can normally be dislodged by high-pressure (underwater) spraying with pool water (or scrubbing with decontamination fluid, if necessary). Smear samples of pool walls and equipment are taken (and contaminated items are decontaminated, as needed) until radioactive contamination is reduced to levels acceptable for unrestricted release.

Radioactive waste (dewatered resins and filters) generated during the cleanup of the contaminated facility is packaged in standard disposal drums for disposition at an approved LLW disposal site.

2.1.6 Key Bases and Assumptions

The purpose of this study is to provide technical bases and background data for possible future NRC rulemaking regarding decommissioning, for evaluating the reasonableness of planned decommissioning actions, and for determining if adequate funds are reserved by the licensees for decommissioning of their large irradiator facilities. Another purpose of this study is to provide background and information to assist licensees in planning and carrying out the decommissioning of their irradiator facilities.

Many aspects of decommissioning may change from plant to plant, depending on facility location, specific facility design, operating practices during the lifetime of the facility, shutdown conditions, and residual radionuclide inventory and contamination levels. The bases used in this study must therefore be carefully examined before the results can be applied to a different facility.

The key bases and assumptions used in this study are:

- The study must yield realistic and up-to-date results. This primary basis is a requisite to meeting the objective of the study, and provides the foundation for most of the other bases.

- The DECON decommissioning alternative is the only option considered in detail for large irradiator facilities. Cases in which a licensed broker, radionuclide supplier, or other contractor takes possession of a sealed source for interim storage or re-use are considered for the original owner/user, but not for the second or subsequent owner/user.

- The methods used to accomplish decommissioning utilize presently available technology; i.e., the results do not depend on any breakthroughs or advances in present-day technology.
- The study is conducted within the framework of the existing regulations and regulatory guidance. No assumptions are made regarding what future regulatory requirements or guidance may be.
- Decommissioning and radiation protection philosophies and techniques conform to the principle of keeping occupational radiations doses As Low As Reasonably Achievable (ALARA).
- An LLW disposal facility is in operation. The existence of an operable disposal facility is requisite to all options requiring disposal of the sealed sources and any LLW which may have been generated during decommissioning of the large irradiator facility.
- All costs are given in constant dollars of early 1993.

From the above major study bases and assumptions, more specific bases and assumptions are derived for specific study areas. These specific bases and assumptions are presented in their respective report sections.

2.2 Approach and Bases for Sealed Sources

The term "decommissioning" is generally applied to the decommissioning of nuclear facilities rather than small devices. In this conceptual study, the term "decommissioning" is used to refer to the steps needed to decontaminate, package, store, and dispose of devices that use small sealed sources. The decommissioning steps include preparing a plan for decommissioning the sealed source, decontaminating the area if there was any leakage from the source, packaging the source and waste from decontamination, transportation, and disposal or storage of the source. These steps are discussed in more detail in Chapter 4.

The approach used to develop this conceptual study was to first identify devices that contain the most commonly used small sealed sources. Sealed sources are employed in a wide variety of applications, from estimating the thickness of asphalt during road construction to irradiating specific cells in the human body for medical purposes. The sources are generally categorized by application type and radionuclide. The more frequent uses of sealed sources are in gauges and in medical applications. The more common radionuclides used in sealed sources are Fe-55, Ni-63, Cs-137, Am-241, and I-125.

The purpose of this study is to develop a reasonable approach to decommission sealed sources that are representative of the ones licensed in the U.S., and to estimate the cost, labor, and dose during decommissioning. This section identifies the estimated number of sealed sources and how the reference devices were chosen.

2.2.1 Number and Distribution of Sealed Sources

The total number of commercial sealed sources in the U.S. may be nearly 2,000,000.[1] The estimated number of licensees (including NRC specific, Agreement State specific, NRC general, and Agreement State general) is approximately 129,000. A survey was conducted by the NRC[2] to estimate the number of potential commercial Greater-than-Class-C (GTCC) low-level radioactive waste sources and devices. The survey suggests the following number of specific licensees (including both GTCC and non-GTCC) are included in this total:

	Licensees	Sources
NRC Specific	8,204	45,204
Agreement State Specific	15,783	86,964
Total	23,987	132,168

The NRC survey assumes that specific licensees, on average, have 5.51 sources each. Applying this average to the total population of the NRC specific and Agreement State specific licensees shown above indicates that there are over 132,000 sealed radiation sources being used or held by licensees.

In a Federal Register Proposed Rules Notice,[3] the NRC states the number of general licensees using or holding devices containing sealed sources as:

	Licensees	Sources
NRC General	35,000	600,000
Agreement State General	70,000	1,200,000
Total	105,000	1,800,000

The most common use of sealed sources is in gauging equipment, which accounts for approximately 40% of the devices, followed by calibration devices, then medical applications. The more common radionuclides used in these devices are Fe-55, Co-60, Ni-63, Sr-90, I-125, Cs-137, Ir-192, and Am-241. For this conceptual study, five radionuclides (Fe-55, Ni-63, Cs-137, Am-241, and I-125) were chosen as references cases.

2.2.2 How the Reference Devices were Chosen

There are thousands of sealed sources used in the U.S. that are handled under specific licenses of the NRC or Agreement States. These sources range from the short-lived isotopes used by the medical industry to the large-scale processing materials used for irradiation purposes. Because of the diversity in nature of the isotopes and how they are used, it is not practical to include, in one study, examples of the decommissioning of all types and devices that use sealed sources. However, by examining selected devices that use commonly used isotopes, this conceptual study will assist the reader in estimating the requirements and costs of decommissioning other types of sealed sources not specifically considered.

The four major types of sealed sources currently used in commercial industries are x-ray sources, low-intensity beta-gamma sources, high-intensity beta-gamma sources, and neutron/x-ray sources. Estimates of the number and distribution of sealed sources and their application are provided in DOE/LLW-163.[4] Sealed sources have activities that range from 1 μCi to over 1,000 Ci. However, most sealed sources have activities less than 100 mCi.

The reference devices chosen, which use the most common sealed sources, are classified into the five major types. Details on these types of sealed sources are given in Chapter 3. The devices chosen are listed in Table 2.1.

2.2.3 Technical Approach

Many of the bases and assumptions for small sealed sources are similar to those described for large irradiator facilities in Section 2.1.6.

In the postulated decommissioning of a sealed source, or the device containing one, there are three possible final outcomes for the disposition of a sealed sources: to transfer the sealed source to another user or back to the manufacturer, to package the sealed source for disposal at a commercial LLW burial facility, or to package the source for storage while awaiting for a disposal facility to open.

Transfer back to the manufacture or to another user is the most desired case. When a source can be transferred, the life of the source is extended. In addition, the space

Table 2.1 Sealed source reference devices

Source type	Reference device	Isotope	Activity
X-Ray	X-ray Fluorescence	Fe-55	50 mCi
Low-Intensity Beta-Gamma	Gas Chromatograph	Ni-63	10 mCi
High-Intensity Beta-Gamma	Thickness Gauges	Cs-137	500 mCi
Neutron/X-Ray	Moisture Density Gauge	Am-241	50 mCi
Medical Applications		I-125	10 mCi

required and the cost for storage or disposal is saved. Many manufacturers will accept the source they sold to their customer for a fee ranging from $500 up to $7,000, depending on the manufacturer.[a] In some cases, a licensee may be able to find another party that will accept the responsibility for their sealed source and transfer ownership to that other party. Unfortunately, holders of sources that have been classified as Greater-Than-Class-C may not be able to find a willing party to accept their source. In this case, the source is packaged and stored until a disposal facility or another licensed user will accept it.

A sealed source that cannot be transferred back to the manufacturer or to another user is generally buried. Sealed sources can be disposed of (buried) at two facilities in the U.S.—at the U.S. Ecology Facility located at Richland, Washington, or at the Chem-Nuclear Facility located at Barnwell, South Carolina. The burial facility located at Richland, Washington, accepts only low-level radioactive waste generated in the states of the Northwest or Rocky Mountain Compacts. Currently, the Chem-Nuclear Facility accepts waste generated in all states except the states of the Northwest and Rocky Mountain Compacts and from the state of North Carolina. For this conceptual study, it is assumed that the sealed source will be disposed of in the U.S. Ecology Facility.

The steps required to decommission a sealed source include planning and preparation, decontamination if required, packaging, transportation, storage, and disposal. The decommissioning of a device that contains a sealed source is initiated by a period of planning and preparation that includes activities to ensure that the decommissioning effort is performed in a safe and cost-effective manner in accordance with all applicable federal, state, and local regulations.

The objectives of decontamination, if necessary, are to: 1) reduce the radiation contamination levels caused by the leaking source to minimize exposure to personnel working in the facility, and 2) to clean as much material as possible to unrestricted use levels, thereby allowing reuse of the facility.

Packaging and transportation are regulated principally by the Department of Transportation (DOT) and the NRC. The regulations of the DOT and NRC are found in Title 49 and Title 10 of the Code of Federal Regulations, respectively. Adherence to the regulations provides protection from hazards of radiation, both to transport workers and to the general public.

Estimates of cost for storage, disposal, and transfer are made for each type of sealed source. Decontamination of a leaking sealed source is considered for the storage and disposal options. Costs include labor, equipment, supplies, and waste management costs. Some key bases and assumptions for estimating costs are given in Appendix D. The costs for decommissioning sealed sources are expressed in early 1993 dollars. The total costs include a 25% contingency.

2.3 References

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(a) Personal communication: A J. Villegas (PNL) and Chris Morie (Troxler), April 20, 1993.

3 Descriptions of Reference Facilities

Descriptions of the reference large irradiator and sealed sources facilities are provided in this chapter. The reference facilities are composites of the more typical commercial facilities currently in operation in the United States.

3.1 Reference Large Irradiator Facility

For most commercial large irradiators, the sealed radioactive sources are stored in water pools when not in use. To irradiate the product, the sources are raised from the storage pool to the radiation room. The total activity of the sources typically exceeds one million curies (1 megacurie) and may range up to 10 megacuries (10 MCi). The product to be irradiated moves past the sources on an automated conveyor system or in carriers suspended from an overhead monorail.

Roughly 85% of the large irradiator capacity in the United States is used to sterilize disposable medical/surgical products and supplies such as rubber gloves and syringes. Most of the remaining irradiation processing capacity is used for food irradiation for disinfestation and preservation of foodstuffs, induction of polymerization in plastics, research on the effects of very high doses of radiation, and other specialized uses. The irradiator industry has matured during the last decade, and is a fairly stable commercial industry.

3.1.1 Reference Facility Description

The reference large irradiator site consists of a warehouse-type building of approximately 30,000 square feet area, constructed of standard construction materials such as concrete cinder blocks or sheet metal siding and roof, and divided into the following areas: 1) warehouse and storage area for product before and after irradiation (about 75-85% of the total area), 2) the irradiation cell (about 10-15%), and 3) the process control and support area (about 5-10%). The irradiation cell includes massive shielding (usually reinforced concrete) to limit the external radiation field to less than 0.25 mrem/hr and a below-grade concrete structure containing a stainless-steel-lined pool of water in which to store the radioactive sources when not in use.

The reference large irradiator facility uses sealed irradiation sources containing cobalt-60 for gamma-ray irradiation with a total radioactivity level of two million curies (2 MCi). The basic components of the reference large irradiator facility consist of the following:

- the radiation shield
- the storage pool
- the source racks and hoist system
- the conveyor system for transporting the material through the cell
- the aluminum carriers and totes
- the control system.

The control system ties all these systems together, making the irradiation process a highly automated and controllable operation.[1] A typical large irradiator facility is illustrated in plan and vertical section views in Figures 3.1 and 3.2. The size of the typical facility illustrated is somewhat smaller than the two megacurie capacity of the postulated reference facility.

The radiation shield is a concrete enclosure within the facility providing shielding designed to limit the external radiation dose rates to less than 0.25 mrem/hr. It consists of a concrete irradiation cell and entrance maze to allow access by a continuous overhead conveyor. The cobalt-60 sources are stored underwater in a below-grade pool when the irradiator is not in operation. Radiation fields inside the radiation room do not exceed 2 mrem/hr when the maximum licensed source capacity is stored in the pool. These fields are continuously monitored while the sealed sources are in the storage pool.[2]

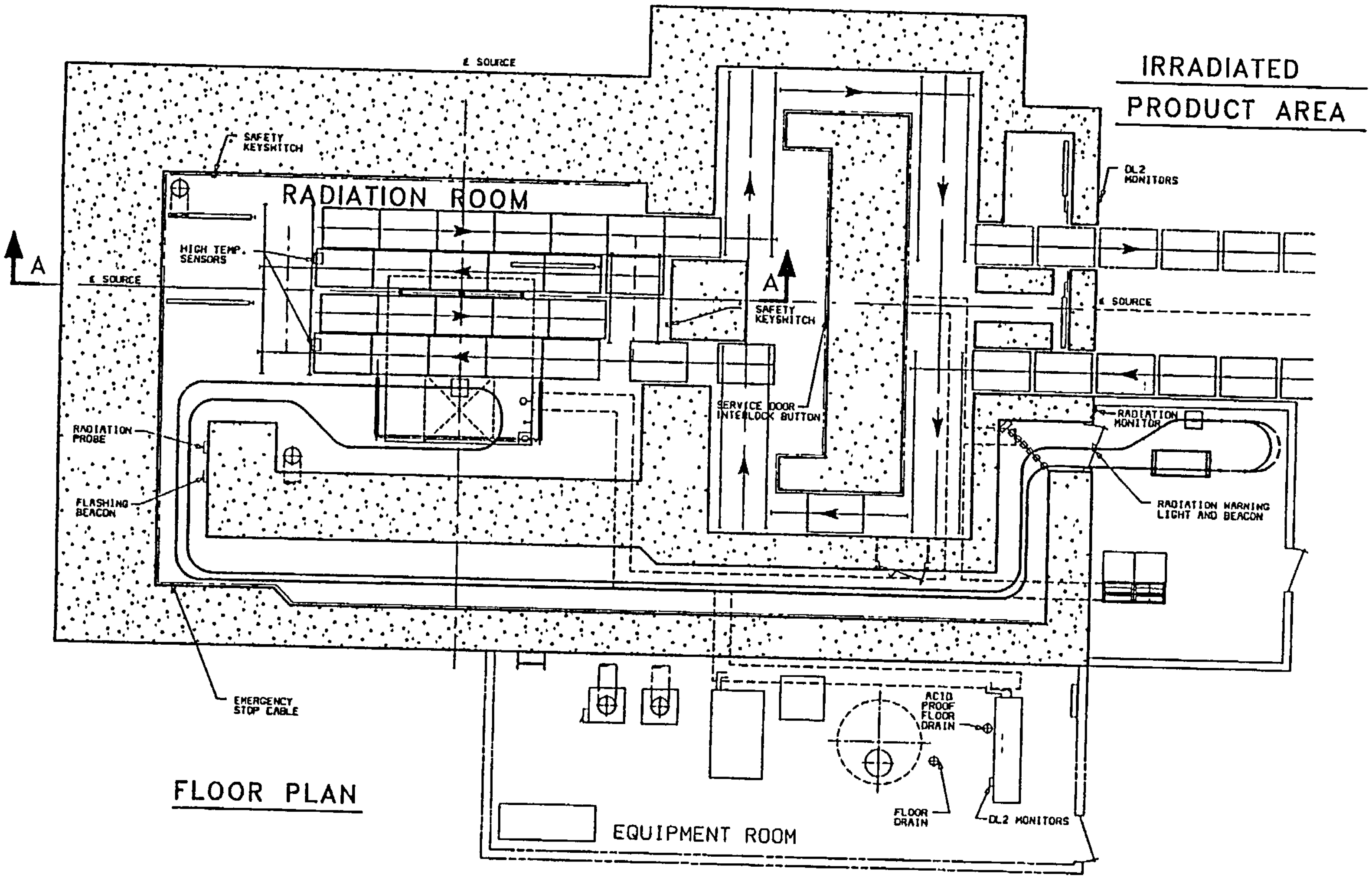

Figure 3.1 Plan view of a typical large irradiator facility

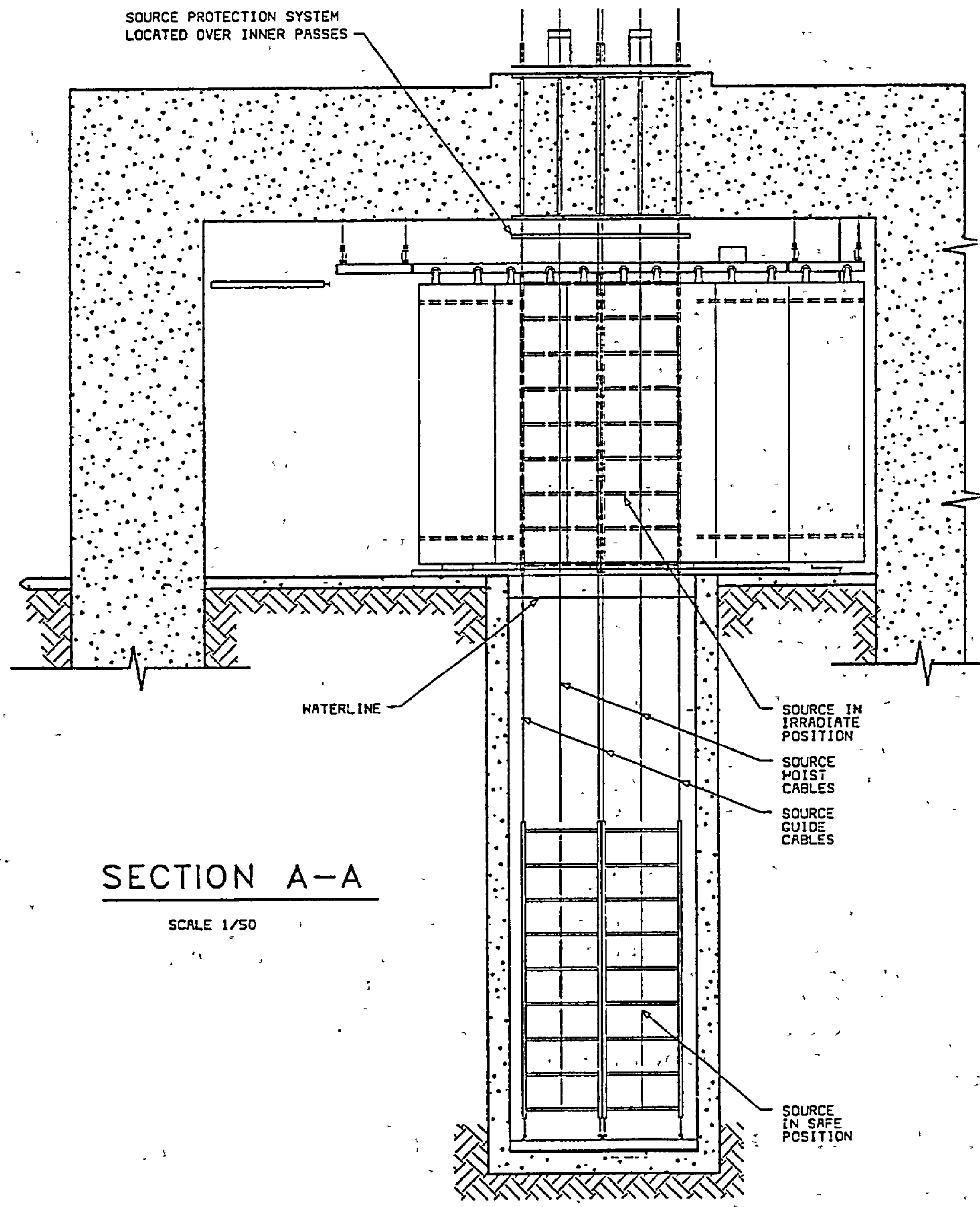

Figure 3.2 Vertical view of a typical large irradiator facility

The storage pool is 16 feet long, 20 feet deep, and 6 feet wide. It is constructed of reinforced concrete with a stainless-steel liner. The water in the pool is de-ionized and filtered by circulating it through a water treatment system located adjacent to the cell. The water level in the pool is controlled to pre-set limits, with abnormally high and low level warnings.(3)

The components within the pool, in addition to the source racks and source modules containing the cobalt-60 source pencils, are constructed of stainless steel to withstand radiation damage and to minimize corrosion. Some of the plumbing external to the pool may be plastic.(3)

The radioactive cobalt-60 source material is doubly encapsulated in source pencils similar to the AECL Type C-188 sources illustrated in Figure 3.3. These pencils are inserted into sub-assemblies called modules, which, when assembled in the rigid stainless-steel source rack, constitute the source. Each pencil is identified by an engraved serial number for accountability purposes. Its position in a module is recorded. Each module has a capacity of 42 source pencils. When fewer than this number are required to make up the desired source strength, the remaining spaces are filled with non-radioactive "dummies." The weight of cobalt per C-188 pencil is 105.6 grams, giving a total source pencil assembly weight of 242 grams. Each module is closed by a latch that cannot be opened while the module is in the source rack.(4)

Aluminum carriers are loaded with aluminum totes (boxes) that contain the product to be irradiated. These carriers are suspended from an overhead monorail conveyor system, as illustrated in Figure 3.2. The carriers are automatically conveyed around the cobalt-60 gamma source, exposing the product to the required dose of radiation before being released to the unloading station where the irradiated product is then moved by conveyor belt to the storage area.

3.1.2 Operating Process Description

The sources of radiation, cobalt-60 pellets that are doubly encapsulated in welded stainless-steel source elements called pencils, are delivered to the facility in DOT-approved, lead-shielded steel casks by the isotope supplier. The casks are lowered by crane through an opening in the roof of the gamma irradiation cell to the bottom of the pool and the cask cover is removed underwater. A basket containing pencils is lifted out of the cask and positioned on the bottom of the pool. Individual pencils are removed from the basket with long-handled tools and inserted into source modules. Once loaded, each source module is positioned on one of the two source racks (see Figure 3.1 for details). Each pencil bears a serial number and a certified curie content for accountability purposes. During loading, special care is given to the proper distribution of pencils between the source racks to obtain relatively uniform distribution of dosage to the product during irradiation. Each source rack is approximately 10 feet in length.(3)

The doubly encapsulated source pencils are stored in a flowing-water medium while not in use and are raised and lowered in that medium before and after irradiations. In effect, one has a continual washing action of the surface and thereby a good means of detecting an incipient leak at the early stages. The pool contamination test is routinely conducted every day the irradiator is operated.

A radiation monitor to detect possible activity buildup on the filters and demineralizers of the water treatment system, while not the most sensitive, may actually be the earliest sign of a leaking source capsule. The water treatment system is monitored routinely to detect possible leaking source capsules.(5)

During routine operations, the source racks are raised and lowered by cables connected to winches located on the roof of the cell. Guide wires maintain the horizontal positioning of the racks. The electrical winches are programmed to permit a controlled descent of the racks into the pool in the event of either a power failure or earthquake. Also, any failure in the system or violation of the safety controls will cause the racks to be automatically lowered into the pool. When the facility is in use, the sources are centered vertically on the product carriers. Personnel access to the irradiation room is allowed only after lowering the source racks to the bottom of the storage pool.(5)

Routine irradiation of medical products requires that the products be conveyed into and through various positions of the radiation cell to achieve the specified dosage. Mechanically, these functions are performed by a lift unit and a conveyor system. Programmed control throughout

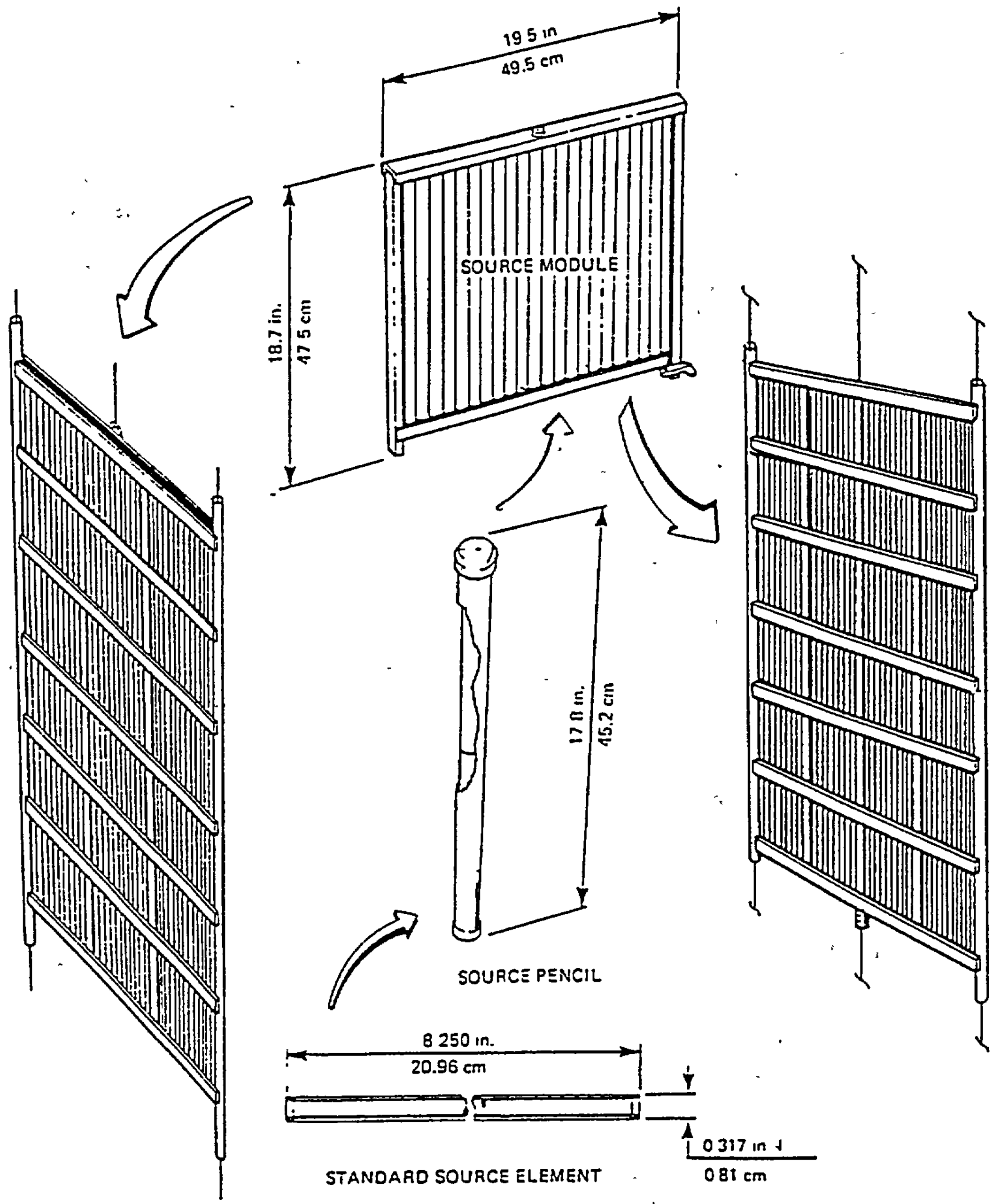

Figure 3.3 Arrangement of source pencils into source racks

the process is provided by a programmable controller. With each mechanical cycle, photocells, proximity and limit switches provide the information to monitor each movement of the product. Typically, material to be processed is conveyed through the irradiation cell on three-tiered carriers supported by an overhead power and free conveyor system. Product is loaded into metal tote boxes, measuring 20" x 50" x 36", which in turn are loaded onto the bottom shelf of the three-tiered carrier. To obtain maximum dose uniformity for the designed dose delivery, each tote passes through the radiation cell three times, once at each shelf level. The totes are automatically elevated one level after each pass through the cell. After the third pass, they are automatically removed from the carrier and transported to the unloading area. All loading and unloading of the totes is performed in the warehouse area.[3]

The irradiator can also be operated without using a conveyor system in a batch operation. The product is manually placed in the cell either in a static array or on turntables that rotate the product stack about its own axis. This system generally does not involve close proximity to the source and does not produce the potential for jamming that a moving conveyor would. This mode normally would be used for 1) oversize packages, 2) overweight packages, 3) long-term irradiations (8 to 100 megarads), or 4) liquids where movement may be a concern. Cell entry in the batch mode is made only by authorized personnel following appropriate procedures.[5]

3.2 Sealed Source Descriptions

A sealed source is defined as any radioactive byproduct material that is encased in a capsule designed to prevent leakage or escape of the byproduct material (10 CFR 30.4). Sealed sources are used in construction and commercial industries, and for medical applications. There are no current data that accurately estimate the total number or distribution of sealed sources and their principal uses in the U.S. A survey was performed that captured information pertaining to devices with Greater-Than-Class C (GTCC) sources.[6] This survey categorized the devices into 15 separate categories that used GTCC sealed sources, the distribution of each device category relative to each other, and the principal radioisotopes for each of the principal devices. Five reference devices (listed in Table 2.1) were selected as being representative of those currently used in industry.

The primary limitation of this survey was that Classes A, B, and C sealed sources are not characterized. In addition, the survey report deals only with sealed sources handled by specific licensees, not General Licensees (10 CFR 30). It is assumed, for the purposes of this conceptual decommissioning study, that the distribution of Classes A, B, and C sealed sources is similar to the GTCC sealed sources and that the distribution is similar for both General and Specific Licenses.

In the following sections, the five reference sealed source devices are described.

3.2.1 X-Ray Source

A cross section of a typical x-ray source is shown in Figure 3.4. X-ray sources are manufactured from isotopes such as Fe-55, Co-57, Ba-133, Au-195, and Bi-207 that decay by electron capture. The radioactivity of an x-ray source can vary from a few microcuries to several curies. A typical source consists of radioactive material that is deposited by evaporation or electroplating on a thin metallic disc of iron, copper, or platinum. The disc containing the radioactive material is hermetically sealed or bonded with epoxy resin to an aluminum or copper backing disc. A very thin window (~0.1 mm) of beryllium or aluminized mylar is epoxy-bonded over the active surface to prevent accidental contact with the radioactivity. The unit is then encased in an aluminum or copper retaining ring that is

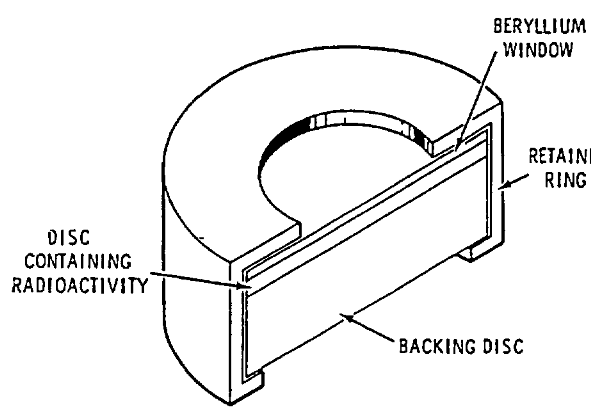

Figure 3.4 X-Ray source

bonded to the backing with epoxy resin. Typical dimensions are 15-mm diameter and 10-mm thick.

Primary radiation from the radioisotope source excites atoms of the elements present in the sample, removing electrons from the sub-shells around the nucleus. X-rays characteristic of each element are emitted as electrons from the outer shells and move to fill the gaps created in the inner shells. The shell from which the electron is removed determines the series of x-rays produced. The intensity of the x-ray is indicative of the concentration of the particular element in the sample. Since radioisotopes emit specific radiations, a limitation results on the range of elements whose characteristic x-ray can be excited. Thus, a series of nuclides is employed in order that excitation of all elements from silicon to uranium can be achieved. The geometry for x-ray fluorescence is provided in Figure 3.5.

For the purposes of this conceptual study, it is assumed that a device for x-ray fluorescence contains an Fe-55 sealed source with an activity of 50 mCi. Examples of applications for x-ray sources include alloy analysis for checking stock, scrap sorting, and checking components; in mining, analysis of material excavated from pits, and cores, chippings and slurries from drilling operations, and analysis of electroplating solutions.

3.2.2 Low-Intensity Beta-Gamma Source

A cross section of a typical low-intensity beta-gamma source is shown in Figure 3.6. The radioactivity of the source can vary from a fraction of a microcurie to a few millicuries. The radioisotope is deposited by controlled evaporation in the cavity at the top of a brass plug. The

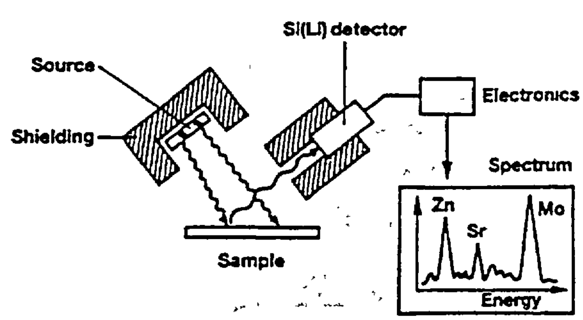

Figure 3.5 Geometry for X-Ray fluorescence source

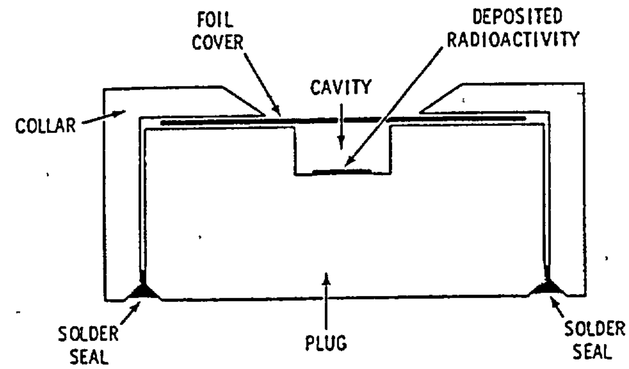

Figure 3.6 Low-intensity beta-gamma source

cavity is then covered by a thin copper foil that is soldered to the brass plug. A collar is placed over the plug and soldered to the plug at its interface at the bottom of the mount. Aluminum or stainless steel may be used in place of brass and copper for fabrication of the source mount and foil cover. Typical dimensions are 8-mm diameter and 4-mm thick.

An example of an application for a low-intensity beta source is a gas chromatography device, shown in Figure 3.7. The cylindrical ion chamber containing a low energy beta source maintains a standing current with a stream of pure argon. When material with a high electron affinity enters the chamber, the ion current falls and this is displayed. Some instruments also have a gas chromatography column attached that enables specific compounds to be measured when the atmosphere is already contaminated by other pollutants.

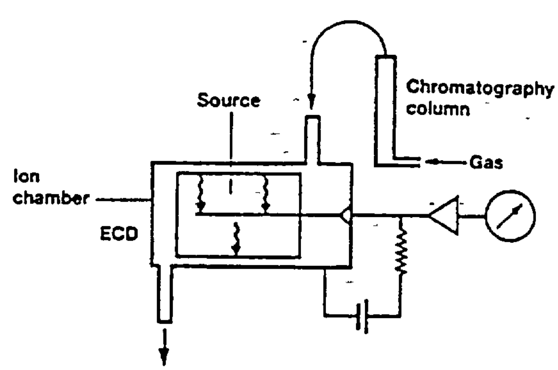

Figure 3.7 Geometry for a gas chromatograph

For the purposes of this conceptual study, it is assumed that a gas chromatograph contains an Ni-63 sealed source in the form of a foil with a typical activity of 10 mCi.

3.2.3 High-Intensity Beta-Gamma Source

A cross section of a typical high-intensity beta-gamma source is shown in Figure 3.8. The source is manufactured from Cs-137 or Co-60 and is doubly encapsulated. Typical uses include industrial gauging, oil well logging, or other industrial uses that require a source with a large gamma output.

Radioactive cesium sources can range up to 25 curies in source strength. Cesium-137 as anhydrous chloride is fused with alumina by heating the mixture to approximately 650°C. The fused material is then compressed into the inner capsule and the capsule is sealed as illustrated below. Typical dimensions are 8-mm outside diameter thickness.

Radioactive cobalt sources can range up to 25 curies in source strength. Cobalt-60 in the form of a metal ingot or nickel-plated pellet, wire, or foil is placed in the inner capsule. A fused glass member, sphere, or molecular sieve is placed in the capsule with the cobalt source to hold it in place.

An inner capsule plug of stainless steel is press-fitted to the inner capsule and sealed by tungsten-inert-gas (TIG) or heliarc welding techniques. The inner fuel capsule is then press-fitted into an outer capsule that is plugged and TIG or heliarc welded. Typical capsule materials are Type 316, 318, and 348 stainless steel and K-500 Monel. Construction is at least 0.6 mm thick. The source can be designed for use with a remote tool by incorporation of a threaded mounting hole in the outer capsule. In addition to visual and dimensional checks, each source is given a vacuum leak test and wipe test before shipment.

An application for a high-intensity gamma source is for a level detection gauge. The transmission of gamma radiation through a container is affected by the level of the contents. The intensity of the transmitted radiation is measured and used to activate switches when pre-set intensity levels are reached. Figure 3.9 illustrates an example application of these sources.

For the purposes of this conceptual study, a thickness gauging device that contains a Cs-137 sealed source with an activity of 500 mCi is considered.

3.2.4 Neutron/X-Ray Source

Americium-241 sources are used as alpha reference sources, as x-ray excitation sources, and as neutron source moisture density gauges.

This alpha source consists of Am-241 as americium fluoride electroplated on a thin stainless-steel or platinum disc and fixed to the disc by high-temperature air annealing. The disc with the alpha activity is then bonded to an aluminum backing disc with epoxy resin. The source is protected by a 1 mg/cm^2 mica window or a 0.0025-mm-thick

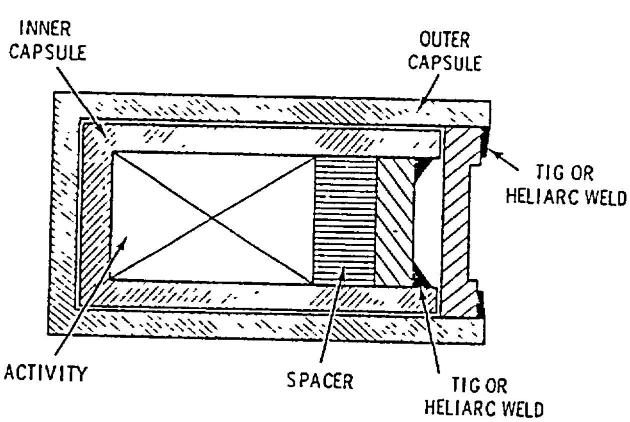

Figure 3.8 High-intensity beta-gamma source

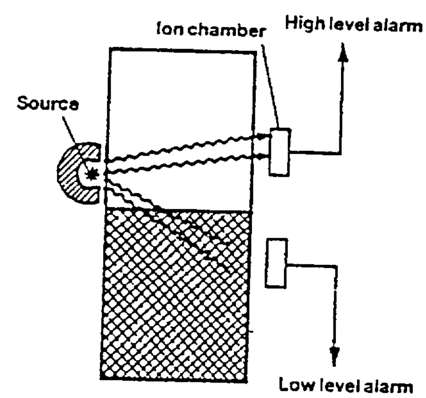

Figure 3.9 Level gauging

nickel foil cemented to the source disc. Typical source activities range from 0.01 to 1.0 mCi. Some sources are equipped with a mounting hole that is threaded for insertion of a handling tool, as shown in Figure 3.10.

For an x-ray excitation source, the americium is in the form of compressed americium oxide in an aluminum matrix. The radioactive material is encapsulated in an aluminum tube 1.6 mm in diameter with a 0.12-mm-thick wall, sealed by TIG-welded end plugs. This tube is formed into an annulus and set into the groove of an annular source shield. This assembly is then sealed into an outer, secondary aluminum capsule by TIG welding. Typical source strengths range from 1 to 300 μCi.

The Am-241 neutron source for a moisture density gauge consists of americium oxide and beryllium powder compressed into a cup that is press-fitted into the shell of the inner source capsule. This combination is then sealed by welding at the end opposite the active material. The inner capsule is then press-fitted into the outer capsule cup followed by the outer capsule that is press-fitted into place and welded to the outer capsule cup. Both the inner and the outer capsules are constructed of stainless steel and have 0.65-mm-thick walls.

An application for an americium source is for thickness gauging. The intensity of backscattered radiation from a sample is measured to give sample thickness or mean atomic number. It can be used for the measurement of substances of low atomic number for which transmission measurements are not sufficiently sensitive. Thickness gauging can be applied to the measurement of light alloys, glass, plastics, rubbers, and asphalt. Figure 3.11 illustrates an example application of americium sources.

For the purposes of this conceptual study, it is assumed that a moisture density gauging unit contains an Am-241 sealed source with an activity of 50 mCi.

3.2.5 Medical Industry Source

Sources used in medical applications range widely in variety in terms of radioisotope, activities, and uses. Medical sealed sources are used in the radiopharmaceutical industry for uptake and excretion analysis, in brachytherapy via implants into patients, for teletherapy, and other related procedures.

Strontium-90 is used as an ophthalmic beta applicator. The applicator contains a strontium-90 compound incorporated in a rolled silver disc with a face thickness of 0.05 mm. The disk is sealed in a welded stainless-steel holder having a window thickness of 0.05 mm. The typical activity is 55 mCi.

Iridium-192 is used in brachytherapy, typically in the form of wires, small tubes, and needles. The source material is usually in the form of a thin wire of iridium metal called a "seed," sealed in a metal capsule typically made of platinum or titanium/nickel.[7,8] Individual sources typically contain about 10 curies of Ir-192.[9] These sources are also commonly used in industrial radiography, often in portable units for nondestructive testing of welds,

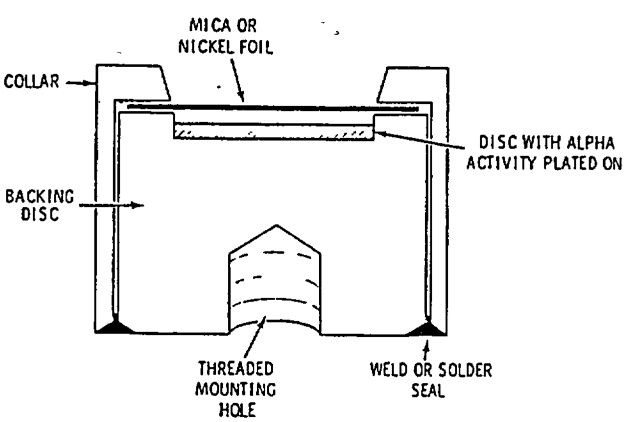

Figure 3.10 Neutron/X-Ray source

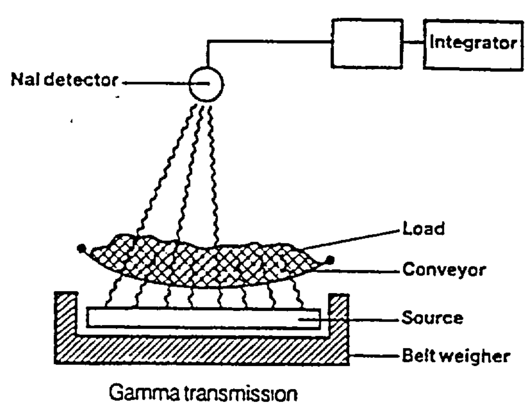

Figure 3.11 Thickness gauging application

examination of pipes, and similar applications. Industrial sources of Ir-192 contain from 2 to 135 curies of Ir-192.[7]

Radioactive implants have been used extensively for early stage treatment of prostate cancer in brachytherapy.[10,11] This treatment involves the use of I-125 to irradiate areas in the prostate where carcinoma exists. Five to fifteen hollow 17-gauge needles are hand-placed uniformly throughout the prostate gland. The needles are then withdrawn sequentially, injecting the radioactive pellets. Typical source activities range from 5 to 70 mCi. Figure 3.12 illustrates an example of an I-125 sealed source used in a medical application.

For the purposes of this conceptual study, a medical sealed source of I-125 with an activity of 10 mCi is considered.

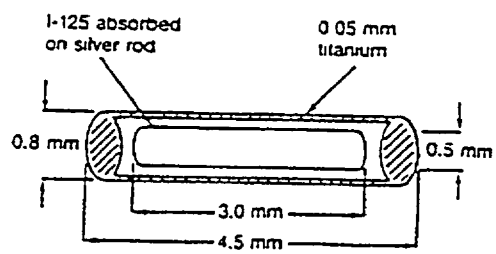

Figure 3.12 Medical sealed source

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4 Decommissioning Activities, Labor Requirements, and Costs

The activities necessary to decommission the reference large irradiator facility and sealed source facilities, the labor requirements to complete the defined tasks, and the costs associated with those activities are discussed in this chapter. The decommissioning of the reference large irradiator facility is discussed in Section 4.1. The decommissioning of the five typical reference small sealed sources is discussed in Section 4.2.

4.1 Decommissioning of a Reference Large Irradiator Facility

Two scenarios for the decommissioning of the reference large irradiator facility are evaluated in this study. The first scenario assumes that the facility is not radioactively contaminated; the second scenario assumes that one of the cobalt-60 source capsules has leaked radioactivity into the storage pool, resulting in radioactive contamination which is contained within the facility.

For both of the above-described scenarios, two alternatives were assumed for disposal of the source capsules. The sources are assumed either to be returned to the source supplier (or another licensed facility), or are transported to a licensed low-level waste (LLW) burial facility. For the contaminated facility scenario, the radioactive wastes generated from cleanup of the facility are assumed to be sent to a licensed LLW burial facility.

Suppliers of cobalt-60 source capsules customarily offer licensees the option of returning the spent capsules to them for recycle or disposal. The licensees who provided information for the questionnaire (See Appendices B and C) indicated this option was the choice of all surveyed for removal and disposal of the source capsules at the time of decommissioning. This option (the most likely mode of decommissioning a large irradiator facility) is one of the cases in the clean facility scenario.

Although the value of sources returned would be a negotiable item to be considered for each case, the supplier does not normally allow a credit for the returned sources. To recycle those sources, the supplier would incur testing and likely re-encapsulation costs such that the source could be certified for reuse. If the source could not meet the warranty requirements, the supplier would then incur disposal costs. Therefore, for this study, no credit is assumed for the returned sealed sources.[a]

4.1.1 Removal of Source Capsules - Clean Facility

A major worldwide supplier of cobalt-60 source capsules, Nordion International, Inc., has provided an estimate of the work activities necessary to remove and package the remaining source capsules from a typical large irradiator facility. Certain steps of that procedure are dependent on the total inventory of capsules present at decommissioning. Table 4.1 presents the decommissioning procedure, including estimated times and costs for removal of a source inventory of 2.0 megacuries, assuming a two-man crew experienced in handling the radioactive capsules.[1] The work durations for this procedure are given in Figure 4.1.

4.1.2 Cleanup of Contaminated Facility

In the operating experience of large irradiators in the United States, there have been three events in which the encapsulation of the radioactive cobalt-60 sources appears to have failed, resulting in contamination of the storage pool. In one event in 1974, a source was damaged from mishandling, but no source leakage was immediately detected. An excessive contamination level in the pool was reported in 1982. The measured contamination was not uniformly distributed throughout the depth of the pool. In a second event, routine maintenance early in the facility life resulted in the chemical contamination of the pool water. The licensee hypothesized that this chemical contamination ultimately led to corrosion of the source encapsulation and subsequent radioactive contamination of the pool water. In the third event, late in 1975, the licensee detected a cobalt-60 concentration of 1,300 pCi/ml in the water of a research and development pool. The licensee stated that the activity level may have been the result of corrosion scale activity from a batch of cobalt-60 sources recently installed in the pool or activity from one source

(a) Private communication: D. R. Haffner (PNL) and Dick McKinnon (Nordion), 5/20/94.

Table 4.1 **Decommissioning procedure for a Category IV cobalt-60 panoramic wet storage gamma irradiator**[a]

	Task performed	Crew-hours[b]	Labor costs[c] (1993 $)
1.	Preparatory paperwork and arrangements.	9.0	2,700
2.	Travel to site.	9.0	2,700
3	Radiation surveys and contamination tests.	0.6	180
4.	Preparation for source removal.	4.8	1,440
5.	Remove sources and load into shipping containers.	25.2[d]	7,560
6.	Prepare shipping containers for transport.	18.0[d]	5,400
7.	Confirm all sources are removed, perform contamination tests, take water samples.	4.8	1,440
8.	Remove test sources and return to supplier, remove radiation warning signs.	2.4	720
9.	Travel from site.	9.0	2,700
10	Remove, test and store sources at supplier site.	20.0[d]	6,000
11.	Analyze water samples, prepare report.	4.8	1,440
	Totals	107.6	32,280
	Total Labor (person-hours)	215.2	

Assumptions

(a) Procedures, crew-hours, and labor costs provided by Nordion International, Inc

(b) Crew-hours include a work duration adjustment factor = 1.2

(c) Crew makeup: 2 persons

	Labor Rate ($/hr)
Decon technician (1)	125
Supervisor (or health physicist) (1)	175
Total $/crew-hr	300

(d) This time will vary depending on the number of cobalt-60 radiation sources removed For the reference irradiator using 2 megacuries having an average of 5 kCi per source, and 200 kCi per shipping container, a total of 10 shipping containers would be required.

that had a loose cap. Demineralization of the pool water successfully reduced the activity of the pool to the normal operational level.[2]

For this study, the contamination in the facility is postulated to be present only in the storage pool and the associated pool water treatment equipment, resulting from the leakage of cobalt-60 from one of the source capsules. Detection of this contamination is through the routine periodic monitoring of the ion exchange column in the pool water cleanup system and/or sampling of the pool water.

When cobalt-60 contamination has been confirmed in a source storage pool of a Category IV wet storage cobalt-60 gamma irradiator, the following procedure, presented in Table 4.2 (Pool Decontamination),[3] is performed by qualified personnel to decontaminate the pool

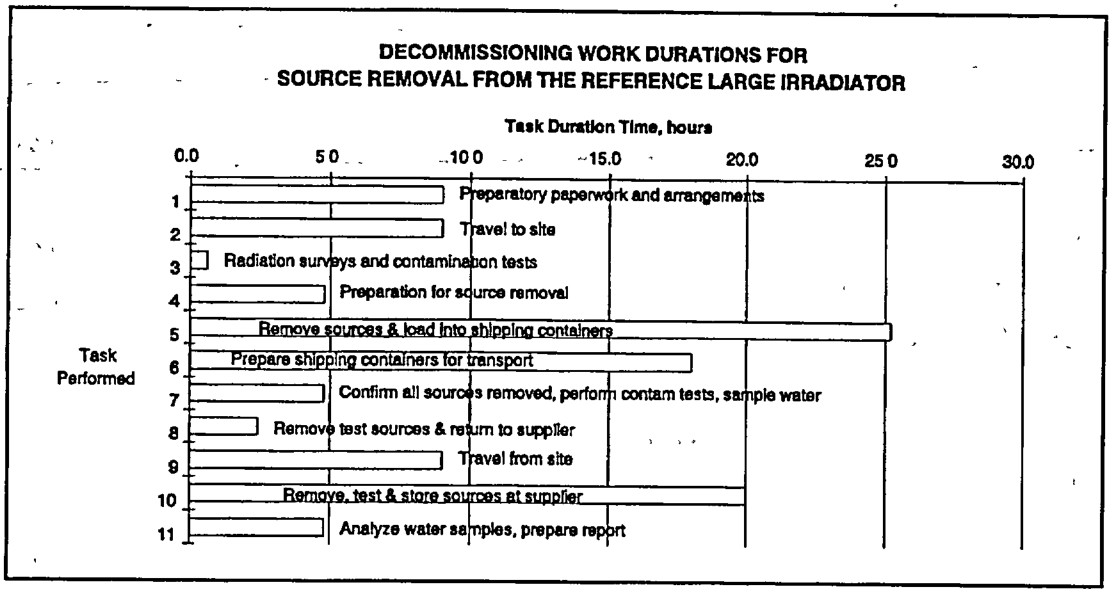

Figure 4.1 Reference large irradiator decommissioning work durations—source removal

water, pool surfaces, equipment in the pool, and equipment in which pool water is circulated.

The decontamination team will be comprised of three qualified personnel—an installation technician familiar with the overall layout of typical irradiator facilities, a decontamination technician, and a professional supervisor (or health physicist). All personnel involved in the cleanup of the contamination will be equipped with personal dosimeters, radiation survey meters, protective clothing and any other equipment deemed necessary to perform the task.

Equipment requirements for the task of decontaminating a source storage pool and detection and isolation of leaking source capsules are as follows:

- Radiation Monitoring Equipment
  - Two radiation survey meters with audible response
  - Radiation survey meter with thin-window pancake G-M probe or scintillation detector.

- Personnel Monitoring
  - Personal TLD
  - Finger TLDs
  - Direct reading pocket dosimeter with alarm.

- Protective Clothing
  - Rubber overshoes
  - Latex gloves
  - External protective clothing
  - Respirators (if necessary).

- Supplies
  - Cloth wipes
  - Styrofoam wipe pads
  - Zip-lock plastic bags
  - Plastic wrapping materials.

- Equipment
  - Portable resin column and filter with pump (if necessary)
  - Attachment for high-pressure spraying
  - Underwater handling tools
  - Metal waste drums with lids
  - Shielded shipping containers (if necessary).

Table 4.2 Procedure for pool decontamination of a panoramic wet storage gamma irradiator[a]

Task performed[b]	Crew-hours[c]	Labor costs[d] (1993 $)
1. Preparatory paperwork and arrangements.	9.0	4,050
2. Travel to site.	9.0	4,050
3. Radiation surveys and contamination tests; cordon off contamination areas.	3.6	1,620
4. Analysis of water samples	3.6	1,620
5. Install portable water treatment system.	2.4	1,080
6. Pool decontamination and contamination testing.	36.0[e]	16,200
7. Load contaminated materials into drums for disposal.	3.6[e]	1,620
8. Travel from site.	9.0	4,050
9. Prepare report	2.4	1,080
Totals	78 6	35,370
Total Labor (person-hours)	235.8	

Assumptions:

(a) Procedures, crew-hours, and labor costs provided by Nordion International, Inc.

(b) Medium contamination scenario - 2,000 pCi/ml, 109 mCi

(c) Crew-hours include a work duration adjustment factor = 1.2

(d) Crew makeup: 3 persons

	Labor Rate ($/hr)
Installation technician (1)	150
Decon technician (1)	125
Supervisor (or health physicist) (1)	175
Total $/crew-hr	450

(e) This time will vary depending on the level of contamination present in the pool.

The procedure shown in Table 4.3 (Detection and Isolation of a Leaking Source) is a subset of the pool decontamination procedures to be implemented once the level of pool contamination is determined and pool water treatment equipment is operating.[4]

For this study, the estimated cleanup costs and associated occupational dose were determined assuming three pool contamination scenarios—low, medium, and high. The low contamination scenario was established as the upper limit (30 pCi/ml) where the facility water treatment equipment could be used to remove the cobalt-60 contamination in the pool. Pool contamination levels above 30 pCi/ml would require a portable water treatment unit with greater capacity.[3] The medium contamination scenario was assumed to be 2,000 pCi/ml. For the high contamination scenario, a concentration near the highest contamination level experienced to date[2] (200,000 pCi/ml, see Appendix B, Table B.3) was assumed. Cleanup rates and costs

Table 4.3 Procedure for detection and isolation of a leaking cobalt-60 source capsule in a panoramic wet storage gamma irradiator[a]

Task performed[b]	Crew-hours[c]	Labor costs[d] (1993 $)
1. Perform underwater test to determine approximate location of leaking capsule(s).	9.6	4,320
2. Perform tests on small groups of source pencils to isolate leaking capsule(s).	72.0	32,400
3. Load leaking capsule(s) and contaminated capsules into insert for shipment.	3.6[e]	1,620
4. Load insert into shipping container and prepare for shipment.	3.6	1,620
Totals	88.8	39,960
Total Labor (person-hours)	266.4	

Assumptions:

(a) Procedures, crew-hours, and labor costs provided by Nordion International, Inc

(b) This procedure is performed together with Pool Decontamination (Table 4.2)

(c) Crew-hours include a work duration adjustment factor = 1.2

(d) Crew makeup: 3 persons

	Labor Rate ($/hr)
Installation technician (1)	150
Decon technician (1)	125
Supervisor (or health physicist) (1)	175
Total $/crew-hr	450

(e) This time will vary depending on the number of source leaks. For the reference irradiator, the number of source leaks is assumed to be one.

were provided by industry experts with significant contamination cleanup experience.[a] Results of this analysis for the three contamination scenarios are shown in Table 4.4. Cleanup costs in Table 4.4 are incremental to the normal decommissioning costs of source removal, packaging, transportation, and transfer to the supplier or disposal shown in Tables 4.5 through 4.7.

4.1.3 Waste Transportation and Storage/Disposal

Once the sources have been removed from the facility, they would be transported in approved DOT shipping containers to either the source supplier (or another licensed facility) for recycle or to an approved LLW disposal facility. The two LLW disposal facilities currently available in the United States are located at the U.S. Ecology site at Richland, Washington, and the Chem-Nuclear site at Barnwell, South Carolina. The U.S. Ecology facility accepts only wastes generated in the eleven states of the Northwest and Rocky Mountain Regional Waste Compacts. The Chem-Nuclear facility currently accepts waste generated from all states except states of the Northwest and Rocky Mountain Compacts and from North Carolina.

The following tables, Tables 4.5 through 4.7, present the estimated decommissioning costs and dose rates resulting from a spreadsheet analysis for two source disposition cases—returning the sources to the supplier, and disposing of the sources in an approved LLW disposal facility.

(a) Private communications: D. R. Haffner (PNL) and D McCoy (Scientific Ecology Group), 5/4/94; D. R. Haffner (PNL) and R. Chu (Nordion), D. McKinnon (Nordion), 4/28/94.

Table 4.4 Incremental decommissioning costs and radiation doses—cleanup of irradiator pool contaminated by a leaking source capsule

Contamination scenario	Source leaked (mCi)	Pool contam (pCi/ml)	Labor (person-hrs)	Labor cost ($)	Dose (person-rem)	Pool cleanup system(s) Plant (days)	Portable (days)	Portable Cost ($)	Disposal cost ($)	Total cost ($)
Low	1 63E+00	3.00E+01	502 2	75,330	1 004	2 00	0 00	0	321	75,651
Medium	1 09E+02	2 00E+03	563 8	84,571	1.128	2 00	2 05	7,134	321	92,026
High	1 09E+04	2.00E+05	665 3	99,792	1 331	2 00	5 44	15,590	3,489	118,871

Assumptions:

Contaminated Pool Cleanup (Leaking Source)

Pool Volume, liters =	54,368
Pool Cleanup Rate, mCi/hr =	0 034
Portable System Cleanup Rate, mCi/hr =	83 33
Portable System Rental Rate, $/day =	2,500
Mobilization/Demobilization Fee, $/job =	2,000
Disposal Rate, $/Ci = (includes packaging, transport, & disposal)	321[a]
Number of source leaks =	1

Crew makeup: 3 persons	Labor Rate[b] ($/hr)
Installation technician (1)	150
Decon technician (1)	125
Supervisor (or health physicist) (1)	175
Total $/crew-hr	450
Work duration adjustment factor =	1 2
Hours Per Shift =	10.00
Dose Rate (max), person-rem/hr =	0 002

(a) Disposal at Richland, WA, with non-leaking sources
(b) Crew makeup and labor rates provided by Nordion International, Inc.

Cask rental fees and high integrity container (HIC) costs assumed in this analysis reflect values used in NUREG/CR-5884.[5] The two optional waste disposal sites assumed are 1) the U.S. Ecology site at Richland, Washington, and 2) the Chem-Nuclear site at Barnwell, South Carolina. Transportation rates for radioactive waste shipments to LLW disposal facilities were provided by Tri-State Motor Transit Company and are presented in Appendix D, Table D.5. LLW disposal fee schedules, provided by the two disposal site operators, are presented in Appendix A, Tables A.1 and A.2, respectively. Results are presented for source activity levels ranging from 0.5 megacuries up to 12.0 megacuries. These results are also presented graphically in Figures 4.2 through 4.4.

4.1.4 Estimated Radiation Doses for Decommissioning Large Irradiators

For loading of 200,000 Ci Co-60 (about 40 source capsules) into a cask, total dose incurred would be about 5-10 mrem. This would include remotely loading the sources into the cask while underwater, raising the loaded cask, performing cask wipe tests and surveys, purging of water from the cask and preparing the cask for shipment.[a] For this study, the assumed radiation dose rate is 7.5 mrem/cask loading.

Part of preparing the cask for shipment includes a radiation survey of the cask (before and after loading) to confirm that the radiation level does not exceed 0.5 mrem/hr at any location on the surface of the cask. This assures that no significant dose would be incurred by either the shipper, the public, or the recipient of the sources during transport for final disposition.[1]

For the leaking source scenario, steps necessary to decontaminate the pool water, the storage pool and the water treatment facility result in additional radiation dose being incurred by the cleanup crew. If radiation dose rates greater than 2 mrem/hr are measured at a distance approximately 1 meter from a contaminated area, it may be necessary to remotely remove the contaminated materials into a shielded container prior to cleaning the contaminated

(a) Private communications S. M. Short (PNL) and R. Chu (Nordion), 7/9/92.

Table 4.5 Irradiator decommissioning costs and radiation doses—source return to supplier

Source activity (MCi)	Labor (person-hrs)	Dose (person-rem)	Total source removal costs ($)	Number of casks	Cask rental cost ($)	Packaging costs ($)	Number of shipments	Transportation costs ($)	Supplier handling charges ($)	Total D&D costs ($)
0.5	154.7	0 0225	23,208	3	8,240	--	1	3,240	44,100	78,788
1	172.0	0 0375	25,800	5	10,400	--	2	6,480	85,000	127,680
2	215.2	0.0750	32,280	10	15,800	--	4	12,960	170,000	231,040
4	301.6	0.150	45,240	20	26,600	--	7	22,680	340,000	434,520
6	388 0	0 225	58,200	30	37,400	--	10	32,400	510,000	638,000
8	474 4	0.300	71,160	40	48,200	--	14	45,360	680,000	844,720
10	560 8	0.375	84,120	50	59,000	--	17	55,080	850,000	1,048,200
12	647.2	0.450	97,080	60	69,800	--	20	64,800	1,020,000	1,251,680

Assumptions:

Source Removal from Clean Facility

Crew Size, persons =	2
Crew Labor Rate, $/hour =	300.00
Hours Per Shift =	10.00
Hours Per Job =	64.40
Hours Per Cask =	4.32
Dose Per Cask, person-rem/cask =	0 0075
Cask Capacity, megacuries/cask =	0.200
Gross Cask Weight, pounds =	12,000
Cask Rental Fee, $/cask/day =	1,250 00
Disposal Volume, cubic feet =	54 00
Container Cost, $/container =	7,825.00

Transportation Charges

Shipment Weight, lbs/shipment =	40,000
Base Fee, $/shipment =	800 00
Shipment Miles, one-way =	1,000
Miles Per Day =	500
Cost Per Mile, $/mile =	2.44

Supplier Handling Charges[a]

Container Handling Charge, $/cask =	3,200 00
Source Handling Charge, $/source =	345.00
Avg Source Strength, curies/source =	5,000

Reference Irradiator

(a) Supplier handling charges provided by Nordion International, Inc.

area. All cleanup operations assume that the maximum radiation dose rate to personnel involved is limited to 2 mrem/hr.[6]

Estimated radiation doses for the postulated decommissioning scenarios are included with the labor and cost analyses presented in Tables 4.4 through 4.7.

4.1.5 Post-Accident Cleanup of Large Irradiators

In the event of an accident that leads to contamination from a leaking source, the common practice is to immediately remove the leaking source and the resulting contamination and restore the facility to normal operating conditions, thereby minimizing necessary cleanup costs.

Table 4.6 Irradiator decommissioning costs and radiation doses—source disposal at Richland, Washington

Source activity (MCi)	Labor (person-hrs)	Dose (person-rem)	Total source removal costs ($)	Number of casks	Cask rental cost ($)	Packaging costs ($)	Number of shipments	Transportation costs ($)	Richland disposal costs ($)	Total D&D costs ($)
0.5	154.7	0.0225	23,208	3	8,240	23,475	1	3,240	272,383	330,546
1	172.0	0.0375	25,800	5	10,400	39,125	2	6,480	513,611	595,416
2	215.2	0.0750	32,280	10	15,800	78,250	4	12,960	1,027,223	1,166,513
4	301 6	0 150	45,240	20	26,600	156,500	7	22,680	2,054,445	2,305,465
6	388.0	0.225	58,200	30	37,400	234,750	10	32,400	3,081,668	3,444,418
8	474 4	0 300	71,160	40	48,200	313,000	14	45,360	4,108,890	4,586,610
10	560.8	0.375	84,120	50	59,000	391,250	17	55,080	5,136,113	5,725,563
12	647.2	0 450	97,080	60	69,800	469,500	20	64,800	6,163,335	6,864,515

Assumptions:

Source Removal from Clean Facility

Crew Size, persons =	2
Crew Labor Rate, $/hour =	300 00
Hours Per Shift =	10 00
Hours Per Job =	64 40
Hours Per Cask =	4 32
Dose Per Cask, person-rem/cask =	0 0075
Cask Capacity, megacuries/cask =	0 2
Gross Cask Weight, pounds =	12,000
Cask Rental Fee, $/cask/day =	1,250.00
Disposal Volume, cubic feet =	54 00
Container Cost, $/container =	7,825 00

Transportation Charges

Shipment Weight, lbs/shipment =	40,000
Base Fee, $/shipment =	800.00
Shipment Miles, one-way =	1,000
Miles Per Day =	500
Cost Per Mile, $/mile =	2 44

Waste Disposal Fees at U S Ecology, Richland, Washington

Basic Disposal Fee, $/cu ft =	28 30
Liner Surcharge, $/liner =	207 60
Curie Surcharge, $/cask =	7,058 60
Curie Excess Fee, $/curie > 15 kCi =	0 336
Cask Handling Fee, $/cask =	25,000
Site Volume Surcharge, $/cu.ft =	9.83
Site Adder Surcharge, % of = rates & charges	6.50%

[illegible] Reference Irradiator

The costs of post-accident cleanup can be substantially larger than the costs of decommissioning. Assurance of funds for post-accident cleanup activities is more properly covered by the use of insurance. Post-accident cleanup activities are broader in scope than decommissioning; that is, they can lead ultimately to either reuse or decommissioning. Funding requirements for accident cleanup could be stipulated such that licensees of large irradiator facilities obtain insurance to cover decontamination and cleanup costs associated with onsite property damage resulting from an accident. Because this insurance would be necessary to operate the irradiator and the cost of such insurance premiums would be ongoing during the operational period of the irradiator facility, these costs should be considered operational costs and not a decommissioning cost.

The International Nutronics, Inc. (INI) large irradiator facility, located near Dover, New Jersey, experienced such an accident in 1982 while cleaning up pool contamination resulting from a leaking cobalt-60 source. During unattended cleanup operations at the facility, a pool cleanup system line broke and contaminated pool water was released to the facility floors and to the soil outside. The Lexington Insurance Company paid for the majority

Table 4.7 Irradiator decommissioning costs and radiation doses—source disposal at Barnwell, South Carolina

Source activity (MCI)	Labor (person-hrs)	Dose (person-rem)	Total source removal costs ($)	Number of casks	Cask rental cost ($)	Packaging costs ($)	Number of shipments	Transportation costs ($)	Barnwell disposal costs ($)	Total D&D costs ($)
0.5	154.7	0 0225	23,208	3	8,240	23,475	1	3,240	682,255	740,418
1	172 0	0 0375	25,800	5	10,400	39,125	2	6,480	1,137,092	1,218,897
2	215.2	0.0750	32,280	10	15,800	78,250	4	12,960	2,274,185	2,413,475
4	301.6	0.150	45,240	20	26,600	156,500	7	22,680	4,548,369	4,799,389
6	388.0	0.225	58,200	30	37,400	234,750	10	32,400	6,822,554	7,185,304
8	474 4	0.300	71,160	40	48,200	313,000	14	45,360	9,096,739	9,574,459
10	560.8	0.375	84,120	50	59,000	391,250	17	55,080	11,370,923	11,960,373
12	647.2	0 450	97,080	60	69,800	469,500	20	64,800	13,645,108	14,346,288

Assumptions:

Source Removal from Clean Facility

Crew Size, persons =	2
Crew Labor Rate, $/hour =	300 00
Hours Per Shift =	10.00
Hours Per Job =	64 40
Hours Per Cask =	4.32
Dose Per Cask, person-rem/cask =	0 0075
Cask Capacity, megacuries/cask =	0.2
Gross Cask Weight, pounds =	12,000
Cask Rental Fee, $/cask/day =	1,250 00
Disposal Volume, cubic feet =	54 00
Container Cost, $/container =	7,825.00

Transportation Charges

Shipment Weight, lbs/shipment =	40,000
Base Fee, $/shipment =	800 00
Shipment Miles, one-way =	1,000
Miles Per Day =	500
Cost Per Mile, $/mile =	2.44

Waste Disposal Fees at Chem-Nuclear, Barnwell, South Carolina

Base Disposal Charge, $/cu.ft =	59.00
Weight Surcharge, $/container =	1,685.00
Curie Surcharge Max, $/cask =	200,000
Cask Handling Charge, $/cask =	15,000
SE Compact Fee, $/cu ft. =	74.00
Barnwell Surcharge, % of = rates & charges	2.40%

(shaded) Reference Irradiator

of the cleanup and facility decommissioning costs, about $2 million, resulting from that accident.[2]

4.2 Decommissioning of Reference Sealed Sources

Estimated labor requirements, occupational radiation doses, and total costs for decommissioning the reference devices that use sealed sources are summarized in this section, using unit cost and labor data described in Appendix D. The reference devices described in this section include:

- a device that contains an x-ray sealed source
- a device that contains a low-intensity beta-gamma sealed source
- a device that contains a high-intensity beta-gamma sealed source
- a device that contains an americium sealed source
- a device that is used by the medical industry.

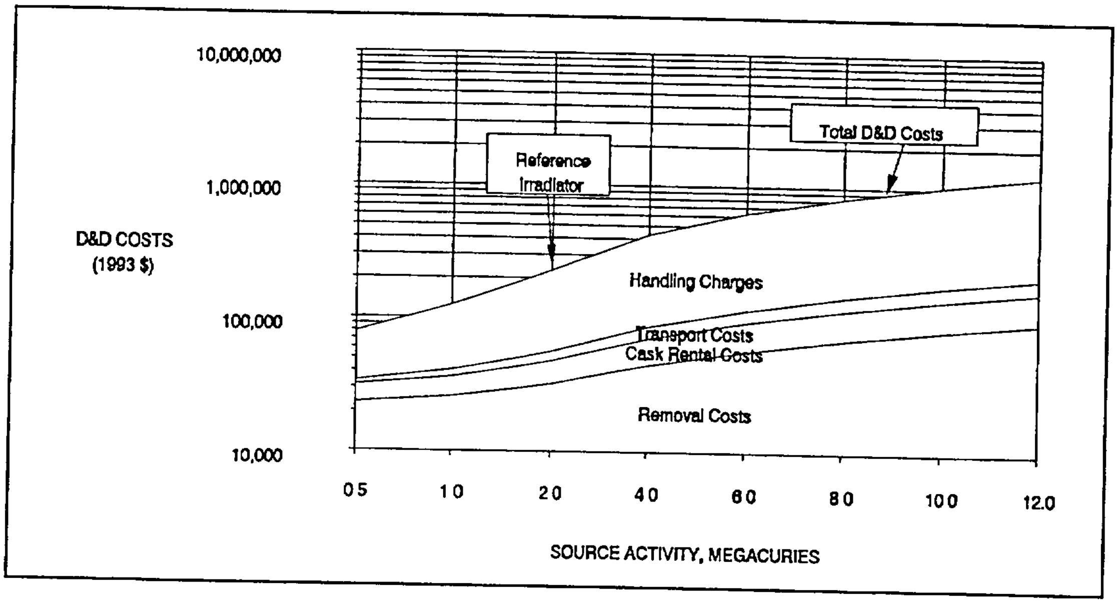

Figure 4.2 Irradiator decommissioning costs—source return to supplier

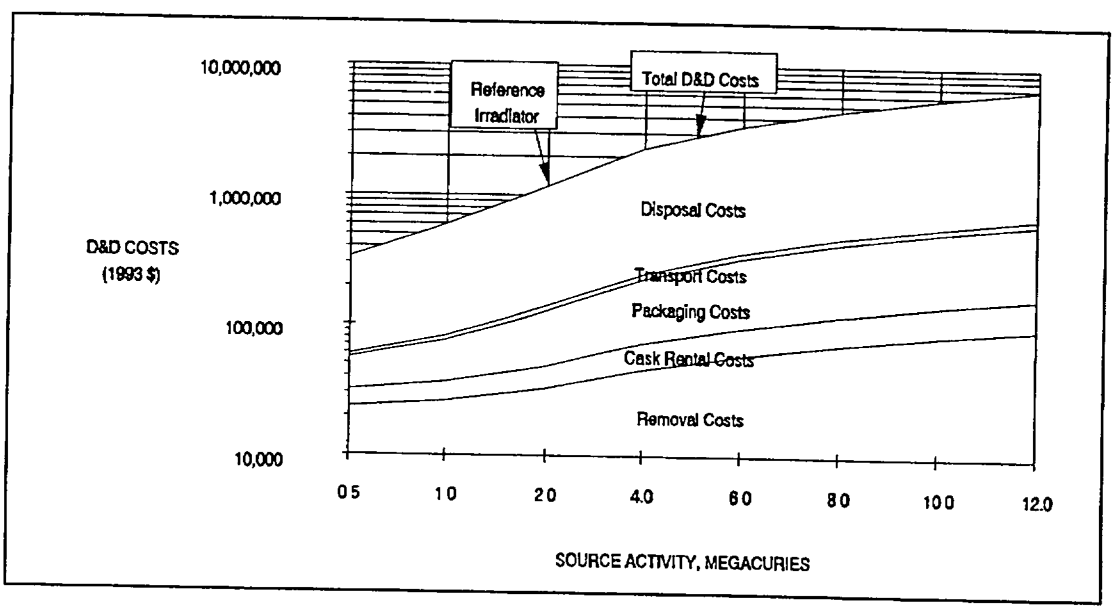

Figure 4.3 Irradiator decommissioning costs—source disposal at Richland, Washington

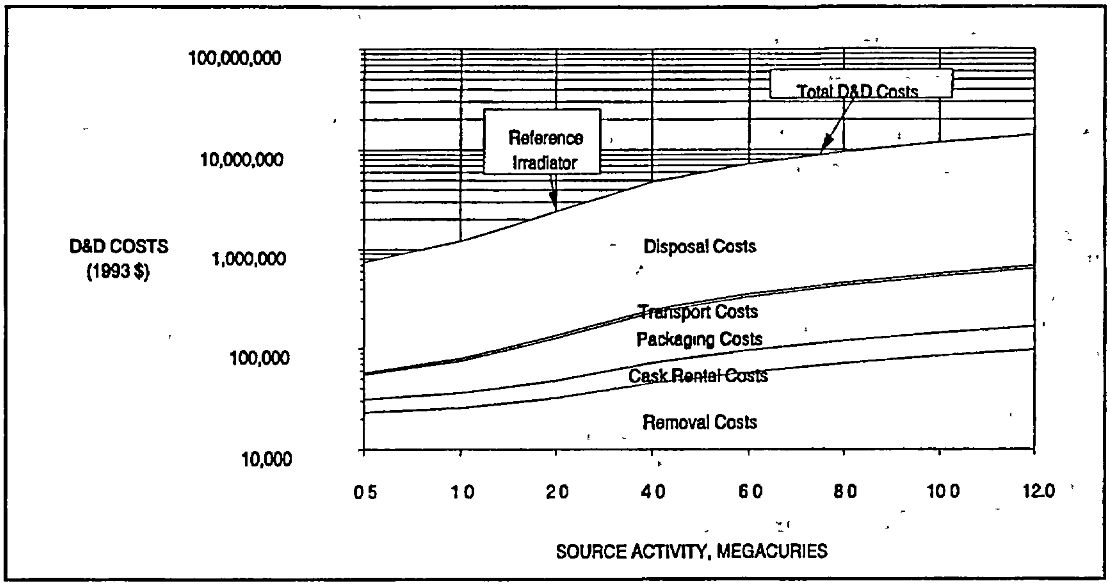

Figure 4.4 Irradiator decommissioning costs—source disposal at Barnwell, South Carolina

The technical approach and some key bases used to define requirements and to estimate costs and safety of decommissioning the five reference devices that use sealed sources are discussed in Sections 4.2.1 through 4.2.8. These discussions include planning and preparation, packaging, transportation, decontamination, storage and disposal.

Detailed analyses results of labor requirements and waste management costs for decommissioning the five reference devices that contain sealed sources are given in Appendix E. A summary of these detailed results is presented in Chapter 5, Discussion of Results and Conclusions.

4.2.1 Planning and Preparation

The decommissioning of a device that contains a sealed source is preceded by a period of planning and preparation that includes activities to ensure that the decommissioning effort is performed in a safe and cost-effective manner in accordance with all applicable federal, state, and local regulations. These planning and preparation activities include: 1) preparation of documentation for regulatory agencies, 2) an initial radiation survey of the device to ensure that the sealed source encapsulation has not been compromised, and 3) the development of a detailed work plan.

For this conceptual study, the planning and preparation for the disposal, transfer, or storage of a sealed source includes a work plan developed by an engineer and reviewed by a supervisor. A contracted radiation protection technician (RPT) would conduct a survey of the device containing the source and surrounding area. A contracted RPT is preferred since most industrial facilities do not employ this type of technician on their staff. The survey would include an onsite technician to check for any physical damage or anomalies with the device. For the purposes of this conceptual decommissioning study, it is assumed that the device would be disposed of with the source.

Documentation for Regulatory Agencies

Before terminating a license, regulatory agencies require documentation concerning the fate of an unwanted source and any associated contamination (Title 10, Code of Federal Regulations, Part 30). Upon receipt of this information, the license for the sealed source will be terminated.

If a sealed source is transferred to another user, or back to the manufacturer, the licensee must verify to the regulating agency that the transferee's license authorizes the receipt of the type, form, and quantity of byproduct material contained in the sealed source (10 CFR 30.41; Transfer of Byproduct Material). The recipient of the sealed source must comply with all requirements for specific licenses or general licenses.

If the source must be stored, the regulating agency should be notified concerning the type of source and activity and how it is stored. If the license should expire, an application for renewal on Form NRC-313 must be submitted.

If the source will be disposed of, the licensee must indicate where the material will be disposed of (10 CFR 30.36, Expiration and Termination of Licenses). In addition, the report should contain the results of a radiation survey that indicates the radiation level of the source.

Where decontamination and decommissioning are required, the following information must be submitted to the NRC (10 CFR 30.36):

- A description of the condition of the site to evaluate the acceptability of the plan
- A description of the planned decommissioning activities
- A description of the methods to ensure protection of workers and the environment against radiation hazards
- A description of the planned final radiation survey
- An updated detailed cost estimate for decommissioning, comparison of that estimate with present funds set aside for decommissioning, and a plan for assuring the availability of adequate funds for completion of decommissioning
- For decommissioning plans calling for completion of decommissioning later than 24 months after plan approval, the plan shall include a justification for the delay.

Development of a Work Plan

A work plan is prepared to guide the performance of the activities for decommissioning a sealed source. The plan should address the following items:

- mission and objectives
- project work scope
- documentation required for decommissioning
- methods and procedures
- schedule of operations
- safety
- quality assurance
- potential problem areas.

4.2.2 Packaging

Wastes generated during decommissioning and decontamination of small sealed sources include:

- the sealed source
- the device containing the sealed source
- combustible and non-combustible trash (protective clothing, contaminated tools, rags, paper, plastic, etc.)
- immobilized liquid from chemical decontamination activities.

Packaging and transportation are regulated principally by the Department of Transportation (DOT) and the NRC. The DOT regulations are found in Title 49 of the Code of Federal Regulations, primarily in 49 CFR Parts 170-178, "Hazardous Material Regulations." The NRC regulations are found in Title 10 of the Code of Federal Regulations, primarily in 10 CFR 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions." These regulations are applicable to both persons who package radioactive materials for shipment and who load and transport such materials. Adherence to the regulations provides protection from hazards of radiation, both to transport workers and the general public.

Disposal at a licensed LLW burial facility is the current method for disposing of these wastes. This requires that the material be properly packaged and transported to the burial site. Because of limited access to burial sites (only two commercial sites are currently operating), interim onsite storage of decommissioning waste may be necessary. In addition, due to the radioactive waste acceptance criteria at the burial facilities, some forms of radioactive waste cannot be buried at these facilities and must be packaged for onsite storage.

For this conceptual study, an individual sealed source or a device containing a sealed source will be packaged into a 55-gallon drum that meets the DOT Specification 7A for Type A packaging. In general, packaging of sealed sources that meets DOT requirements can be buried at an LLW burial facility, assuming that the package and contents meet all disposal criteria. Details for packaging requirements are provided in *Test and Evaluation for DOT Specification 7A Type A Packaging*[7] based on 49 CFR 178.

In packaging an individual sealed source for burial, the source is first placed into a DOT 2-R container. The 2-R container is then centered in a 55-gallon DOT 17-H drum. In the case of neutron sources, the neutron source is placed into a specially designed polyethylene holder designed for insertion into the 2-R container prior to placing the 2-R container into a drum. The drum is then filled with cement and allowed to cure in order to encapsulate the 2-R container. The drum cover is placed on top and sealed with a bolt ring (12 gauge). A final radiological survey is completed to ensure the source has been packaged so that the radiation level at the surface is in compliance with regulatory requirements.

For packaging a device containing a sealed source, the device is first placed into a polyethylene bag (20 mil). It is assumed that the device itself provides adequate attenuation since it was normally used in the workplace on a continual basis. The bag containing the device is then centered in a 55-gallon DOT 17-H drum. The drum is then filled with cement and allowed to cure in order to encapsulate the device and bag. Finally, the drum cover is placed on top and sealed with a bolt ring (12 gauge). A final radiological survey is completed to ensure the source has been packaged so that the radiation level at the surface is in compliance with regulatory requirements.

Waste generated from decommissioning is placed into a 55-gallon drum and stabilized with cement based on DOT criteria. The drum with the waste will either be stored onsite along with the sealed source, or disposed of in a low-level waste burial facility.

4.2.3 Transportation

Decommissioning of a sealed source may require that the sealed source be transported to another user, back to the manufacturer, or to an LLW burial facility. This requires that the radioactive materials be packaged based on regulations that pertain to the packaging and transportation of radioactive materials.

Primary reliance for safety in transportation of radioactive material is placed on the packaging. The DOT regulations prescribe general standards and requirements for all radioactive material packages, and for labeling, handling, and intermediate storage of those packages by carriers.

For packages that contain no significant fissile radioactive material and only small quantities of other radioactive materials, the DOT standards and requirements provide adequate assurance of containment and shielding of the contents. While these small-quantity packages, termed Type A packages, may fail in accident situations, the radiological consequences are minimal because of the limited package contents.

When the radioactivity of a package exceeds the Type A quantity limit, it may be transported in a Type B package. A Type B package must be designed to withstand a series of specified impact, puncture, and fire environments, thus providing reasonable assurance that the package will withstand severe transportation accidents. The design must be independently reviewed by the NRC to verify its accident resistance. Finally, a certificate must be issued by the NRC before a Type B package fabricated from that design can be used to transport radioactive material. The standards that have been established in the DOT and NRC regulations provide that the packaging shall prevent loss or dispersion of the radioactive contents, provide shielding and heat dissipation, and prevent nuclear criticality under both normal and accident conditions of transportation. The normal conditions of transportation that must be considered are specified in the regulations in terms of hot and cold environments, pressure differential, vibration, water spray, impact, puncture, and compression tests. The accident conditions that must be considered are specified in terms of impact, puncture, and fire tests.

For this conceptual study, transportation of the packaged sealed source or device from the facility to the LLW burial facility is assumed to be done by Tri-State Motor Transit Company, which is certified to carry radioactive materials. It is assumed that the package is transported a distance of 800 km to a disposal facility or to a new user or the manufacturer.

4.2.4 Decontamination

Contamination from sealed sources can occur in a variety of ways. For this conceptual study, estimated time and labor requirements, total costs, and occupational radiation doses for decontaminating a device that has a leaking sealed source assumes that the device would only contaminate the device itself and a workbench on which the device was sitting. Workbenches come in a range of sizes. The workbench for which decommissioning requirements and costs are estimated is assumed to be 0.9 m high with a bench top that is 4.6 m long and 0.75 m wide.

The objectives of decontamination are to 1) reduce the radiation contamination levels on the workbench in order to minimize exposure to personnel working in the facility, and 2) to clean as much material as possible to unrestricted use levels thereby allowing reuse of the workbench.

The procedures should follow ALARA (As Low As Reasonably Achievable) principles in consideration of the state of technology and the economic improvement in relation to 1) benefits to the public health and safety, 2) other societal and socioeconomic considerations, and 3) the utilization of atomic energy in the public interest.

Methods to decontaminate surfaces contaminated with radiation such as laboratory workbenches have been reviewed in NUREG/CR-1754.[8,9] These documents provide technical information for decommissioning non-fuel-cycle facilities. Attention is given to laboratory work areas such as workbenches, fume hoods, etc Many of the techniques discussed in these documents have wide applications to decontaminating facility components such as workbenches and fumehoods.

The first step in removal of radioactive contamination is usually the removal of loose or lightly-held contamination using relatively simple "janitorial" techniques such as vacuuming, sweeping, brushing, damp mopping, or scrubbing. Water or a variety of detergents, cleaners, solvents, or other chemicals may be used in mopping or scrubbing steps.

Some chemical decontaminants that are recommended for use on different surfaces are listed in Table 4.8. Several commercially available proprietary compounds have also been used to decontaminate laboratory surfaces and equipment.

Chemical decontaminants should be used with caution in order to avoid the generation of mixed waste. In 40 CFR Part 261, mixed waste is defined as low-level radioactive waste combined with hazardous wastes. It is important to identify the chemical decontaminants to be used prior to decontamination to avoid the generation of mixed waste, if possible. The issue of mixed waste is discussed further in Section 4.2.6.

The most widely used reagents for gross decontamination of surfaces are water and steam. Methods for applying chemical decontaminants to contaminated workbench surfaces include wiping, spraying, soaking, swabbing, scrubbing, and mopping in an enclosed area.

Requirements and costs for decontamination are based on cleaning the bench top and other surfaces to reduce residual surface contamination to unrestricted release levels. These contamination levels are shown in Table 4.15. Decontamination is performed by a work crew consisting of a supervisor and one technician. The total cost for decontamination is estimated to be between \$2,800 and \$3,200, of which \$1,300 is labor. Occupational radiation doses are estimated to range from negligible ($< 3 \times 10^{-10}$ person-rem) to 2×10^{-5} person-rem, depending on the type of contamination. During decontamination, all of the radiation dose to workers is assumed to come from radioactive contamination on the workbench.

Table 4.8 Chemical decontaminants for various surfaces

Surface	Decontaminant
All Surfaces	Steam or water and non-hazardous detergent
	Organic solvents[a]
Stainless Steel	20% HNO_3 - 3% H by weight[a]
	20% sodium hydroxide[b] - 2% tartaric acid[b]
	Complexing agents (EDTA, oxalates[a], carbonates, citrates)
	Alkaline permanganate-ammonium citrate
Carbon Steel	Commercial rust removers[c]
	Inhibited H_3PO_4,1 Molar
	Complexing agents (EDTA, oxalates[a], carbonates, citrates)
Aluminum	Dilute NaOH[b]
	Mixture of citric acid and non-hazardous detergent
	Complexing agents (EDTA, oxalates[a], carbonates, citrates)
Copper, Brass	Dilute HNO_3[a]
	Household and industrial cleaners of copper and brass[c]
	Complexing agents (EDTA, oxalates[a], carbonates, citrates)
Lead	Dilute HNO_3[a]
	Concentrated HCl[b]
Glassware	Chromic Acid[a]
	Concentrated HNO_3[a]
	KOH + EtOH[b]
Floor Tile	Ammonium citrate
	Trisodium phosphate
	Household cleaners containing grit or pumice[c]
Painted Surfaces	Commercial paint removers[c]
	Trisodium phosphate
	Household cleaners containing grit or pumice[c]
	Complexing agents (EDTA, oxalates[a], carbonates, citrates)

(a) Use of this chemical for decontamination will most likely produce mixed waste.
(b) Use of this chemical for decontamination may produce mixed waste.
(c) Further information is required to determine if mixed waste is produced.

4.2.5 Storage of Small Sealed Sources

Currently, some sealed sources cannot be buried in an LLW burial facility or cannot be transferred to a new user or back to the manufacturer. These sealed sources must be stored onsite until a disposal facility may accept them, or until the source can be transferred to another licensed user. Once the use of the source has been terminated, a notice must be sent to the regulating agency (e.g., the NRC or regulating Agreement State) stating that the sealed source use has been terminated and placed into storage, and how the sealed source is to be stored.

A sealed source can be stored in the existing device as long as the device provides adequate attenuation to ensure worker and environmental protection. The device should be checked and surveyed periodically to ensure that no radiation leakage has occurred, and to verify the presence of the source in the device.

The sealed source could also be packaged for disposal but stored onsite. The packaging should meet DOT standards for transportation to a disposal facility. The package should be surveyed periodically to ensure that no radiation leakage has occurred and verify the presence of the source in the device. The primary considerations for storage are to have adequate storage space and to develop a long-term surveillance plan to monitor the sealed source. Additional detailed information for design of storage facilities is provided in *Storage of Radioactive Wastes*.[10]

Waste generators in states without disposal capability must store their sources until their delegated disposal facility opens. Unfortunately, the waste acceptance criteria for these unopened facilities have not been developed. The possibility exists that the packaging criteria for disposal of sealed sources at existing disposal facilities may not be applicable at new facilities. For this conceptual study, it is assumed that the packaging criteria at the existing facility will be similar to those at the future facilities. It is also assumed that the sealed source and the device containing the source are packaged for disposal, then stored onsite.

When possible, advantage of natural decay should be taken to avoid disposal of unwanted short-lived radioisotopes by allowing for the isotopes to decay to a non-radioactive risk level.[10] Decay-in-storage is normally applied to routinely segregated LLW from user hospitals, universities, research laboratories and other institutions that commonly use Mo-99 (66 hr), I-131 (8 days), or I-125 (60 days). A medical licensee may hold byproduct material with a physical half-life of less than 65 days for decay-in-storage before disposal in ordinary trash if the licensee complies with the following requirements (10 CFR 35.92):

- Holds byproduct material for decay a minimum of ten half-lives
- Monitors byproduct material at the container surface before disposal as ordinary trash and determines that its radioactivity cannot be distinguished from the background radiation level with a radiation detection survey meter set on its most sensitive scale and with no interposed shielding
- Removes or obliterates all radiation labels
- Separates and monitors each generator column individually with all radiation shielding removed to ensure that it has decayed to background radiation level before disposal.
- Retains a record of each disposal for three years. The record must include the date of the disposal, the date on which the byproduct material was placed in storage, the radionuclides disposed, the survey instrument used, the background dose rate, the dose rate measured at the surface of each waste container, and the name of the individual who performed the disposal.

4.2.6 Disposal of Small Sealed Sources

The subject of LLW disposal has become an extremely complicated issue during the past 15 years. In 1980, the United States Congress passed the Low-Level Radioactive Waste Policy Act making each state responsible for its own LLW. The three states that had a low-level waste burial facility in 1980 (Nevada, South Carolina, and Washington) quickly formed regional compacts with other states. A compact is a group of states that share a common burial facility within one of their member states. States that do not belong to a compact are called unaligned states and are responsible for siting an LLW burial facility within their borders. Table 4.9 lists the compacts, their member states, and the unaligned states.

Table 4.9 List of compacts, member states, and unaligned states

Compact	Member states
Northeast	Connecticut, New Jersey
Appalachian	Delaware, Maryland, Pennsylvania, West Virginia
Southeast	Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, Virginia
Central States	Arkansas, Kansas, Louisiana, Nebraska, Oklahoma
Midwest	Indiana, Michigan, Minnesota, Missouri, Iowa, Ohio, Wisconsin
Central Midwest	Illinois, Kentucky
Rocky Mountain	Colorado, Nevada, New Mexico, Wyoming
Southwest	Arizona, California, North Dakota, South Dakota
Northwest	Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington
Unaligned States	Maine, Massachusetts, New Hampshire, New York, Puerto Rico, Rhode Island, Texas, Vermont, Virgin Islands, Washington DC

The Northwest Compact will only accept LLW from its own member states, and from states who are members of the Rocky Mountain Compact. The Southeast Compact will accept waste from all other states except North Carolina.

Low-level radioactive waste is categorized in three classes (A, B, and C), as defined in 10 CFR 60. The classification of waste is dependent on the radionuclides and concentrations. Each LLW burial facility must adhere, as a minimum, to the 10 CFR 60 concentration limits. Radionuclides that exceed the Class C limits are categorized as Greater-Than-Class-C (GTCC) low-level waste. The disposal of GTCC low-level waste has become the responsibility of the Department of Energy. As of this date, the DOE has not established a procedure for disposal of GTCC low-level waste and has no operating disposal site. Hence, sources classified as GTCC low-level waste are generally stored by the licensee until disposal becomes available, or in some cases, the manufacturer may accept GTCC sealed sources. Waste brokers generally do not accept GTCC sealed sources.

Each LLW burial facility possesses an operating license issued by its respective state regulatory agency. This license specifies the concentration limits of radionuclides that can be disposed of at the facility. One of the primary differences between the U.S. Ecology facility and the Chem-Nuclear facility is in the activity concentration averaging allowed.. At the U.S. Ecology burial facility, the sealed source activity may be averaged over the solidification matrix containing the sealed source, but not at the Chem-Nuclear facility. Averaging the activity of the sealed source over the total volume of the solidification matrix is consistent with the Technical Position taken by the NRC stating "..large sealed source is solidified with a 55-gallon drum using a binder such as cement or bitumen ... a solid mass within the container and the waste classification volume may be considered to be the volume of the solidified mass."(11)

For this conceptual study, it is assumed that the sealed source and the waste generated during decontamination procedures are generated within the Northwest or Rocky Mountain Compact, and will be disposed of at the LLW burial facility located at Richland, Washington. The sealed source and/or device are placed into a 55-gallon drum acceptable for burial by solidifying with cement. The activity of the sealed source, therefore, may be averaged over the volume of the solidification matrix.

Mixed Wastes

In cases where decontamination procedures require the use of chemicals, a review of the Resource Conservation and Recovery Act (RCRA) should be done to ensure that the chemicals used do not generate mixed waste. The Environmental Protection Agency (EPA), under RCRA, promulgated a listing of hazardous materials banned from land disposal based on characteristics of ignitability, corrosivity, reactivity, and toxicity (40 CFR Part 261). Low-level radioactive waste with these additional characteristics is known as "mixed waste." It is generated by virtually all types of users of radionuclides and consists of radioactively-contaminated organic solvents, oils, lead shielding, and chromate solutions.(12)

Mixed wastes present land burial problems because the nonradioactive components are hazardous and may promote the mobility of radionuclides. They also present problems to regulatory authorities since these wastes are under the authority of the EPA, NRC, and different state agencies under different statutes. It is now the responsibility of generators to identify and properly manage mixed wastes. At present, disposal options do not exist for mixed wastes, nor may they be legally stored by the generator for more than 90 days unless the facility has an RCRA Part B permit, which is difficult to obtain.

If mixed wastes may be generated due to decontamination procedures, it is recommended, if reasonable, that the contaminated components and surfaces be packaged for disposal without decontamination to avoid the generation of mixed wastes.

4.2.7 Cost Estimates

Estimates of cost for storage, disposal, and transfer are made for each type of sealed source. Decontamination of a leaking sealed source is considered for the storage and disposal options. Costs include labor, equipment, supplies, and waste management costs. A summary of the cost estimates is provided for each of the five sealed source types in Tables 4.10 through 4.14. Some key bases and assumptions for estimating costs are given in Appendix D. The costs for decommissioning sealed sources are expressed in 1993 dollars. The total costs include a 25% contingency.

Labor costs are determined by multiplying the person-hours required to decommission a component by the labor rates provided in Appendix D, Table D.1. To determine the total time required to decommission a device, an

Table 4.10 Summary of decommissioning costs for storage, transfer, and disposal of Fe-55 Sources

	Cost in dollars				
Cost item	Ship to new user or manufacturer	Disposal	Disposal w/decon	Storage	Storage w/decon
Labor	813	1,006	2,399	1,557	2,862
Equipment & Supplies	100	276	952	100	952
Waste Management					
Packaging	41	109	214	41	214
Transportation	1,213	1,213	1,213		
Storage				500	750
Disposal		1,137	1,210		
Subtotals	2,167	3,741	5,988	2,198	4,779
25% Contingency	542	935	1,497	549	1,195
Total	2,709	4,677	7,484	2,747	5,973

Table 4.11 Summary of decommissioning costs for storage, transfer, and disposal of Ni-63 sources

Cost item	Cost in dollars				
	Ship to new user or manufacturer	Disposal	Disposal w/decon	Storage	Storage w/decon
Labor	813	1,006	2,399	1,557	2,862
Equipment & Supplies	100	276	952	100	952
Waste Management					
Packaging	41	109	214	41	214
Transportation	1,213	1,213	1,213		
Storage				500	750
Disposal		1,137	1,210		
Subtotals	2,167	3,741	5,988	2,198	4,779
25% Contingency	542	935	1,497	549	1,195
Total	2,709	4,677	7,484	2,747	5,973

Table 4.12 Summary of decommissioning costs for storage, transfer, and disposal of Cs-137 sources

Cost item	Cost in dollars				
	Ship to new user or manufacturer	Disposal	Disposal w/decon	Storage	Storage w/decon
Labor	813	1,006	2,399	1,557	2,862
Equipment & Supplies	100	276	952	100	952
Waste Management					
Packaging	41	109	214	41	214
Transportation	1,213	1,213	1,213		
Storage				500	750
Disposal		1,137	1,210		
Subtotals	2,167	3,741	5,988	2,198	4,779
25% Contingency	542	935	1,497	549	1,195
Total	2,709	4,677	7,484	2,747	5,973

estimate is made of the time required for efficient performance of the work by a postulated work crew. These time estimates are increased by 50% to provide for preparation and set-up time, rest periods, etc. (ancillary time). Detailed time and labor estimates are presented in Appendix E.

The time required to complete a particular decommissioning task is usually estimated on the basis of a work crew consisting of a supervisor and two technicians. The

Table 4.13 Summary of decommissioning costs for storage and transfer of Am-241 sources

Cost item	Cost in dollars		
	Ship to new user or manufacturer	Storage	Storage w/decon
Labor	813	1,557	2,862
Equipment & Supplies	100	100	952
Waste Management			
Packaging	41	41	214
Transportation	1,213		
Storage		500	750
Subtotals	2,167	2,198	4,779
25% Contingency	542	549	1,195
Total	2,709	2,747	5,973

Table 4.14 Summary of decommissioning costs for storage and transfer of I-125 sources

Cost Item	Cost in Dollars		
	Ship to new user or manufacturer	Storage	Storage w/decon
Labor	813	1,213	2,515
Equipment & Supplies	100	100	952
Waste Management			
Packaging	41	41	214
Transportation	1,213		
Storage		200	300
Subtotals	2,167	1,554	3,985
25% Contingency	542	388	996
Total	2,709	1,942	4,981

technicians are assumed to have some experience working with radiochemicals, and be trained in radiological safety procedures. A radiation protection technician is assumed to be contracted during decommissioning.

Decontamination of a workbench contaminated by a leaking source is assumed to be performed by employees of the licensee of the sealed source. Workbenches contaminated with radionuclides are decontaminated with chemical surfactants. Radiation survey equipment and equipment for the analysis of the wipe samples is assumed to be provided by the radiation protection technician and not chargeable to decommissioning.

Waste management costs include container costs, transportation costs, storage costs, and waste disposal costs. Due to the uncertainty of transportation, it is assumed that one truck would be contracted to transport the device a distance of 800 km for either transfer or disposal. It is assumed that materials from decontamination and for disposal will be packaged in 55-gallon steel drums. Sources to be transferred or stored are packaged in 20-gallon poly containers. Because transportation and waste disposal activities are contracted activities, labor costs for the transportation and disposal of radioactive wastes are included in the total costs of these items.

The neutron/x-ray sealed source (Am-241) is considered a Greater-Than-Class-C (GTCC) source as it exceeds the definitions of Class A, B, and C waste listed in the waste classification in 10 CFR 61.55. The Department of Energy has the responsibility for disposing of GTCC sources.(13) Currently, the U.S. Ecology LLW disposal facility will accept small amounts material with a concentration up to 100 nanocuries/gram, with prior approval. Therefore, the reference device with a 50 mCi Am-241 source could not be disposed of at the U.S. Ecology facility and would be stored until an approved disposal facility that accepts GTCC waste has opened. For this study, the cost estimate made assumed that the source would be stored onsite for a 5-year period.

The cost estimates for the I-125 medical sealed source and the neutron/x-ray sealed source do not consider the disposal of these sources. The licensee of an I-125 medical sealed source may hold this radioactive material for 10 half-lives (600 days for I-125), before disposing of the source into ordinary trash (10 CFR 35.92). For this study, it was assumed that the source would be stored onsite for a period of 2 years.

4.2.8 Occupational Radiation Dose Estimates

Estimates of occupational radiation dose are made for each sealed source assuming that the sealed source is contained in the device (no leaks), and for the decontamination option (sealed source has leaked). The estimated worker dose rates for direct exposure and inhalation exposure are listed in Table 4.15. For this conceptual decommissioning

Table 4.15 Estimated exposures during decontamination of sealed sources

Radionuclide	Fe-55	Ni-63	Cs-137	Am-241	I-125
Estimated Dose Rate for Uncontaminated Device (mrem/hr)	0.2	0.2	20.5	20.5	0.2
Assumed Surface Contamination Level (d/m/100 cm^2)	2×10^3	2×10^3	5×10^3	5×10^1	2×10^3
Allowable Contamination Limits for Unrestricted Release(14) (d/m/100 cm^2)	10^3	10^3	10^3	2×10^1	2×10^1
Exposure Estimates during Packaging					
Direct Exposure (mrem)	0.00×10^{-0}	0.00×10^{-0}	2.25×10^{-3}	1.13×10^{-6}	1.64×10^{-5}
Inhalation Exposure (mrem)	3.51×10^{-7}	9.29×10^{-7}	1.17×10^{-5}	1.64×10^{-3}	8.37×10^{-7}
Total Exposure during Packaging (mrem)	3.51×10^{-7}	9.29×10^{-7}	2.27×10^{-3}	1.64×10^{-3}	1.73×10^{-5}
Exposure Estimates during Decontamination					
Direct Exposure (mrem)	0.00×10^{-0}	$0\,00 \times 10^{-0}$	1.39×10^{-2}	6.95×10^{-6}	1.01×10^{-4}
Inhalation Exposure (mrem)	2.16×10^{-6}	5.73×10^{-6}	7.20×10^{-5}	1.01×10^{-2}	5.16×10^{-6}
Total Exposure during Decontamination (mrem)	2.16×10^{-6}	5.73×10^{-6}	1.40×10^{-2}	1.01×10^{-2}	1.07×10^{-4}
Total Exposure during Decontamination and Packaging					
Total Exposure (mrem)	2.51×10^{-6}	6.66×10^{-6}	1.62×10^{-2}	1.18×10^{-2}	1.24×10^{-4}

study, it is assumed that no exposure occurs through ingestion. These dose rates are in reasonable agreement with experience at typical radioactive material processing and use laboratories.

The worker dose rates were estimated using dose rate conversion factors to estimate exposures for evaluating conditions of unrestricted release of slightly radioactive material in buildings and soil following decommissioning of licensed facilities. Models and assumptions used to calculate the worker dose rate conversion factors given in Table 4.15 are described in NUREG-1500.[15] Dose rate calculations are based on residual contamination levels remaining on the surface of the workbench. Representative values are used for resuspension rates, worker breathing rates, and dose conversion factors.

Most of the dose rates listed in Table 4.15 are very small; many are not considered significant. Because of the potentially significant inhalation rates associated with decommissioning components contaminated with Am-241, it may be necessary for persons involved in decontaminating the workbench to be equipped with protective respiratory equipment. The use of such equipment would reduce inhalation exposure by one or two orders of magnitude.

4.3 References

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5 Discussion of Results and Conclusions

The results and conclusions of this study are provided in this chapter. The majority of the large irradiator and sealed source licensees have facilities and devices that do not require any major decommissioning effort. For most licensees, the transfer or disposal of the radioactive sealed sources, a radiation survey of the facility, and a notice to the regulatory agency certifying that all sources have been accounted for may constitute the necessary decommissioning actions.

5.1 Results of Large Irradiator Decommissioning Analysis

The major conclusions of the large irradiator decommissioning analysis are summarized below and in Table 5.1.

- Decommissioning costs vary over a wide range from hundreds of thousands dollars, if the sources are returned to the supplier, to a few million dollars with the major factor being the cost for disposal of the sealed sources as low-level radioactive waste.
- Decommissioning of large irradiator facilities, whether clean or contaminated, can be accomplished with a minimum of radiation dose to decommissioning workers and with no significant impact to the general public.
- Decommissioning of large irradiator facilities can be accomplished using currently available technology.

5.1.1 Large Irradiator Decommissioning Costs

Decommissioning cost estimates for the reference large irradiator range from \$231,000 (\$289,000 with 25% contingency) for the most likely decommissioning option to \$2.4 million (\$3.0 million with contingency) for the most expensive waste disposal option. Additional costs of about \$92,000 (\$115,000 with contingency) to clean up a contaminated facility (medium contamination level) caused by sealed source leakage may also be incurred. The most likely decommissioning option is returning the sealed sources to the supplier (or another potential user). If that option cannot be exercised, disposal of the sealed sources in an approved LLW burial facility would be required.

Interim storage of the sealed sources, either at the licensee's irradiator facility storage pool or in a shielded container, is a possible alternative in lieu of the expensive disposal fees at an LLW disposal facility. Both the Richland and the Barnwell disposal facilities apply a curie surcharge for high-activity, low-level wastes (see Appendix A for waste disposal rate schedules). These curie surcharges constitute the most significant portion of the disposal costs. Because of the short half-life of cobalt-60 (5.27 years), it may be more cost-effective to temporarily place the spent sealed sources in interim storage until the activity level has decreased.

5.1.2 Radiation Dose to Occupational Workers and to the Public from Large Irradiator Decommissioning

Occupational radiation dose to decommissioning workers in most instances (clean facility) should be minimal and nearly the same as expected during operation when the sealed source inventory is replenished. Normal dose rate during the exchange of depleted sealed sources with fresh sources (performed underwater) is estimated to be 0.0075 person-rem per cask. Loading of the sealed sources from the reference large irradiator would require 10 casks, therefore resulting in a total occupational radiation dose of 0.075 person-rem.

Additional radiation dose, incurred during cleanup if the facility was contaminated, would also be minimal. Dose rates for all decommissioning operations should not exceed 2 mrem/hr. For the medium pool contamination scenario (2,000 pCi/ml), the maximum total occupational radiation dose accumulated during cleanup is estimated to be 1.128 person-rem.

The impact to the public from decommissioning the reference large irradiator in terms of radiation dose would be several orders of magnitude less than the impact to the decommissioning workers. Transportation of the sealed sources and any radioactive wastes generated during

Table 5.1 Summary of reference large irradiator decommissioning analysis

		Total cost (1993 $K)	Total cost (with 25% contingency)	Total person-hours	Total dose (person-rem)
Clean facility					
Return sources to supplier		231 0	288.8	215	0 075
Dispose of sources	- Richland Site	1,167	1,458	215	0 075
	- Barnwell Site	2,413	3,017	215	0 075
Contaminated facility (In addition to above)					
Clean up facility	- low contamination	75 7	94 6	502	1 004
	- medium contamination	92.0	115 0	564	1.128
	- high contamination	118 9	148 6	665	1 331

decommissioning would meet Department of Transportation packaging and transportation regulations and thereby result in negligible impact to the public.

5.2 Results of Sealed Source Decommissioning Analysis

The results of analyses of the labor requirements, total costs, and occupational doses for decommissioning small sealed sources are presented in this section. The analyses performed for the various components include disposal, decontamination, and storage. Total costs include the cost of labor, equipment and supplies, and waste management (e g., packaging, transportation, storage, or disposal of radioactive waste).

Five scenarios for decommissioning small sealed sources are investigated in this section for each reference device. The scenarios include:

- Ship back to the manufacturer or to a new user
- Disposal at a low-level radioactive waste burial facility
- Decontamination of a workbench, then disposal at a low-level radioactive waste burial facility
- Onsite storage of the sealed source
- Decontamination of a workbench, then onsite storage of the sealed source and waste generated from decontamination activities.

The unit costs used in the analyses of decommissioning sealed sources are presented in Appendix D. The estimated labor requirements, total costs, and occupational doses associated with decommissioning sealed sources via disposal at an LLW burial facility, or storage onsite and decontamination, are shown in Table 5.2, summarized from Tables 4.10 through 4.15 and Appendix E. Costs for the decontamination option are based on the decontamination of a workbench contaminated by a leaking sealed source, allowing release for unrestricted use.

The estimated total cost to decommission a sealed source ranged from about $2,000 up to $7,500, depending on the decommissioning option, as shown in Table 5.2. About one-half of the labor cost results from radiation surveys needed to establish residual contamination levels prior to starting decommissioning procedures, to verify compliance with DOT packaging requirements, and for final surveys to confirm achieving unrestricted release guidelines when decontamination is completed. The decontamination alternative increased the decommissioning cost by a factor of two due to the increase of labor requirements, packaging, storage, and disposal costs.

About one third of the cost to dispose of a sealed source is attributed to disposal charges at the U.S. Ecology facility located at Richland, Washington. If the sealed source were to be disposed of at the Chem-Nuclear facility located at Barnwell, South Carolina, the disposal fee would increase by a factor of 2.7 above the cost of disposal at the U.S. Ecology facility.

Table 5.2 Summary of reference small sealed sources decommissioning analysis

Item	Ship to new user or manufacturer	Disposal	Disposal w/decon	Storage	Storage w/decon
X-ray sealed source, radionuclide: Fe-55					
Labor (person-hrs)	25	31	77	43	86
Costs (thousand $)	2.7	4.7	7.5	2.7	6.0
Occupational dose (person-rem)	Negligible	3.51×10^{-10}	2.51×10^{-9}	3.51×10^{-10}	2.51×10^{-9}
Low-intensity beta-gamma sealed source, radionuclide: Ni-63					
Labor (person-hrs)	25	31	77	43	86
Costs (thousand $)	2.7	4.7	7.5	2.7	6.0
Occupational dose (person-rem)	Negligible	9.29×10^{-10}	6.66×10^{-9}	9.29×10^{-10}	6.66×10^{-9}
High-intensity beta-gamma sealed sources, radionuclide: Cs-137					
Labor (person-hrs)	25	31	77	43	86
Cost (thousand $)	2.7	4.7	7.5	2.7	6.0
Occupational dose (person-rem)	Negligible	2.27×10^{-6}	1.62×10^{-5}	2.27×10^{-6}	1.62×10^{-5}
Neutron/x-ray sealed sources, radionuclide: Am-241					
Labor (person-hrs)	25	N/A	N/A	43	86
Cost (thousand $)	2.7	N/A	N/A	2.7	6.0
Occupational dose (person-rem)	Negligible	N/A	N/A	1.64×10^{-6}	1.18×10^{-5}
Medical source, radionuclide: I-125					
Labor (person-hrs)	25	N/A	N/A	35	78
Cost (thousand $)	2.7	N/A	N/A	1.9	5.0
Occupational dose (person-rem)	Negligible	N/A	N/A	1.73×10^{-8}	1.24×10^{-7}

6 Glossary

Absorbed dose	The energy imparted to matter in a volume element by ionizing radiation divided by the mass of irradiated material in that volume element. The SI derived unit of absorbed dose is the gray (Gy); 1 Gy = 100 rads = 1 J/kg (also commonly called "dose").
Activity	The number of spontaneous nuclear disintegrations occurring in a given quantity of material during a suitably small interval of time divided by that interval of time. The unit of activity is the curie (Ci) (also called the disintegration rate).
Agreement States	States that have entered into an agreement with the NRC that allows each state to license and regulate organizations using radioactive materials for certain purposes.
Byproduct material	Any radioactive material (except source material and special nuclear material) obtained incidentally during the production or use of source or special nuclear material.
Carrier	A container mounted on the product conveyor system into which the product is loaded.
Cask	A tightly sealing, heavily shielded, reusable shipping container for radioactive materials.
Cask liner	A tightly sealing, disposable metal container used inside a cask for shipping radioactive materials.
Code of Federal Regulations (CFR)	A codification of the general rules by the executive departments and agencies of the Federal government. The Code is divided into 50 Titles that represent broad areas subject to federal regulation. Each Title is divided into Chapters that usually bear the name of the issuing agency. Each Chapter is further subdivided into Parts covering specific regulatory areas.
Contamination	Undesired (e.g., radioactive or hazardous) material that is 1) deposited on the surfaces of, or internally ingrained into, structures or equipment, or 2) mixed with another material.
Curie (Ci)	A unit of radioactivity measured in disintegrations per unit time. One curie = 3.7×10^{10} disintegrations per second (dps).
Decay, radioactive	A spontaneous nuclear transformation in which charged particles and/or gamma radiation are emitted.

Decommission	To remove (as a facility) safely from service and reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of license.
Decontamination	Those activities employed to reduce the levels of contamination in or on structures, equipment, and materials.
Deep geologic disposal	Placement of radioactive materials in stable geologic formations far beneath the earth's surface, to isolate them from the environment.
Disposal	The disposition of materials with the intent that they will not enter the environment in sufficient amounts to cause a significant health hazard.
Dose rate, absorbed	The increment in absorbed dose during a suitably small interval of time divided by that interval of time.
Dosimeter	An instrument used for measuring or evaluating the absorbed dose, exposure, or similar radiation quantity.
Doubly encapsulated sealed source	A sealed source in which the radioactive material is sealed within a capsule and that capsule is sealed within another capsule.
Exposure	For x or gamma radiation in air, the sum of the electrical charges of all of the ions of one sign produced in air when all electrons liberated by photons in a suitably small element of volume of air are completely stopped in air, divided by the mass of the air in the volume element. It is commonly expressed in roentgens, but the SI unit of exposure is coulombs per kilogram, where 1 R = 2.58×10^{-4} C/kg exactly.
Fission	The splitting of a heavy atomic nucleus into two or more nearly equal parts (nuclides of lighter elements), accompanied by the release of a relatively large amount of energy and (generally) one or more neutrons. Fission can occur spontaneously, but usually it is caused by nuclear absorption of gamma rays, neutrons, or other particles.
Gamma rays	Short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense material such as lead or uranium. The rays are similar to x-rays, but are nuclear in origin, i.e., they originate from within the nucleus of the atom.
Gray	A unit of absorbed dose; 1 Gy = 1 J/kg = 100 rads.
Half-life, radioactive	For a single radioactive decay process, the time required for the activity to decrease to half its value by the process.

Health physicist	A person trained to perform radiation surveys, oversee radiation monitoring, estimate the degree of radiation hazard, and advise on operating procedures for minimizing radiation exposure.
Hot spot	An area of radioactive contamination of higher than average concentration.
Ion exchange	A chemical process involving the selective adsorption (and subsequent desorption) of certain chemical ions in a solution onto a solid material, usually a plastic or resin. The process is used to separate contaminants from process streams, purifying them for reuse or disposal.
Irradiation	Exposure to ionizing radiation.
Irradiator	A facility that uses radioactive sealed sources for the irradiation of objects or materials and in which radiation doses exceeding 500 rads per hour exist at 1 meter from the sealed radioactive sources in air or water, as applicable for the irradiator type, but does not include irradiators in which both the sealed source and the area subject to irradiation are contained within a device and are not accessible to personnel.
Low-level waste	Wastes containing low but not hazardous quantities of radionuclides and requiring little or no biological shielding; low-level wastes generally contain no more than 100 nanocuries of transuranic material per gram of waste. These wastes are presently classified as Classes A, B, C, and Greater-Than-Class C in 10 CFR 61.
Low-level waste burial ground	An area specifically designated for shallow subsurface disposal of solid radioactive wastes to temporarily isolate the waste from the environment.
Monitoring	Making measurements or observations so as to recognize the status or adequacy of, or significant changes in, conditions or performance of a facility or area.
Nuclide	A species of atom characterized by its mass number, atomic number, and nuclear energy state provided the mean life in that state is long enough to be observable.
Occupation dose (regulatory)	Dose (or dose equivalent) resulting from exposure of an individual to radiation in a restricted area or in the course of employment in which the individual's duties involve exposure to radiation (see 10 CFR 20.3).
Offsite	Beyond the boundary line marking the limits of plant property.
Onsite	Within the boundary line marking the limits of plant property.

Overlap	An irradiator design with source rack overlapping the carrier resulting in more uniform dose of the product.
Package	The packaging plus the contents of radioactive materials.
Packaging	The assembly of radioactive material in one or more containers and other components as necessary to ensure compliance with applicable regulations.
Panoramic wet source storage irradiator	An irradiator in which the irradiations occur in air in areas potentially accessible to personnel and in which the sources are stored under water in a storage pool.
Person-rem	Used as a unit measure of population radiation dose, calculated by summing the dose equivalent in rem received by each person in the population. Also, it is used as the absorbed dose of one rem by one person, with no rate of exposure implied
Product	The objects of materials which are intentionally irradiated in a commercial or research facility.
Product conveyor system	A system for moving the product to be irradiated to, from, and within the area where irradiation takes place.
Rad	A special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joules/kilogram.
Radiation	1) The emission and propagation of radiant energy: for instance, the emission and propagation of electromagnetic waves or photons. 2) The energy propagated through space or through a material medium: for example, energy in the form of alpha, beta, and gamma emissions from radioactive nuclei.
Radiation area	Any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive a dose in excess of 5 millirem in any one hour, or a dose in excess of 100 millirem in any 5 consecutive days. (See 10 CFR 20.202.)
Radiation survey (radiation protection)	An evaluation of the radiation hazard potential associated with a specified set of conditions incident to the production, use, release, storage, or presence of radiation.
Radiation room	A shielded room in which irradiations take place.
Radioactive material	Any material or combination of materials that spontaneously emits ionizing radiation and has a specific activity in excess of 0.002 microcuries per gram of material. [See 49 CFR 173.389(e).]

Radioactivity	The property of certain nuclides of spontaneously emitting particles or gamma radiation or of emitting x radiation following orbital electron capture or of undergoing spontaneous fission.
Radionuclide	A radioactive nuclide.
Rem	A special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors (originally derived from roentgen equivalent man).
Restricted area	Any area to which access is controlled for protection of individuals from exposure to ionizing radiation and radioactive materials.
Sealed source	Radioactive material sealed in a capsule, the capsule being strong enough to prevent dispersion of the radioactive material under the conditions of use for which it is designed.
Shield	A body of material used to reduce the passage of ionizing radiation. A shield may be designated according to what it is intended to absorb (as a gamma-ray shield or neutron shield), or according to the kind of protection it is intended to give (as a background, biological, or thermal shield). A shield may be required to protect personnel or to reduce radiation enough to allow use of counting instruments.
Shuffle mode	The rearrangement of the loaded product for multiple passes through the irradiator.
Shutdown	The time during which a facility is not in productive operation.
Source capsule	See Sealed source.
Source module	The component of the irradiator source rack into which the source capsule is positioned, including any retaining screws, pins, clips, etc.
Source rack	The vertical framework into which the source modules are mounted to form a flat panel array for raising and lowering into the storage pool.
Surface contamination	The deposition and attachment of radioactive materials to a surface. Also, the resulting deposits.
Tote	A container into which the product to be irradiated is loaded into the carrier of the conveyor system.

Waste management	The planning and execution of essential functions relating to radioactive and/or hazardous wastes, including treatment, packaging, interim storage, transportation, and disposal.
Waste, radioactive	Equipment and materials (from nuclear operations) that are radioactive and have no further use. Also called "radwaste."

Appendix A

Cost Estimating Bases for Decommissioning of the Reference Large Irradiator Facility

Appendix A

Cost Estimating Bases for Decommissioning of the Reference Large Irradiator Facility

The key bases and assumptions used in this conceptual decommissioning study of the reference large irradiator facility are identified in Chapter 2, Section 2.1.6. More specific bases and assumptions are presented in Chapter 4, Section 4.1, where the evaluation of the necessary decommissioning is developed. These include labor rates, equipment rental rates, container costs, packaging costs, waste transportation rates, and waste disposal rates. Certain cost elements, such as the radioactive waste disposal rate schedules presented below, are common to the decommissioning analyses of both the reference large irradiator and the reference small sealed sources.

Currently, there are two operating, licensed, low-level radioactive waste disposal facilities in the United States. One is located in the Northwest Compact at Richland, Washington, and is operated by U.S. Ecology, Inc. The other is located in the Southeast Compact at Barnwell, South Carolina, and is operated by Chem-Nuclear Systems, Inc. The U.S. Ecology facility will only accept low-level radioactive waste from member states of the Northwest and the Rocky Mountain Compacts. The Chem-Nuclear facility will accept waste from all states except from the Northwest and Rocky Mountain Compacts and from North Carolina.

The low-level radioactive waste disposal rate schedules (effective January 1, 1993) for the U.S. Ecology site (Table A.1) and the Chem-Nuclear site (Table A.2) were used in this study for estimating waste disposal costs. However, the availability of these two sites referred to throughout this report reflects the current status as of the publication date.

Table A.1 Low-level radioactive waste disposal rate schedule for U.S. Ecology Site, Richland, Washington

US ECOLOGY
WASHINGTON NUCLEAR CENTER
RADIOACTIVE WASTE DISPOSAL
EFFECTIVE JANUARY 1, 1993

SCHEDULE A
DISPOSAL CHARGES

A. DISPOSAL CHARGES

1. Packages (except as noted in Section 2)

R/HR AT CONTAINER SURFACE	PRICE PER CU. FT.
0.00 - 0.20	$28.30
0.21 - 1.00	29.70
1.01 - 2.00	30.80
2.01 - 5.00	32.00
5.01 - 10.00	35.10
10.01 - 20.00	41.90
20.01 - 40.00	48.40
Greater than 40.00	$52.70 + ($0.426 x R/HR in excess of 40)

2. Disposal Liners Removed From Shield (Greater Than 12.0 Cu.Ft. Each)

R/HR AT CONTAINER SURFACE	SURCHARGE PER LINER	PRICE PER CU. FT.
0.00 - 0.20	No Charge	$28.30
0.21 - 1.00	207.60	28.30
1.01 - 2.00	467.10	28.30
2.01 - 5.00	787.20	28.30
5.01 - 10.00	1,254.30	28.30
10.01 - 20.00	1,643.50	28.30
20.01 - 40.00	1,885.70	28.30
Greater than 40.00	2,063.70 + ($18.09 x R/HR in excess of 40)	28.30

B. SURCHARGE FOR CURIES (PER LOAD)

Less than 50 curies	No Charge
50 - 100 curies	$ 865.00
101 - 300 curies	1,730.00
301 - 500 curies	2,162.50
501 - 1,000 curies	2,595.10
1,001 - 5,000 curies	3,027.60
5,001 - 10,000 curies	4,411.60
10,001 - 15,000 curies	6,228.20
Greater than 15,000 curies	7,058.60 + ($0.336 x curies in excess of 15,000)

C. MINIMUM CHARGE PER SHIPMENT
All shipments will be subject to a minimum charge of $1,000 per generator per shipment.

Table A.1 (Continued)

US ECOLOGY
WASHINGTON NUCLEAR CENTER
RADIOACTIVE WASTE DISPOSAL
EFFECTIVE JANUARY 1, 1993

SCHEDULE B
SURCHARGES AND OTHER SPECIAL CHARGES

A. CASK HANDLING FEES

1. Truck Casks

a. Remains on Vehicle During Unloading	$1,000 each
b. Removed from Vehicle During Unloading	$25,000 each

2. Rail Cask

$50,000 each plus outside riggers' charges

B. POLY HICS IN ENGINEERED CONCRETE BARRIERS

1. Large Barrier - $9,520 plus other applicable costs herein

2. Small Barrier - $8,325 plus other applicable costs herein

C. SURCHARGE FOR HEAVY OBJECTS (NON-CASK SHIPMENTS)

Less than 5,000 pounds	No Charge
5,001 -10,000	$ 500.00
10,001 -15,000	1,000.00
15,001 -20,000	2,500.00
20,001 -25,000	5,000.00
Over -25,000	10,000.00

D. SURCHARGE FOR SPECIAL NUCLEAR MATERIAL

Greater than 5 grams per shipment	$10.00 per gram

E. DECONTAMINATION SERVICES (IF REQUIRED)

Per Hour	$150.00
Supplies	Cost Plus 25%

Table A.1 (Continued)

US ECOLOGY
WASHINGTON NUCLEAR CENTER
RADIOACTIVE WASTE DISPOSAL
EFFECTIVE JANUARY 1, 1993

SCHEDULE C
TAX AND FEE RIDER

The rates and charges set forth in Schedule A and B as applicable shall be increased by the amount of any fee, surcharge or tax assessed on a volume or gross revenue basis against or collected by US Ecology, as listed below:

Perpetual Care and Maintenance Fee	$1.75 per cubic foot
Business & Occupation Tax	5.5% of rates and charges
Site Surveillance Fee	$1.58 per cubic foot
Surcharge (RCW 43.200.233)	$6.50 per cubic foot
Commission Regulatory Fee	1.0% of rates and charges

1560R/1-93

Table A.2 Low-level radioactive waste disposal rate schedule for Chem-Nuclear Site, Barnwell, South Carolina

CHEM-NUCLEAR SYSTEMS, INC.
140 Stoneridge Drive • Columbia South Carolina 29210

**BARNWELL LOW-LEVEL RADIOACTIVE
WASTE MANAGEMENT FACILITY
RATE SCHEDULE**

All radwaste material shall be packaged in accordance with Department of Transportation and Nuclear Regulatory Commission Regulations in Title 49 and Title 10 of the Code of Federal Regulations, Chem-Nuclear's Nuclear Regulatory Commission and South Carolina Radioactive Material Licenses, Chem-Nuclear's Barnwell Site Disposal Criteria, and amendments thereto.

1. BASE DISPOSAL CHARGES: (Not including Surcharges, Barnwell County Business License Tax, and Cask Handling Fee)

A. Standard Waste	\$59.00/ft^3
B. Biological Waste	\$61.00/ft^3
C. Special Nuclear Material (SNM)	\$59.00/ft^3

Note 1: Minimum charge per shipment, excluding Surcharges and specific other charges is \$1,000.

Note 2: Base Disposal Charge includes:

Extended Care Fund	\$ 2.80/ft^3
South Carolina Low-Level Radioactive Waste Disposal Tax	\$ 6.00/ft^3
Southeast Regional Compact Fee	\$ .89/ft^3

2. SURCHARGES:

A. Weight Surcharges (Crane Loads Only)

Weight of Container	Surcharge Per Container
0 - 1,000 lbs.	No Surcharge
1,001 - 5,000 lbs.	\$ 675.00
5,001 - 10,000 lbs.	\$1,200.00
10,001 - 20,000 lbs.	\$1,685.00
20,001 - 30,000 lbs.	\$2,170.00
30,001 - 40,000 lbs.	\$3,185.00
40,001 - 50,000 lbs.	\$4,185.00
greater than 50,000 lbs.	By Special Request

Effective January 1, 1993

(803) 256-0450 • Telex 216947

Table A.2 (Continued)

Barnwell Rate Schedule
Page Two

Effective January 1, 1993

B. Curie Surcharges For Shielded Shipment:

Curie Content Per Shipment	Surcharge Per Shipment
0 - 5	$ 4,150.00
> 5 - 15	$ 4,710.00
> 15 - 25	$ 6,235.00
> 25 - 50	$ 9,405.00
> 50 - 75	$11,460.00
> 75 - 100	$15,525.00
> 100 - 150	$18,630.00
> 150 - 250	$24,955.00
> 250 - 500	$31,280.00
> 500 - 1,000	$37,375.00
> 1,000	By Special Request

C. Curie Surcharges for Non-Shielded Shipments Containing Tritium and Carbon 14:

Curie Content Per Shipment	Surcharge Per Shipment
0 - 100	No Surcharge
greater than 100	By Special Request

D. Class B/C Waste Polyethylene High Integrity Container Surcharge

Curie Content Per Shipment	Large Liners with Maximum Dimension of 82" Diameter and 79" Height	Overpacks with Maximum Dimension of 33" Diameter and 79" Height	55-Gallon Drum size with Max. Dimension of 25.5" Diameter and 36" Height
0 - 25	$29,325	These containers will be assessed charges the same as other containers in accordance with this rate schedule plus $2,900 per overpack and $750 per drum	
> 25 - 50	$30,760		
> 50 - 75	$32,775		
> 75 - 100	$35,300		
>100 - 150	$38,525		
>150 - 250	$44,965		
>250 - 500	$52,210		
>500	Upon Request		

NOTES: 1. Class B/C poly HICs which do not conform to the above require prior approval and pricing will be provided upon request.

2. The above Large Liner charges are inclusive of the base disposal charge (1.A.), weight surcharge, curie surcharge, cask handling surcharge, disposal overpack charge, and the Barnwell surcharge.

Table A.2 (Continued)

Barnwell Rate Schedule
Page Three

Effective January 1, 1993

E. Cask Handling Fee — $1,795.00 per cask, minimum

F. Special Nuclear Material Surcharge — $8.15 per gram

G. Barnwell Surcharge — 2.4%

3. MISCELLANEOUS:

A. Transport vehicles with additional shielding features may be subject to an additional handling fee which will be provided upon request.

B. Decontamination services (if required): $150.00 per man-hour plus supplies at current Chem-Nuclear rate.

C. Customers may be charged for all special services as described in the Barnwell Site Disposal Criteria.

D. Terms of payment are NET 30 DAYS upon presentation of invoices. A service charge per month of 1-1/2% shall be levied on accounts not paid within thirty (30) days.

E. Company purchase orders or a written letter of authorization in form and substance acceptable to CNSI shall be received before receipt of radioactive waste material at the Barnwell Disposal Site and shall refer to CNSI's Radioactive Material Licenses, the Barnwell Site Disposal Criteria, and subsequent changes thereto.

F. All shipments shall receive a CNSI allocation number and conform to the Prior Notification Plan. Additional information may be obtained at (803) 259-3577 or (803) 259-3578.

G. This Rate Schedule is subject to change and does not constitute an offer of contract which is capable of being accepted by any party.

H. A charge of $12,650.00 is applicable to all shipments which require special site set-up for waste disposal.

I. Class B/C waste received with chelating agents, which requires separation in the trench, may be subject to a surcharge if Stable Class A waste is not available for use in achieving the required separation from other wastes.

Table A.2 (Continued)

Chem-Nuclear Systems, Inc.

Attachment 1

Barnwell Low-Level Radioactive Waste Management Facility
1993 Disposal Pricing

1. Base Disposal Charges — Refer to Rate Schedule effective January 1, 1993

2. Surcharges

   A. Weight Surcharges — Refer to Rate Schedule effective January 1, 1993 for weights under 50,000 lbs

Weight Surcharges for Shielded Shipments >50,000 lbs	Weight Surcharge Per Shipment
> 50,000 - 60,000	$ 7,350.00
> 60,000 - 70,000	$ 8,950.00
> 70,000 - 80,000	$ 10,500.00
> 80,000 - 90,000	$ 12,100 00
>90,000 - 100,000	$ 13,700 00

   B. Curie Surcharges for Shielded Shipment

   (up to 1,000 curies) — Refer to Rate Schedule effective January 1, 1993

Curie Content per Shielded Shipment	Curie Surcharge Per Shipment
> 1,000 - 5,000	$57,500.00
> 5,000 - 10,000	$71,900.00
> 10,000 - 20,000	$97,800.00
> 20,000 - 30,000	$120,800.00
> 30,000 - 40,000	$149,500.00
> 40,000 - 50,000	$172,500.00

3. Class B/C Waste Polyethylene High Integrity Container Surcharge — Refer to Rate Schedule effective January 1, 1993

Table A.2 (Continued)

Chem-Nuclear Systems, Inc.

4. Cask Handling Fee

Cask Type	Price
NFS-4, NAC-1	$ 11,800.00
NL 1/2 (when approved for horizontal offload)	$ 11,800.00
AP101	$ 11,800.00
FSV-1	$ 14,900.00
CNS 3-5	$ 12,600.00
TN8L	$ 23,700.00
TN RAM	$ 14,900.00

Cask handling fees shown above are applicable only for these casks listed. Special pricing for non-routine handling or for casks not listed is available by special request.

5. Special Nuclear Material Surcharge — Refer to Rate Schedule effective January 1, 1993

6. Barnwell Surcharge — Refer to Rate Schedule effective January 1, 1993

Additionally, Section 3 from our published rate schedule, entitled "Miscellaneous," Item H may also apply (due to the high radiation levels of the liner) if special disposal site set-up provisions must be made prior to cask off-loading and waste disposal. Disposal of low-level radioactive waste will be charged in accordance with the current Barnwell Low-Level Radioactive Waste Management Facility Rate Schedule in effect at the time of disposal.

NOTE 1: The above pricing schedule does not include the Southeast Compact Commission Access Fee of $\$220.00/ft^3$. Battelle will be responsible for prepayment of this access fee on a quarterly basis.

NOTE 2: This pricing is effective January 1, 1993, and is subject to change upon notification to Battelle by Chem-Nuclear.

Appendix B

Review of Decommissioning Information, Experience and Technologies for the Reference Large Irradiator Decommissioning Study

Appendix B

Review of Decommissioning Information, Experience and Technologies for the Reference Large Irradiator Decommissioning Study

A questionnaire was developed to gather typical information on large irradiators currently in operation and those decommissioned. Data obtained from licensees were used to derive a reference large irradiator facility for use in this study. Additional information was obtained from Agreement State and Federal regulatory organizations. A list of the licensees, Agreement States and NRC organizations who provided information is included in Appendix C. The following tables present a summary of the information obtained including recorded experience of sealed source leaks in the United States.

Table B.1 Summary of large irradiators in the United States[a]

Owner	Plant location		Plant designer	Licensing agency	Licensed quantity (MCi)	Possessed quantity (MCi)	Nuclide	Current status
	City	State						
Abbott Laboratories	Vega Alta	Puerto Rico	Nordion	NRC	4.0[b]		Co-60[b]	Operating
Ansell International	El Paso	Texas	Nordion	State	5.0[c]	~2[c]	Co-60[c]	Operating
Applied Radiant Energy	Lynchburg	Virginia	Applied Radiant Energy	NRC	1.25		Cs-137	Shutdown[d]
					0.4		Co-60	Operating
Bausch & Lomb	Greenville	South Carolina	Nordion	State				Operating
Baxter Healthcare Corp. (American Converters)	Aibonito	Puerto Rico	Nordion	NRC	5 0		Co-60[b]	Operating
	El Paso	Texas	Nordion	State				Operating
	El Paso	Texas	Nordion	State				Operating
	El Paso	Texas	Nordion	State	15[b]			Operating
Becton Dickinson	Broken Bow	Nebraska	Nordion	State	3 0[e]	2 5[e]	Co-60[e]	Operating
	North Canaan	Connecticut	Nordion	NRC	1.0[b]		Co-60[b]	Operating
	Holdrege	Nebraska	Nordion	State	5.0[e]	2 235[e]	Co-60[e]	Operating
	Sumter	South Carolina	Nordion	State		1.68		Operating
Cobe Laboratories, Inc.	Lakewood	Colorado	Radiation Sterilizers, Inc	State		5		Operating
Defense Nuclear Agency	Bethesda	Maryland		NRC	0.400[b]		Co-60[b]	Operating
Dow Corning Corp.	Midland	Michigan	Neutron Products	NRC	0.325[b]		Co-60[b]	Operating
Ethicon, Inc. (Owned by Johnson & Johnson)	San Angelo	Texas	Nordion	State	2.0[f]	1 087[f]	Co-60[f]	Operating
	Somerville	New Jersey	Nordion	NRC	0.200[b]		Co-60[b]	Operating
Gammamed, Inc.	Columbus	Mississippi	Nordion	State		0 866		Operating
International Nutronics, Inc. (INI) (Bankrupt)	Irvine	California	International Nutronics	State	1 0[g]	0 3[g]	Co-60[g]	Decommissioned[h]
	Palo Alto	California	International Nutronics	State				Decommissioned[h]
	Dover	New Jersey	International Nutronics	NRC	0.400[i]	0.060[i]	Co-60[i]	Decommissioned[i]
IOTECH, Inc.	Northglenn	Colorado	CH2M Hill	State		15	Cs-137[j]	Shutdown[d]
Isomedix, Inc	El Paso	Texas	Nordion	State	4.0[k]	2-3[k]	Co-60[k]	Operating
	Groveport	Ohio	Nordion	NRC	4 0[b]	~2[l]	Co-60[b]	Operating
	Libertyville	Illinois	Nordion	State				Operating
	Morton Grove	Illinois	Nordion	State		0 5	Co-60	Operating
	Northborough	Massachusetts	Nordion	NRC	0.014[b]		Co-60[b]	Operating
	Sandy City	Utah	Nordion	State				Operating
	Spartanburg	South Carolina	Nordion	State		2.48		Operating
	Whippany	New Jersey	Nordion	NRC	4.0[k]	3-4[k]	Co-60[k]	Operating
	Parsippany	New Jersey	Isomedix	NRC		2.0[l]	Co-60	Decommissioned[l]

Table B.1 (Continued)

Owner	Plant location: City	Plant location: State	Plant designer	Licensing agency	Licensed quantity (MCi)	Possessed quantity (MCi)	Nuclide	Current status
Johnson & Johnson Medical, Inc.	Arlington	Texas	Nordion	State	4 0[f]	3.8[f]	Co-60[f]	Decommissioned[f]
	El Paso	Texas	Nordion	State	12.0[f]	4.0[f]	Co-60[f]	Operating
	Sherman	Texas	Nordion	State	3.0[f]	1.0[f]	Co-60[f]	Operating
Neutron Products, Inc.	Dickerson	Maryland	Neutron Products	State		0.75		Operating
	Dickerson	Maryland	Neutron Products	State		1.5		Operating
Permagrain Products, Inc.	Karthaus	Pennsylvania		NRC	0 4		Co-60	Shut Down
Precision Materials	Mine Hill	New Jersey	Precision Materials	NRC			Co-60	Shut Down
Radiation Sterilizers, Inc. (RSI) (SteriGenics International)	Fort Worth	Texas	Radiation Sterilizers, Inc.	State	10		Co-60	Operating
	Schaumberg	Illinois	Radiation Sterilizers, Inc.	State	30		Cs-137	Shut Down[d]
					5		Co-60	Operating
	Tustin	California	Radiation Sterilizers, Inc.	State	8[h]	~7[h]	Co-60[h]	Operating
	Westerville	Ohio	Radiation Sterilizers, Inc.	NRC	5.0	1.0-3.0[m]	Co-60[m]	Operating
					30		Cs-137	Shut Down[d]
	Decatur	Georgia	Radiation Sterilizers, Inc.	State			Cs-137	Shut Down[d]
Radiation Technology, Inc. (RTI)	Haw River	North Carolina	Radiation Technology, Inc.	State	1.2	0.72		Operating
	Rockaway	New Jersey	Radiation Technology, Inc.	NRC	0 012[b]		Co-60[b]	Operating
	West Memphis	Arkansas	Radiation Technology, Inc.	State	2.25	0.9		Operating
	Salem	New Jersey	Radiation Technology, Inc.	NRC				Operating
Sherwood Medical	Commerce	Texas	Nordion	State	4.000[n]	2.000[n]	Co-60[n]	Operating
	Deland	Florida	Nordion	State	3.000[n]	2.000[n]	Co-60[n]	Operating
	Norfolk	Nebraska	Nordion	State	4 000[n]	2.500[n]	Co-60[n]	Operating
Surgikos	Arlington	Texas	Nordion	State				Operating
	Arlington	Texas	Nordion	State				Operating
Terumo Medical Corp.	Elkton	Maryland	Nordion	State				Operating
Vindicator, Inc.	Plant City	Florida	Nordion	State				Operating
3M Health Care	Brookings	South Dakota	Nordion	NRC		1		Operating

Table B.1 (Continued)

Footnotes

(a) All data are obtained from NUREG-1345, unless otherwise specified
(b) Broaddus, D (NRC-HQ/NMSS), 07/10/92, "Listing of licensees who possess Gamma Irradiators greater than 10,000 curies"
(c) Hamiter, Floyd (Bureau of Radiation Controls-Texas), telecon 8/6/92, 10/6/92
(d) All WESF Cs-137 sources have been recalled by DOE
(e) Lynch, Jackie (Becton Dickinson), questionnaire 9/2/92
(f) Baretta, Ed (Johnson & Johnson), questionnaire 9/4/92
(g) Hartranft, Jim (Orange County, CA), questionnaire 9/22/92
(h) Hartranft, Jim (Orange County, CA), telecon 9/15/92
(i) Thomas, Bruce (Irradiation Consulting Services), 10/87, "Decommissioning of International Nutronics Co-60 Irradiation Facility"
(j) Baggett, Steve (NRC-HQ/NMSS), telecon with Steve Short
(k) Dietz, George (Isomedix, Inc.), questionnaire 8/12/92
(l) Dietz, George (Isomedix, Inc), telecons 8/5/92, 8/11/92
(m) Fairand, Barry (SteriGenics), questionnaire 8/24/92
(n) Price, Don (Sherwood Medical), questionnaire 8/17/92

Table B.2 Large irradiator characteristics

Owner	Plant location: City	Plant location: State	Tote[a]	Carrier[b]	Overlap[c]	Shuffle[d]	Batch[e]	Manual[f]	Automatic[g]
Abbott Laboratories	Vega Alta	Puerto Rico							
Ansell International	El Paso	Texas							A
Applied Radiant Energy	Lynchburg	Virginia							
Bausch & Lomb	Greenville	South Carolina							
Baxter Healthcare Corp.	Aibonito	Puerto Rico							
(American Converters)	El Paso	Texas							
	El Paso	Texas							
	El Paso	Texas							
Becton Dickinson	Broken Bow	Nebraska	T						
	North Canaan	Connecticut	T						
	Holdrege	Nebraska		C					
	Sumter	South Carolina		C					
Cobe Laboratories, Inc.	Lakewood	Colorado							
Defense Nuclear Agency	Bethesda	Maryland							
Dow Corning Corp	Midland	Michigan							
Ethicon, Inc.	San Angelo	Texas		C	O				
(Owned by Johnson & Johnson)	Somerville	New Jersey		C	O				
Gammamed, Inc.	Columbus	Mississippi	T						
International Nutronics,	Irvine	California							
Inc. (INI) (Bankrupt)	Palo Alto	California							
	Dover	New Jersey					B		
IOTECH, Inc.	Northglenn	Colorado							
Isomedix, Inc	El Paso	Texas		C					A
	Groveport	Ohio		C	O	S			
	Libertyville	Illinois		C	O		B		A
	Morton Grove	Illinois	T						
	Northborough	Massachusetts						M	A
	Sandy City	Utah							
	Spartanburg	South Carolina		C					
	Whippany	New Jersey		C			B	M	A
	Parsippany	New Jersey		C			B		
Johnson & Johnson	Arlington	Texas	T						
Medical, Inc.	El Paso	Texas		C					
	Sherman	Texas		C		S			
Neutron Products, Inc.	Dickerson	Maryland					B	M	
	Dickerson	Maryland							A
Permagrain Products, Inc.	Karthaus	Pennsylvania							
Precision Materials	Mine Hill	New Jersey							
Radiation Sterilizers,	Fort Worth	Texas			O	S			
Inc. (RSI) (SteriGenics	Schaumberg	Illinois			O	S			
International)	Tustin	California		C	O	S			
	Westerville	Ohio			O	S			
	Decatur	Georgia			O	S			

Table B.2 (Continued)

Owner	Plant location		Tote[a]	Carrier[b]	Overlap[c]	Shuffle[d]	Batch[e]	Manual[f]	Automatic[g]
	City	State							
Radiation Technology, Inc. (RTI)	Haw River	North Carolina						M	A
	Rockaway	New Jersey		C	O		B		A
	West Memphis	Arkansas						M	A
	Salem	New Jersey						M	A
Sherwood Medical	Commerce	Texas			O				
	Deland	Florida			O				
	Norfolk	Nebraska	T						
Surgikos	Arlington	Texas	T						
	Arlington	Texas							
Terumo Medical Corp	Elkton	Maryland							
Vindicator, Inc	Plant City	Florida							
3M Health Care	Brookings	South Dakota	T						A

Notes:

(a) Tote metal box (usually aluminum) to contain product to be irradiated.
(b) Carrier container into which totes are loaded for transport through irradiator
(c) Overlap irradiator design to produce more uniform dose product
(d) Shuffle rearrangement of product for multiple passes through irradiator
(e) Batch operation mode in which each irradiation is set up before processing.
(f) Manual manual operation of each irradiation pass of the product
(g) Automatic automatic sequential operation of multiple irradiation passes

Table B.3 Pool contamination experience at irradiators with Co-60 source leaks

International Nutronics, Inc., Dover, NJ

Pool volume = 3,000 gallons
Source strength = 1,000 curies/source

Date	Pool Concentration (μCi/ml Co-60)	Total Cobalt-60 (mCi)	Fraction of one Source
Jun-74	7.00E-04	7.9	7.95E-06
Jul-74	9.00E-05	1.0	1.02E-06
Nov-82	5.00E-05	0.6	5.68E-07
Dec-82	1.70E-03	19.3	1.93E-05
Apr-85	7.38E-03	83.8	8.38E-05

Isomedix, Parsippany, NJ

Pool volume = 7,000 gallons
Source strength = 1,000 curies/source

Date	Pool Concentration (μCi/ml Co-60)	TotalCobalt-60 (mCi)	Fraction of one Source
Jul-76	1.36E-01	3,604	3.60E-03
Jul-76	3.77E-01	10,000	1.00E-02

Radiation Technology, Inc., Rockaway, NJ

Pool volume = N/A gallons
Source strength = 1,000 curies/source

Date	Pool Concentration (μCi/ml Co-60)	Total Cobalt-60 (mCi)	Fraction of one Source
Sep-75	1.30E-03	---	---
Oct-75	6.70E-05	---	---

Postulated Source Leak Scenario -- Reference Irradiator

Pool volume = 54,368 liters
Source strength = 8,000 curies/source

Date	Pool Concentration (μCi/ml Co-60)	Total Cobalt-60 (mCi)	Fraction of one Source	
Jun-93	3.00E-05	1.63	2.04E-07	Low contamination scenario - 30 pCi/ml[(a)]
Jun-93	2.00E-03	108.74	1.36E-05	Medium contamination scenario - 2,000 pCi/ml
Jun-93	2.00E-01	10,874	1.36E-03	High contamination scenario - 200,000 pCi/ml

(a) 1 picocurie (pCi) = 1.00E-06 microcurie (μCi)

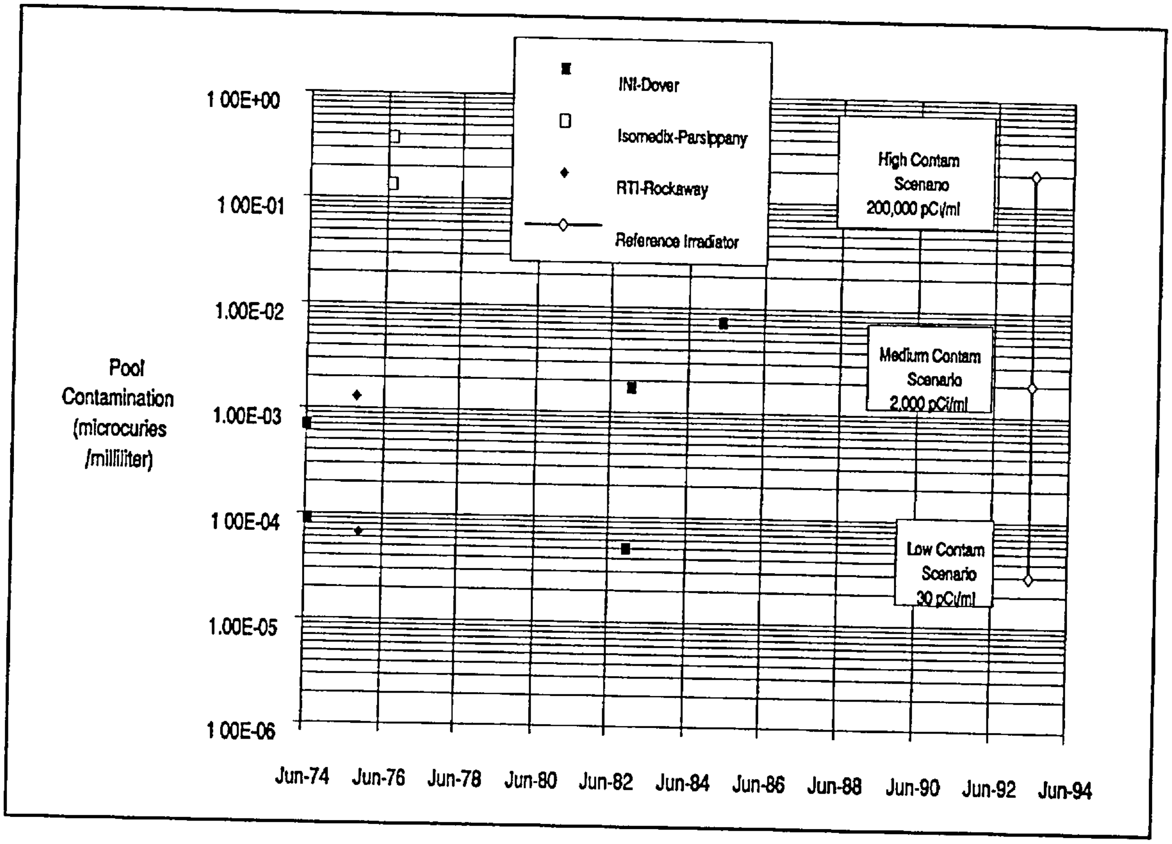

Figure B.1 Pool contamination experience at irradiators with Co-60 source leaks

Appendix C

Study Contacts for Decommissioning of the Reference Large Irradiator Facility

Appendix C

Study Contacts for Decommissioning of the Reference Large Irradiator Facility

The many individuals who contributed information that subsequently led to the completeness of this study on the decommissioning of large irradiators are greatly appreciated and specially acknowledged in this appendix.

Special thanks are expressed to the following individuals who gave so willingly of their time and expertise: Rod Chu and Dick McKinnon of Nordion International, Inc.

A full listing of individuals who contributed to this report is provided below.

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Appendix D

Cost Estimating Bases for Decommissioning of Reference Sealed Sources

Appendix D

Cost Estimating Bases for Decommissioning of Reference Sealed Sources

This appendix provides the bases and develops the unit costs used in this conceptual decommissioning study. Categories for which basic unit cost data are given include: labor salaries, waste packaging, material and supplies, waste and sealed source transportation cask rental, waste and sealed source transportation, and waste disposal.

The costs include decontamination costs, packaging costs, transportation costs, burial volumes and costs, and labor staffing costs. For a specified radioisotope of a specific activity, the spreadsheet analysis calculates the container size required for low-level waste (LLW) burial, container costs, burial charges, transportation charges, and labor requirements. The spreadsheet analysis calculates these costs for different activities for a sealed source.

The cost data presented in this appendix, together with the spreadsheet analyses, can be used to develop cost estimates for other decommissioning projects, based upon appropriate consideration of the assumptions given below. These data should be carefully examined to ascertain their applicability to the sealed source under consideration, and may require significant adjustments for site-specific activities.

D.1 Bases and Assumptions

The following major bases and assumptions apply to this conceptual decommissioning study of small sealed sources:

- The cost estimates in this conceptual study take into consideration only those activities that affect the public health and safety - i.e., costs to reduce exposure from the sealed source to a level that permits termination of the NRC license.

- Cost are in constant dollars of early 1993.

- The cost estimates made in this study are for a generic piece of equipment which uses a sealed source of a specific activity and are not device-specific.

- The labor rates for each craft and salaried worker were obtained from the decommissioning of Trojan PWR Nuclear Power Plant. The labor rates used for the decommissioning of the Trojan facility are assumed to be applicable to this study.

- The cost estimates for this study are direct costs to the sealed source use, and do not include any broker fees and broker services that might be used.

- The radioactive waste disposal costs presented in this study were specifically developed for sealed sources located in the Northwest and Rocky Mountain Compacts assuming disposal at the U.S. Ecology disposal facility near Richland, Washington. Additional information is also given for disposal of sealed sources at the Chem-Nuclear disposal facility near Barnwell, South Carolina.

- Due to the small size and nature of small sealed sources, the labor requirements for decommissioning sealed sources are taken to be the same for each radionuclide, independent of the source activity.
- This study presumes that sealed sources will be disposed of as Class C waste as defined in the U.S. Ecology Washington State Operating License.
- Costs pertaining to handling and disposal of any hazardous or mixed radioactive and hazardous wastes generated from the decommissioning activities are not considered in this study.

D.2 Labor Costs

Salary data for the decommissioning staff positions used in this study, given in Table D.1, are representative of labor costs for a decommissioning project at the Trojan PWR Nuclear Power Plant,[1] located at Rainier, Oregon.

Decommissioning of sealed sources is assumed to be performed by employees of the owner/operator of the sealed source. In NUREG/CR-1754,[2,3] the overhead rates for personnel involved with decommissioning non-fuel-cycle nuclear facilities were identified and applied to this study. Overhead rates applied to staff labor are expected to be significantly higher for a decommissioning contractor/broker than they are for the owner/operator. These higher overhead rates for a contractor/broker apply because of the larger ratio of supervisory and support personnel to direct the labor that usually exists in contractor organizations and because of travel and living expenses associated with having personnel in the field rather than in the office. In Table D.1, an overhead rate of 50% is applied to the direct staff labor for owner/operator personnel and an overhead rate of 110% is applied to direct staff labor for contractor personnel.

The salary data in Table D.1 are given on an annual basis. To obtain hourly rates, the annual salaries are divided by 2080 hrs/yr.

D.3 Waste Management Costs

The radioactive wastes generated from decommissioning small sealed sources considered in this study are as follows: 1) the sealed source itself; 2) in some cases, the device which uses the sealed source; and 3) the materials used to decontaminate the device.

Table D.1 Decommissioning staff salary data

Position	Base annual salary ($/yr)	Owner/operator's staff: Assumed overhead rate (%)	Owner/operator's staff: Annual charge-out rate ($/yr)	Contractor's staff: Assumed overhead rate (%)	Contractor's staff: Annual charge-out rate ($/yr)
Operations Supervisor	61,140	50	91,710	110	128,394
Health Physics Technician	31,710	50	47,565	110	66,591
Technician	30,290	50	45,435	110	63,609
Plant Engineer	51,140	50	76,710	110	107,384
Secretary	20,500	50	30,750	110	43,050

Waste management includes the packaging of the sealed source/device and contaminated materials into containers, transportation of the packaged waste to an approved disposal site, or storage of sealed sources until an NRC-approved burial facility is available for radioactive wastes that are currently not approved for burial.

D.3.1 Radioactive Waste Packaging Cost for Sealed Sources

The shipping containers assumed to be used for packaging radioactive waste materials for LLW disposal are listed in Table D.2. The disposal volume is assumed to be the container volume. Communication with Washington State Department of Health personnel[a] and review of the NRC Proposed Technical Position Paper[4] indicated that the maximum size over which the activity can be averaged is 55-gallon (208-liter) drums. For the purposes of this study, it is assumed that the disposal packaging containers are 55-gallon drums, and that devices being transferred to another user are packaged in 20-gallon (76-liter) containers.

D.3.2 Costs of Supplies and Materials

The supplies and materials required for decommissioning a small sealed source are listed in Table D.3. Only those items that are postulated for use in decommissioning and that represent a significant or special expense are listed. Radiation survey equipment and equipment for the analysis of swipe samples are not listed. This equipment is not chargeable to decommissioning because it is assumed to be required to be available during the operational phase of the device containing the sealed source.

D.3.3 Cask Charges

Some of the radioactive waste material generated from decommissioning sealed sources is sufficiently radioactive to require transport in a reusable, shielded cask. In general, it is more economical to rent such casks for a one-time use than to purchase them. The cask assumed in this study for use in shipping radioactive materials is listed in Table D.4, together with the application and estimated rental charges. For this conceptual study, it is assumed that the cask will contain one 55-gallon drum.

Table D.2 Unit costs of shipping containers and packaging materials

Description	Cost ($)
55-gallon drum, DOT type 17 C, epoxy lined[a]	60.70 ea
20-gallon polypack container[a]	41.00 ea
Pre-mixed cement[b,c]	3.99/bag
2R-type container[d]	5.00 ea

(a) Cost from Lab Safety Supply 1993 General Catalog.
(b) Cost from personal communication with Ace Hardware.
(c) Each bag creates 0 67 ft^3 of cement.
(d) 2R-type of container is assumed to be a section of pipe, capped and sealed at both ends, from Washington State Department of Health, Packaging Guide-Transuranics and Radium This 2-R container is assumed to be a galvanized steel, schedule 40, 1.5-inch pipe.

(a) Personal communication: A. J. Villegas (PNL) with Terry Frazee (Washington State Dept. of Health), October 1993

Table D.3 Unit costs of supplies and materials

Description	Cost ($)
Cleaning Supplies:	
1 liter spray bottle[a]	11.65
(for radioactive decontamination)	
1 gallon rad decon fluid[a]	23.90
towelettes, pkg 100[a]	18.60
Clothing:	
3-ply lead apron[a]	127.75
1 pair radiation gloves[a]	48.45

(a) Cost from Lab Safety Supply 1993 General Catalog (Lab)

Table D.4 Shielded casks for shipment of radioactive materials

Cask description	Application	Daily Rental, $
NuPac No. 10/142 COC No. 9208[1]	Transport of high-integrity container or 55-gallon drums	1,250

D.3.4 Transportation Costs

Transportation of a radioactive sealed source from the licensee's facility to an approved disposal facility is assumed to be accomplished using a commercial truck. The distance from the facility to the disposal site is assumed to be 800 km. A rate schedule for truck shipments of legal size and weight is shown in Table D.5. The table is reproduced from the published rates of Tri-State Motor Transit Co.,[5] which is licensed to transport radioactive materials.

The gross vehicle weight (GVW) for normal shipments by truck (i.e., at or below the legal weight limit) is assumed to be less than 21.77 Mg. It is assumed that the weight of the truck and its cargo will not exceed the maximum legal weight because the truck is dedicated solely to transport the sealed source being decommissioned.

The transportation carrier charges for travel west of the Mississippi River for 800 km (497 mi) are $2.44/mi, or $1,213 for a packaged sealed source for both the transfer and disposal options.

D.3.5 Waste Disposal Costs

A basic assumption of this study is the sealed source will be classified as Class C for disposal purposes. The material used to decontaminate any residual contamination from a leaking sealed source or device will be disposed of in a drum separate from the sealed source. Most decommissioned sealed sources are expected to be shipped for disposal at an approved

Table D.5 Transportation rates for legal-size and legal-weight shipments (effective September 26, 1992)

ICC TSMT 4007-C — Original Page 22

TRI-STATE MOTOR TRANSIT CO.

SECTION 2
DISTANCE COMMODITY RATES

ITEM 30000

COMMODITY: Radioactive Waste (low level) and empty containers therefor moving to or from points of loading, unloading, or storage. (NOTES 1,2,3)

BETWEEN: All points in the United States and Canada as provided in Item 650.

RATES IN CENTS PER MILE

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

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

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

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

(continued)

For explanation of reference marks and abbreviations, see last page of tariff.

ISSUED: September 15, 1992 — EFFECTIVE: September 26, 1992

ISSUED BY: George Cain, Vice President, Pricing & Tariffs
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(P400753A.86)

Table D.5 (contd)

ICC TSMT 4007-C | Original Page 23

TRI-STATE MOTOR TRANSIT CO.

SECTION 2
DISTANCE COMMODITY RATES

ITEM 30000
(concluded)

NOTES

NOTE 1 - Overweight shipments not exceeding a gross vehicle weight of 80M shall be subject to an additional charge of 22 cents for each mile traveled in a state or states requiring overweight permits, in addition to all other applicable charges. For rates on shipments exceeding 80M gross weight, apply Item 21000.

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

NOTE 3 - Shipments originating at points in AZ or CA and delivering to points in NV will be subject to an arbitrary charge of 25 cents per mile, based on the billed miles. Such charge to be in addition to all other applicable charges. Not applicable on round trip shipments when the return load is tendered to carrier on the same day the inbound shipment is delivered.

For explanation of reference marks and abbreviations, see last page of tariff.

ISSUED: September 15, 1992 EFFECTIVE: September 26, 1992

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(P400752B.86)

burial site (U.S. Ecology, Inc., near Richland, Washington, or Chem-Nuclear, near Barnwell, South Carolina). Greater-Than-Class-C (GTCC) sources, which are regulated under the auspices of the Department of Energy, are expected to be disposed of in a geologic repository or other such disposal facility as the NRC may approve.

Costs for Shallow-Land Burial

Disposal costs of LLW in approved shallow-land burial sites are presented in Table D.6. The burial charges listed are applicable to burial of sealed sources based on the January 1, 1993, fee schedule provided by U.S. Ecology, which operates the burial site near Richland, Washington, and the January 1, 1993, fee schedule provided by Chem-Nuclear Systems, which operates the burial site near Barnwell, South Carolina. The complete fee schedules supplied by U.S. Ecology and Chem-Nuclear Systems are presented in Tables A.1 and A.2 of Appendix A.

Costs for Geologic Disposal

Sealed sources that are classified as GTCC are either shipped back to the manufacturer or stored until a final disposal site has been identified. The most likely disposal site would be in a geologic repository. A unit cost value of approximately $6,500 per cubic foot ($229,540 per cubic meter) for geologic repository disposal of GTCC waste is cited in NUREG/CR-5884, Vol. 2.[1] Thus, for the packaging containers considered for geologic repository disposal (208-liter drums) in this study, the disposal charge would be $47,744 for each 208-liter drum. One should recognize that the unit cost presented here is quite speculative, because a geologic repository or other such disposal facility as the NRC may approve does not presently exist, and may not exist for another 10 to 20 years.

Costs for Storage

Sealed sources that are not acceptable for burial at LLW burial facilities are either sent back to the manufacturer, sent to a broker for storage or other disposition, or stored onsite. For those cases in which the sealed source is stored onsite, the sealed source would most likely remain inside the device during storage. In cases where a new sealed source would replace a depleted source, the depleted source would be packaged in an appropriate 2R-type container for future disposal, but stored onsite.

Table D.6 LLW disposal charges for sealed sources

Compact	Location	Burial costs, $[a]
Northwest and Rocky Mountain	Richland, WA	{[$1,000 or (vol x $28.30)][b] + HOS[c] + $9.83 x vol + 0.065 x [($1,000 or (vol x $28.30))[b] + HOS[c]]}
Southeast	Barnwell, SC	Disposal Volume x $132.42/ft^3
All other compacts[d]	Barnwell, SC	Disposal Volume x $280.42/ft^3

(a) The volumes used in the cost equations are in cubic feet.
(b) Either $1,000 or the volume times $28 30, whichever cost is greater.
(c) The Heavy Object Surcharge (HOS) is based on the mass (lb) of the material buried.
(d) Access to Barnwell facility may be denied or limited to waste from some states.

Research institutions are beginning to examine the feasibility of storing radioactive waste onsite because of increasing costs of LLW burial and because LLW burial sites do not accept transuranic and/or GTCC wastes. The facility would store wastes until an appropriate site for disposal has been determined, or until the radioisotopes have decayed to an acceptable level for final disposition.

Cost estimates for storage of sealed sources were made for two scenarios. The first scenario assumes that the device that contains the sealed source provides enough attenuation such that the occupational dose received during storage is below regulatory requirements. The cost estimates made include planning and preparation, packaging the device into a 20-gallon container for later retrieval, and a 5-year surveillance program.

The second scenario assumes that the source was leaking and that a decontamination step was required. The cost estimates made include planning and preparation, decontamination of the workbench and device, packaging the waste material into 55-gallon drums using a solidification matrix (e.g., Portland cement), and a 5-year surveillance program.

D.4 References

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Appendix E

Time and Labor Cost Details of Decommissioning Reference Sealed Sources

Appendix E

Time and Labor Cost Details of Decommissioning Reference Sealed Sources

This appendix contains tables of detailed time and labor costs for waste management planning, decontamination (if necessary), packaging, surveys, and preparation for transportation of decommissioned small sealed sources. Labor person hours are PNL estimates and labor costs are calculated using the labor rates defined in Appendix D.

Table E.1a Details of estimated labor requirements and costs for transfer of an Fe-55 source to a new user or to the manufacturer

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0 5				0.5	18.
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3 0					3 0	132.
Packaging							
Documentation Generation	3 0				1.0	4 0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6 0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	12.0	4.0	1.0	24.5	813.

Table E.1b Details of estimated labor requirements and costs for disposal of an Fe-55 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6 0	1.0		7.0	214.
Develop Work Plan	3 0					3.0	132.
Packaging							
Radiological Survey			6 0			6 0	192.
Documentation Generation	3 0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6 0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	18.0	4.0	1.0	30.5	1,006.

Table E.1c Details of estimated labor requirements and costs for disposal with decon of an Fe-55 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6 0	1.0		7 0	214.
Develop Work Plan	3 0					3.0	132.
Decontamination							
Remove Equipment and Survey Component	2 0	2.0	4 0	10 0		18.0	508.
Decontaminate	2 0	2 0		5 0		9.0	271.
Monitor			6.0			6 0	192
Reclean Hot Spots & Monitor	2 0	2 0	4 0	2 0		10 0	334.
Packaging							
Radiological Survey			6.0			6 0	192.
Documentation Generation	3 0				1 0	4 0	147.
Packaging	2 0			4 0		6 0	176.
Final Radiological Survey			6 0			6 0	192.
Transportation							
Loading & Manifesting				1 0		1.0	22.
Total Labor	14 0	6 5	32 0	23.0	1 0	76 5	2,399.

Table E.1d Details of estimated labor requirements and costs for storage of an Fe-55 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0 5				0 5	18.
Radiological Survey			6.0	1 0		7 0	214
Develop Work Plan	3.0					3 0	132.
Packaging							
Radiological Survey			6 0			6 0	192
Documentation Generation	3.0				1.0	4 0	147.
Packaging	1 0			2 0		3 0	88.
Final Radiological Survey			6 0			6 0	192.
Surveillance							
Monitoring (0 25 hr/mo/5yrs)	13 0					13 0	573.
Total Labor	20 0	0 5	18 0	3 0	1.0	42.5	1,557.

Table E.1e Details of estimated labor requirements and costs for storage with decon of an Fe-55 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18
Radiological Survey			6.0	1.0		7.0	214
Develop Work Plan	3.0					3.0	132.
Decontamination							
Remove Equipment and Survey Component	2.0	2.0	4.0	10.0		18.0	508.
Decontaminate	2.0	2.0		5.0		9.0	271.
Monitor			6.0			6.0	192.
Reclean Hot Spots & Monitor	2.0	2.0	4.0	2.0		10.0	334.
Packaging							
Radiological Survey			6.0			6.0	192.
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88
Final Radiological Survey			6.0			6.0	192.
Surveillance							
Monitoring (0.25 hr/mo/5yrs)	13.0					13.0	573
Total Labor	26.0	6.5	32.0	20.0	1.0	85.5	2,862.

Table E.2a Details of estimated labor requirements and costs for transfer of an Ni-63 source to a new user or to the manufacturer

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3.0					3.0	132.
Packaging							
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6.0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	12.0	4.0	1.0	24.5	813

Table E.2b Details of estimated labor requirements and costs for disposal of an Ni-63 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3.0					3.0	132.
Packaging							
Radiological Survey			6.0			6.0	192
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6.0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	18.0	4.0	1.0	30.5	1,006.

Table E.2c Details of estimated labor requirements and costs for disposal with decon of an Ni-63 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3.0					3.0	132.
Decontamination							
Remove Equipment and Survey Component	2.0	2.0	4.0	10.0		18.0	508.
Decontaminate	2.0	2.0		5.0		9.0	271.
Monitor			6.0			6.0	192
Reclean Hot Spots & Monitor	2.0	2.0	4.0	2.0		10.0	334.
Packaging							
Radiological Survey			6.0			6.0	192.
Documentation Generation	3.0				1.0	4.0	147.
Packaging	2.0			4.0		6.0	176.
Final Radiological Survey			6.0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	14.0	6.5	32.0	23.0	1.0	76.5	2,399.

Table E.2d Details of estimated labor requirements and costs for storage of an Ni-63 source

	Person hours						Labor cost (dollars)
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	
Planning and Preparation							
Determine Source Fate		0.5				0 5	18
Radiological Survey			6 0	1.0		7.0	214
Develop Work Plan	3.0					3 0	132.
Packaging							
Radiological Survey			6 0			6.0	192.
Documentation Generation	3 0				1 0	4 0	147.
Packaging	1 0			2 0		3.0	88
Final Radiological Survey			6 0			6 0	192
Surveillance							
Monitoring (0 25 hr/mo/5yrs)	13 0					13 0	573
Total Labor	20.0	0.5	18 0	3 0	1.0	42.5	1,557.

Table E.2e Details of estimated labor requirements and costs for storage with decon of an Ni-63 source

	Person hours						Labor cost (dollars)
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	
Planning and Preparation							
Determine Source Fate		0 5				0 5	18.
Radiological Survey			6 0	1.0		7 0	214
Develop Work Plan	3 0					3 0	132
Decontamination							
Remove Equipment and Survey Component	2 0	2.0	4 0	10 0		18 0	508.
Decontaminate	2 0	2.0		5 0		9.0	271.
Monitor			6 0			6.0	192.
Reclean Hot Spots & Monitor	2 0	2 0	4 0	2 0		10 0	334
Packaging							
Radiological Survey			6 0			6.0	192.
Documentation Generation	3 0				1.0	4 0	147.
Packaging	1 0			2 0		3.0	88.
Final Radiological Survey			6 0			6.0	192.
Surveillance							
Monitoring (0.25 hr/mo/5yrs)	13 0					13 0	573.
Total Labor	26 0	6.5	32.0	20.0	1 0	85.5	2,862.

Table E.3a Details of estimated labor requirements and costs for transfer of a Cs-137 source to a new user or to the manufacturer

	Person hours						Labor cost
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	(dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3.0					3.0	132.
Packaging							
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6.0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	12.0	4.0	1.0	24.5	813

Table E.3b Details of estimated labor requirements and costs for disposal of a Cs-137 source

	Person hours						Labor cost
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	(dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3.0					3.0	132.
Packaging							
Radiological Survey			6.0			6.0	192.
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6.0			6.0	192
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	18.0	4.0	1.0	30.5	1,006.

Table E.3c Details of estimated labor requirements and costs for disposal with decon of a Cs-137 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0 5				0 5	18
Radiological Survey			6 0	1 0		7 0	214.
Develop Work Plan	3 0					3.0	132
Decontamination							
Remove Equipment and Survey Component	2 0	2.0	4 0	10 0		18.0	508.
Decontaminate	2 0	2.0		5 0		9 0	271.
Monitor			6 0			6 0	192
Reclean Hot Spots & Monitor	2.0	2 0	4.0	2.0		10 0	334
Packaging							
Radiological Survey			6 0			6 0	192
Documentation Generation	3 0				1.0	4 0	147
Packaging	2 0			4 0		6 0	176
Final Radiological Survey			6 0			6.0	192
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	14 0	6.5	32 0	23 0	1 0	76 5	2,399

Table E.3d Details of estimated labor requirements and costs for storage of a Cs-137 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0 5				0 5	18.
Radiological Survey			6 0	1.0		7.0	214
Develop Work Plan	3 0					3.0	132.
Packaging							
Radiological Survey			6 0			6.0	192
Documentation Generation	3 0				1 0	4.0	147.
Packaging	1 0			2.0		3.0	88.
Final Radiological Survey			6 0			6.0	192.
Surveillance							
Monitoring (0.25 hr/mo/5yrs)	13 0					13.0	573.
Total Labor	20 0	0.5	18.0	3.0	1.0	42.5	1,557.

Table E.3e. Details of estimated labor requirements and costs for storage with decon of a Cs-137 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0 5				0 5	18.
Radiological Survey			6 0	1.0		7.0	214.
Develop Work Plan	3 0					3 0	132.
Decontamination							
Remove Equipment and Survey Component	2 0	2 0	4 0	10.0		18 0	508.
Decontaminate	2 0	2.0		5 0		9 0	271.
Monitor			6 0			6 0	192.
Reclean Hot Spots & Monitor	2 0	2 0	4 0	2 0		10 0	334.
Packaging							
Radiological Survey			6 0			6 0	192.
Documentation Generation	3 0				1 0	4.0	147.
Packaging	1 0			2 0		3 0	88.
Final Radiological Survey			6 0			6 0	192.
Surveillance							
Monitoring (0 25 hr/mo/5yrs)	13 0					13 0	573.
Total Labor	26 0	6 5	32 0	20 0	1 0	85 5	2,862.

Table E.4a Details of estimated labor requirements and costs for transfer of an Am-241 source to a new user or to the manufacturer

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0 5				0.5	18.
Radiological Survey			6 0	1 0		7 0	214.
Develop Work Plan	3 0					3 0	132.
Packaging							
Documentation Generation	3 0				1 0	4.0	147.
Packaging	1.0			2 0		3 0	88.
Final Radiological Survey			6 0			6 0	192.
Transportation							
Loading & Manifesting				1 0		1.0	22.
Total Labor	7.0	0 5	12.0	4 0	1 0	24.5	813

Table E.4b Details of estimated labor requirements and costs for storage of an Am-241 source

	Person hours						Labor cost (dollars)
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	
Planning and Preparation							
Determine Source Fate		0 5				0 5	18
Radiological Survey			6 0	1 0		7.0	214.
Develop Work Plan	3 0					3 0	132.
Packaging							
Radiological Survey			6 0			6 0	192
Documentation Generation	3.0				1.0	4 0	147.
Packaging	1.0			2.0		3.0	88
Final Radiological Survey			6 0			6.0	192
Surveillance							
Monitoring (0.25 hr/mo/5yrs)	13.0					13.0	573
Total Labor	20.0	0 5	18.0	3 0	1.0	42.5	1,557.

Table E.4c Details of estimated labor requirements and costs for storage with decon of an Am-241 source

	Person hours						Labor cost (dollars)
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	
Planning and Preparation							
Determine Source Fate		0 5				0.5	18
Radiological Survey			6 0	1 0		7.0	214
Develop Work Plan	3.0					3.0	132.
Decontamination							
Remove Equipment and Survey Component	2 0	2 0	4 0	10.0		18 0	508.
Decontaminate	2 0	2 0		5 0		9 0	271.
Monitor			6.0			6 0	192.
Reclean Hot Spots & Monitor	2 0	2.0	4.0	2 0		10.0	334.
Packaging							
Radiological Survey			6 0			6 0	192.
Documentation Generation	3 0				1 0	4 0	147.
Packaging	1 0			2 0		3 0	88
Final Radiological Survey			6 0			6.0	192.
Surveillance							
Monitoring (0 25 hr/mo/5yrs)	13 0					13.0	573.
Total Labor	26 0	6 5	32 0	20 0	1 0	85.5	2,862.

Table E.5a Details of estimated labor requirements and costs for transfer of an I-125 source to a new user or to the manufacturer

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18.
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3.0					3.0	132.
Packaging							
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6.0			6.0	192.
Transportation							
Loading & Manifesting				1.0		1.0	22.
Total Labor	7.0	0.5	12.0	4.0	1.0	24.5	813.

Table E.5b. Details of estimated labor requirements and costs for storage of an I-125 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0.5	18
Radiological Survey			6.0	1.0		7.0	214
Develop Work Plan	3.0					3.0	132.
Packaging							
Radiological Survey			6.0			6.0	192.
Documentation Generation	3.0				1.0	4.0	147.
Packaging	1.0			2.0		3.0	88.
Final Radiological Survey			6.0			6.0	192.
Surveillance							
Monitoring (0.25 hr/mo/2yrs)	5.2					5.2	229.
Total Labor	12.2	0.5	18.0	3.0	1.0	34.7	1,213.

Table E.5c Details of estimated labor requirements and costs for storage with decon of an I-125 source

	Person hours						
	Supervisor	Engineer	RP technician	Technician	Secretary	Total	Labor cost (dollars)
Planning and Preparation							
Determine Source Fate		0.5				0 5	18
Radiological Survey			6.0	1.0		7.0	214.
Develop Work Plan	3 0					3 0	132.
Decontamination							
Remove Equipment and Survey Component	2.0	2 0	4.0	10 0		18 0	508.
Decontaminate	2 0	2 0		5.0		9.0	271.
Monitor			6 0			6.0	192
Reclean Hot Spots & Monitor	2 0	2 0	4 0	2 0		10.0	334
Packaging							
Radiological Survey			6 0			6 0	192
Documentation Generation	3 0				1.0	4 0	147.
Packaging	1 0			2 0		3 0	88
Final Radiological Survey			6 0			6 0	192.
Surveillance							
Monitoring (0 25 hr/mo/2yrs)	5.2					5 2	229.
Total Labor	18 2	6.5	32 0	20 0	1.0	77 7	2,518.

Appendix F

Study Contacts for Decommissioning of Reference Sealed Sources

Appendix F

Study Contacts for Decommissioning of Reference Sealed Sources

The many individuals who contributed information that subsequently led to the completeness of this study on the decommissioning of small sealed sources are greatly appreciated and specially acknowledged in this appendix.

A full listing of individuals who contributed to this report is provided below.

ADCO Services, Inc.:	Tony Lizzo
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10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

This report contains the results of a study sponsored by the U.S. Nuclear Regulatory Commission (NRC) to examine the decommissioning of large radioactive irradiators and their respective facilities, and a broad spectrum of sealed radioactive sources and their respective devices. Conceptual decommissioning activities are identified, and the technology, safety, and costs (in early 1993 dollars) associated with decommissioning the reference large irradiator and sealed source facilities are evaluated. The study provides bases and background data for possible future NRC rulemaking regarding decommissioning, for evaluation of the reasonableness of planned decommissioning actions, and for determining if adequate funds are reserved by the licensees for decommissioning of their large irradiator or sealed source facilities. Another purpose of this study is to provide background and information to assist licensees in planning and carrying out the decommissioning of their sealed radioactive sources and respective facilities.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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cost estimates/dose
large irradiator/sealed source

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