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***Life Cycle Costs for Disposal
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***National Low-Level Waste
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Life Cycle Costs for Disposal and Assured Isolation of Low-Level Radioactive Waste in Connecticut

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ABSTRACT

This document presents life cycle costs for a low-level radioactive disposal facility and a comparable assured isolation facility. Cost projections were based on general plans and assumptions, including volume projections and operating life, provided by the Connecticut Hazardous waste Management Service, for a facility designed to meet the State's needs. Life cycle costs include the costs of pre-construction activities, construction, operations, closure, and post-closure institutional control. In order to provide a better basis for understanding the relative magnitude of near-term costs and future costs, the results of present value analysis of out-year costs are provided.

EXECUTIVE SUMMARY

Introduction

All states and compacts that are developing new low-level radioactive waste (LLRW) disposal facilities have met strong resistance to the siting of those facilities. Much of that resistance has centered around concerns about the ability of the facilities to protect public health and safety by containing the radionuclides in the waste. These difficulties in siting LLRW disposal facilities have led to a proposal for a new approach to managing LLRW. In this approach the waste is placed in "assured isolation" (sometimes called "assured storage"), which uses man-made components similar to those used in LLRW disposal concepts. Assured isolation facilities are designed to accommodate continuing inspection and preventive maintenance inside the isolation units. This active inspection and maintenance can continue indefinitely after the operations phase of the facility, if desired. This is in contrast to disposal facilities, which are required to be backfilled upon closure to reduce the need for continuing active maintenance. Backfilling the disposal vaults precludes the option of inspection and maintenance inside the vaults.

Proponents of the assured isolation concept suggest it offers several major advantages over the usual LLRW disposal concepts, including reduced site characterization costs. When the present value of the life cycle cost is taken into account, this reduction in early expenses could be significant. This report describes comparative evaluations of the life cycle costs of assured isolation and disposal as methods for managing LLRW over the long term. The designs used as the basis of the cost analyses are representative of those thought to be generally acceptable to the public and protective of human health and the environment.

Conceptual Designs

Two conceptual facility designs form the basis for estimating life cycle costs: one for a disposal facility, and one for an assured isolation facility. Certain features are common to both facility designs. These include the waste to be emplaced, the period over which the waste is assumed to arrive at the facilities, the annual rates of waste receipt, and certain general characteristics of the disposal and isolation units. Generally, the common features are characteristic of facility designs that have been studied for disposal of LLRW in Connecticut. However, they do not necessarily represent what may eventually result in that state.

In both designs, the waste is placed in above-grade, reinforced concrete structures resembling vaults. Only the details and dimensions of the vaults differ. Both the disposal and assured isolation vaults have engineered earthen covers, although the assured isolation vaults do not have covers that are as elaborate as those for the disposal vaults. The total volume of LLRW to be disposed or isolated is 1,454,000 cubic feet, of which 214,000 cubic feet, or about 15 percent, is Class B and Class C waste. All waste is placed inside cylindrical, reinforced concrete canisters. The canisters are then placed inside the vaults. The waste was assumed to be received and emplaced over 50 years.

Options Analyzed

The life cycles of the disposal and assured isolation facilities analyzed were each divided into several phases to facilitate cost estimation. For the disposal facility, the phases are, in chronological order, preoperations, operations (the period when waste is being received at the facility), closure and postclosure, and institutional control. For assured isolation, the phases are preoperations, operations, and

inspection and preventive maintenance. Since there are no specific plans to close the assured isolation facility, there is no phase in its life cycle comparable to the closure and postclosure phase for the disposal facility.

Several options related to the preoperations and to the institutional control or inspection and preventive maintenance phases of the waste management facilities were analyzed. These options include:

- Different costs for the preoperations phase. The different costs represent different levels of effort expended in site characterization and licensing.
- For the disposal facilities, different durations of the institutional control phase.
- For the assured isolation facilities, different durations of the inspection and preventive maintenance phase.

The various phases of the life cycles of the conceptual disposal and assured isolation facilities, and the options for some of those phases, resulted in the definition of 14 "cases" used in the analysis. The cases are defined in Chapter 2 of this report. Those 14 cases could be combined into 6 distinct combinations of cases, called scenarios, for estimating the life cycle cost of the conceptual disposal facility and 6 distinct combinations of cases for estimating the life cycle cost of the conceptual assured isolation facility.

Cost Estimates

Detailed estimates were made for the costs for each phase of the life cycles and for various options. For both types of facilities, for the preoperations phase the costs were principally for siting, site characterization, licensing and permits, and site preparation. For the operations phase, the greatest costs were for construction of the vaults, placement of the wastes, monitoring, and incentive and assistance payments to the host community. Major costs during the closure and postclosure phase at the disposal facility were for placing the final covers over the vaults and for monitoring. During the disposal facility's institutional control phase, the largest cost was for monitoring; during the assured isolation facility's inspection and preventive maintenance phase, the largest cost was for monitoring and inspecting the vault interiors.

It was assumed that enough money is collected during the operations phase to ensure that all activities following cessation of waste receipt can be paid for. Part of that money is needed to ensure that after the end of operations both the disposal facility and the assured isolation facility will have sufficient funds available to cover the cost of retrieving all waste, cleaning up contaminated soil at the site (disposal only), and placing some of those materials in another disposal or assured isolation facility, as appropriate. To prepare the life cycle cost estimates, it was assumed that monies put aside in a trust fund must be sufficient to pay for these activities any time following 100 years after the end of waste receipt.

Present Value Analysis

Present value analysis determines the amount of money that would have to be put aside now to have enough to pay for all activities anticipated to take place during a project's life cycle. One of the factors that must be taken into account when considering the cost of an activity that will not take place until a significant amount of time has elapsed is the effect of inflation. Another factor that must be

considered is the potential earnings on money put aside now for paying expenses well into the future, called the return on investment.

One characteristic of present value analysis is that, whenever the return on investment is greater than inflation (as is usually the case), the present value of an activity decreases the further that activity occurs in the future. Thus, for most analyses where the annual return on investment exceeds the annual inflation rate, costs that are deferred make smaller contributions to the present value life cycle cost than those that are incurred early in the life cycle. For the present value calculations for activities through the end of waste receipt described in this report, the inflation rate used was 4 percent and the return on investment was 7.5 percent. With those parameters, a dollar spent 25 years in the future is equivalent to 44 cents set aside now (i.e., the present value of that dollar is 44 cents); a dollar spent 50 years in the future is equivalent to 19 cents now, and a dollar spent 100 years in the future is equivalent to less than 4 cents now; and beyond about 140 years in the future, the present value of a dollar is less than 1 cent.

Comparison of Present Value Life Cycle Costs

Present values for disposal scenarios range from \$340 to \$410 million while present values for assured isolation scenarios range from \$330 to \$350 million. Assuming a total waste volume of 1,454,000 cubic feet, the present value unit costs per cubic foot range from \$520 to \$630 for disposal and \$510 to \$530 for assured isolation. As a general rule, therefore, the present value life-cycle cost for assured isolation is the same or somewhat lower than for disposal.

Disposal relies primarily on site characteristics for waste isolation. Assured isolation, on the other hand, relies on active inspection and preventive maintenance of the engineered structure. It is anticipated that little if any site characterization would be necessary to ensure waste isolation. Because of this fundamental conceptual difference between the two approaches, it is to be expected that higher preoperations costs generally will be incurred for disposal (due to the extensive site characterization necessary to convince regulators of site licensability). These higher preoperations costs will influence the present value calculation more than costs incurred later in the life cycle.

Conclusion

Assured isolation may result in lower present value life cycle costs than disposal, depending on the assumptions made for costs during the preoperations phase. The advantage of lower costs at the start of the life cycle of typical assured isolation facilities is to some degree offset by higher costs during the operations phase, but not enough to cancel that advantage.

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Life Cycle Costs for Disposal and Assured Isolation of Low-level Radioactive Waste in Connecticut

1. INTRODUCTION

1.1 Background

Most organizations that have attempted to site new (LLRW) disposal facilities have met strong resistance to the placement of those facilities. Much of that resistance has centered around concerns about the ability of the facilities to protect public health and safety by containing the radionuclides in the waste. Recently, a novel approach to managing LLRW has been proposed (Newberry 1995). In this approach the waste is placed in "assured isolation," which uses man-made components similar to those used in LLRW disposal concepts. The basis of the assured isolation concept is reliance on inspection and maintenance of the engineered facility rather than on sometimes uncertain site characteristics. Because they rely on inspection and preventive maintenance, assured isolation facilities require access to the interior of the isolation vaults before, during, and after waste emplacement; such access is not normally available after waste emplacement with disposal facilities. Specifically, in assured isolation the spaces between waste packages and vault walls are left open to allow movement of equipment and personnel involved in inspecting and maintaining the condition of the vaults. The assured isolation concept allows such inspection and maintenance to continue indefinitely.

The proponents of the assured isolation concept suggest it offers several major advantages over the usual LLRW disposal concepts. Because the concept relies on inspection of vault interiors and preventive maintenance, the public might accept an assured isolation facility more readily than a disposal facility. Increased acceptance could reduce the time required for siting such a facility and increase the number of siting options. Any resulting reduced site characterization costs (which for some compact facilities have approached \$100 million) should lower the life cycle cost of the facility. When the present value of the life cycle cost is taken into account, this reduction in early expenses could be significant. Also, because access to the waste will be maintained for an indefinite period, technical advances can be used to help ensure waste isolation, even to the extent of removing the waste to treat and manage it in a different manner.

Assured isolation leaves open the possibility, among several others, of eventually closing a facility once there is high confidence in the overall system's ability to isolate waste. Any such closure would, of course, represent a conversion of the assured isolation facility into a disposal facility. It would require that all regulatory requirements for disposal in effect at that time be met and that approval of the appropriate regulatory agency be obtained.

1.2 Purpose

The purpose of this report is to assist in comparative evaluations of the life cycle costs of assured isolation and disposal as methods of managing LLRW over the long term. This report does not examine other issues regarding the relative merits of the two waste management methods, such as their acceptability to the public or their ability to protect the public or the environment. The designs used in the cost analyses are, however, representative of those thought to be generally acceptable and protective.

The waste volumes and characteristics used in this comparative analysis are similar to those that may require management in Connecticut. However, the conceptual facility designs and cost estimates are not intended to represent those that may ultimately result in that state.

This report presents the results of present value analyses of costs associated with the major life cycle phases of conceptual assured isolation and disposal facilities for LLRW. For some of those phases, several options for activities conducted during the phase were analyzed. In this report, the information on present values of costs is presented separately for each phase of the life cycle and (if applicable) for each option.

1.3 Overview

The conceptual designs and the major phases of the facility life cycles for which the present value life cycle costs were estimated are described in Chapter 2. Chapter 2 also defines the 12 plausible combinations of "cases"—6 combinations for disposal and 6 combinations for assured isolation—for which present value costs were estimated. Chapter 3 provides brief descriptions of how present value analyses are conducted and how unit costs for waste placement are estimated. Chapter 4 presents and discusses the estimated present value life cycle costs for a selected set of cases and, more briefly, for all plausible combinations of cases.

Appendix A gives brief descriptions of what each of the cost elements, or building blocks, for the cost estimates involves. Appendix B describes methods used to scale estimates of individual cost elements for the disposal and assured isolation facilities from those for a reference disposal facility. Appendix C presents major cost elements used in estimating the life cycle costs for a selected set of the cases described in Section 2.4. Appendix D presents detailed cost estimates for all cases.

2. CONCEPTUAL DESIGNS

This chapter describes the conceptual facility designs that form the basis for the comparative life cycle costs. It also discusses the concepts of operation for the facilities, including such details as the durations and levels of monitoring after all the waste has been emplaced. Because the present value of life cycle costs is influenced by the time in the life cycle when the costs are incurred, the concepts of operation influence the comparisons that are the subject of this report. This chapter concludes with descriptions of the twelve combinations of cost cases that were analyzed.

2.1 COMMON FEATURES

Certain features, shown in Table 2-1, are common to both facility designs. These include the waste to be emplaced, the period over which the waste is assumed to arrive at the facilities, the annual rates of waste receipt, and certain gross characteristics of the disposal and assured isolation units. Generally, these features are characteristic of waste and designs that have been studied for disposal of LLRW in Connecticut. However, they do not necessarily represent what may eventually result in that state.

For the purposes of this study, the facilities were assumed to operate full time, with staffs sized according to the waste receipt rates. In both designs, the waste is put in above-grade, reinforced concrete structures resembling vaults. Only the details and dimensions of the vaults differ, as described in Sections 2.2 and 2.3. The disposal units and assured isolation units have engineered earthen covers, although the isolation units do not have covers that are as elaborate as the disposal units (unless a decision were to be made later to convert the assured isolation facility into a disposal facility).

The total volume of LLRW to be disposed of or stored is 1,454,000 cubic feet, of which 214,000 cubic feet, or about 15 percent, is Class B and Class C waste. The waste acceptance criteria were assumed to be the same for disposal and assured isolation. All waste is placed, still in its shipping containers, inside cylindrical, reinforced concrete canisters that are approximately 9 feet high and 8 feet in diameter. These canisters can hold fourteen 55-gallon drums in two layers of seven drums each, a 96-cubic-foot box, or a 170-cubic-foot liner holding waste. Voids in the canisters are then filled and the canisters are placed inside the vaults. While the vaults described in this report might be used to accommodate large irradiated components from nuclear power plants, no decision on whether they would be appropriate for such use has been made at this time.

The waste was assumed to be received and emplaced over 50 years at the rates shown in Figure 2-1, with operations assumed to start in the year 2002. The waste was assumed to be received at a rate of 16,000 cubic feet per year from 2002 through 2007. Starting in 2008, when reactor decommissioning in Connecticut is expected to begin, and ending in 2039, when decommissioning is expected to end, an average waste receipt rate of 40,560 cubic feet per year was assumed.* From 2040 through 2051 (the last year the facilities receive waste), an average waste receipt rate of 5,000 cubic feet per year was assumed.

* Subsequent to the preparation of these analyses, a decision was made to begin decommissioning one of the nuclear power plants in Connecticut in 1998 or 1999. The analyses have not been changed to reflect that decision.

Table 2-1. Common features of the assured isolation and disposal facility designs.

Feature	Description
Waste location	Above grade
Disposal units	Reinforced concrete vaults with engineered earthen covers ^a
Waste canisters	Reinforced concrete cylinders approximately 9 feet high and 8 feet in diameter
Waste volume	1,454,000 cubic feet (15 percent is Class B and Class C waste)
Waste emplacement rate	Shown in Figure 2-1

a. Earthen cover designs for assured isolation are generally different from those for disposal (see Sections 2.2.1 and 2.3.1).

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Figure 2-1. Waste receipt rates.

2.2 Conceptual Design For Disposal

The conceptual design for LLRW disposal involves placing concrete canisters in concrete vaults. Waste in its shipping containers is placed inside the canisters, grout is added to fill all the voids in the canisters, and the canisters are sealed. The canisters are then loaded through the open tops of the vaults before the roofs are built. When a vault is full, the spaces between and above the canisters are filled with gravel and the vault roof is constructed. Eventually, the vaults in a disposal unit are covered with an engineered earthen cover system. The system of concrete canisters, concrete vaults, and an earthen cover helps isolate the waste from the biosphere, and the cover protects the concrete vaults from the effects of temperature and moisture.

A single vault design is used for all three classes of LLRW. The interior of this vault is high enough to accommodate three layers of concrete canisters. If all of the waste is shipped in 55-gallon drums, the vault can accommodate almost 16,000 cubic feet of waste. The bottom layer of the canisters is placed on a 6-inch layer of gravel to help keep it above any water that may accumulate on the cell floor. The thickness of the gravel is included in determining the vault's interior height.

To satisfy regulatory requirements for their disposal, including the disposal depth requirement for Class C wastes, Class B and C wastes are only put in the lowest layer of canisters. The combination of the vaults and the canisters provides the 300 years of structural stability required for the Class B and C wastes. Therefore, all three classes of waste can be placed in the same vault.

Drains route any water that may reach the vault floors into collection tanks. These tanks are normally dry. If any water is detected in the tanks, it is sampled and analyzed for all potential contaminants.

Figure 2-2 is a perspective drawing of the vaults used in the disposal facility. Figure 2-3 is a plan view which shows the arrangement of the vaults in the larger of the two disposal units in the facility. Note that the vaults are constructed in pairs that are isolated from one another by an expansion joint. The two rows of vaults that make up the disposal unit are separated by an aisle to allow the use of a bridge crane to load the waste into the vaults. Vault walls are shown with various thicknesses. Generally, the outermost walls of the disposal unit are thickest to resist potential chemical attack from soil and water. Wall thickness is also determined by the span of the vault roof.

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Not to Scale

Figure 2-2. Perspective drawing of disposal vaults.

Figure 2-3. Plan view of the larger disposal unit.

Figure 2-4 is a vertical cross section of a disposal vault. The exterior of this vault measures about 92 feet long, 46 feet wide, and 37 feet high from the bottom of the foundation to the top of the lowest point on the roof. The interior of each vault is about 86 feet long, 43 feet wide, and 28 feet high.

Figure 2-5 shows the layout of the disposal facility. As mentioned above, the vaults in this design are arranged in two disposal units, one larger than the other. The larger unit contains 2 rows of 26 vaults each, while the smaller contains 2 rows of 20 vaults each. The area covered by the disposal facility, including a 400-foot wide buffer zone, totals 123 acres.

Earthen Covers—The final component of the disposal unit is the cover system. After each vault is filled, an interim cover is placed over it. The lower 3.5 feet of the interim cover are identical to the lower 3.5 feet of the final cover shown in Figure 2-6. The upper 4 feet of the interim cover are a temporary layer of soil which supports vegetation that helps reduce potential erosion and increases evapotranspiration to reduce water infiltration. The interim covers have the same slope over the tops of the vaults as the final cover but have a 50 percent slope at the sides of the vaults.

When the disposal facility is closed, the top 4 feet of the interim covers that are over the tops of the vaults are replaced with the materials that constitute the top 4 feet of the final cover shown in Figure 2-6. Around the sides of the vaults, native soil is placed to support the final cover with the shallow slopes shown in Figures 2-3, 2-4, and 2-5.

The layers of the final cover system and their functions, starting at the bottom of the cover and proceeding upward, are as follows:

- At least 6 inches of gravelly sand. The sand serves as a lower drainage layer to help divert away from the vaults any water that comes through the clay layer above. It also serves as bedding for the clay layer.
- Three feet of carefully compacted clay. The clay layer acts as a barrier that keeps precipitation from reaching the vaults.
- A layer of 60-mil, high-density polyethylene (HDPE). The HDPE layer serves as a barrier to precipitation.
- A layer of geotextile. The geotextile keeps the coarse gravel and cobble from damaging the HDPE layer.
- Two feet of coarse gravel and cobble. This layer serves as a major drainage pathway to divert precipitation away from the vaults. Water moving downward through the cover is stopped by the HDPE liner and clay layer and, because of the slope of the cover layers, runs off through the coarse gravel and cobble. The gravel and cobble layer also serves as a capillary break by preventing moisture from being drawn upward out of the clay layer (the clay layer must remain moist to serve as a barrier to precipitation), as a physical barrier to animal intrusion, and as a deterrent to plant root intrusion because it holds very little of the moisture necessary to support plant life.
- Six inches of pea gravel topped by a 6-inch layer of sand. The pea gravel and sand provide gradual changes in soil grain size to keep the soil in the top layer from moving down into the coarse gravel and cobble.

Figure 2-4. Vertical cross section of a disposal unit.

Figure 2-5. Layout of the disposal facility.

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Figure 2-6. Final cover system for the disposal units.

- One foot of topsoil. The topsoil allows growth of short-rooted plants, such as grass, that prevent wind or water erosion of the cover. The vegetation on top of the cover also reduces, through transpiration, the amount of precipitation that the lower layers of the cover have to divert away from the vaults.

Immediately above the disposal vaults, the slope of the cover system is about 3 percent. This gradient encourages rainfall runoff without creating significant potential for erosion. The slope of the final cover system at the sides of the disposal vaults is 20 percent.

The disposal facility also includes a runoff retention pond to hold runoff from the disposal units. Water collected in the pond is analyzed and, if found to be uncontaminated, released to the environment. If the water in the retention pond is found to be contaminated, it is processed to remove contaminants and then released.

Surrounding the disposal units and retention pond is the buffer and security zone of at least 400 feet required by Connecticut regulations. Administrative and other support facilities are located within the buffer and security zone.

Life Cycle—The life cycle of the disposal facility includes preoperations, operations, closure and postclosure, and institutional control phases. The facility is located at a volunteer site. During the 5-year preoperations phase, the site for the disposal facility is selected and characterized, and the facility is designed and licensed. Some initial construction of support facilities occurs during the preoperations phase.

The facility's operations phase, during which all of the waste is received at the site, lasts 50 years. Waste arriving at the facility is disposed of as soon as it is received and placed in concrete canisters. As waste is accumulated in the disposal units, a program for monitoring for any releases from the disposal units, and from the waste canisters inside the disposal units, is maintained. The environment around the facility also is carefully monitored for any releases of contaminants. If any releases are detected, they would be appropriately remediated.

The disposal facility's closure and postclosure phase lasts 5 years. This phase begins with the end of waste receipt and involves closure and intense monitoring of the facility. Activities during this phase include removal of most support buildings and placement of the final covers over the vaults.

The closure and postclosure phase is followed by an institutional control phase, during which the radioactivity in the disposed waste decays significantly and the facility is monitored to detect releases of radioactive contaminants and signs of deterioration of the waste containment system. Figure 2-7 illustrates how the total radioactive content of typical Connecticut waste decays with time. Note that in 100 years the radioactivity decays to about 8 percent of its original value. In 500 years, it drops to less than 1 percent of its original value.

It was assumed that during institutional control, as confidence is gained in the performance of the facility, the monitoring and maintenance effort (and therefore the rate of expenditure) will be approximately halved at some point, and later halved again. Costs for two durations of institutional control were analyzed—100 years and 300 years (see Section 2.4). For the 100-year duration, it was assumed that the effort is halved 10 years after the start of institutional control and halved again 25 years after the start of institutional control. The corresponding points for the 300-year duration are 30 years and 75 years after the start of institutional control. The cutoff point for the cost analyses was the end of the institutional control phase.

Table 2-2 lists the major phases of the disposal facility life cycle.

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Figure 2-7. Decay of radioactivity in waste with time.

Table 2-2. Major life cycle phases of the disposal facility.

Phase	Duration (yr)	Major Activities
Preoperations	5	Site selection Site characterization Design Licensing
Operations	50	Waste placement Interim cover placement Intense monitoring
Closure and postclosure	5	Final cover placement Intense monitoring
Institutional control	100 or 300	Monitoring and maintenance

2.3 Conceptual Design For Assured Isolation

Like the disposal facility design, the assured isolation facility design involves placing concrete canisters in concrete vaults. However, in the assured isolation design, granular materials such as gravel or sand are used to fill any void spaces between the waste shipping containers and the canister walls. This feature facilitates retrieval of individual waste containers within the canisters.

Among other things, the design of the assured isolation facility does not preclude a subsequent decision to convert the facility into a disposal facility. Of course, any such conversion will depend on being able to meet the regulatory requirements for disposal in effect at that time and on getting approval from the appropriate regulatory agency.

To allow continual monitoring of the condition of the vaults, the assured isolation facility incorporates a remotely operated, mobile, visual inspection device. This device, which is equipped with a television camera, is used to check the vaults during the operations phase, and for as long after the end of operations as inspection and preventive maintenance continue. The device must raise the camera almost 30 feet above the vault floor and maneuver it horizontally about 25 feet over the top layer of waste canisters to inspect the vault roof. To accommodate the remotely operated camera, the design for the assured isolation vaults incorporates 3.5-foot-wide aisles between the waste canisters and the vault walls.

Drains route any water that may reach the floors of the vaults into collection tanks. These tanks are normally dry. If any water is detected in the tanks, it is sampled and analyzed for all potential contaminants.

Unlike the construction sequence for the disposal facility, the roofs of assured isolation vaults are constructed before waste placement begins, and the waste is emplaced from the sides of the cells. This sequence is primarily dictated by two differences between disposal and assured isolation. In the disposal facility designs, gravel is placed on top of the waste canisters when each vault is filled, serving as a lower form when the concrete roof is constructed. This cannot be done in the assured isolation design because the vault roof must be inspected from inside. Also, since there must be access to the vaults to inspect their interiors, the waste is loaded into the vaults through openings in the walls instead of through the roof.

A less complex earthen cover is placed over the assured isolation vaults after they are filled with waste. This cover protects the concrete from freezing temperatures and helps divert precipitation away from the vaults. Furthermore, if repair of the vault roofs becomes necessary, this cover is much easier to replace than the more complex cover placed over disposal vaults.

As mentioned, the condition of the vault walls, floors, and roofs is inspected using a remotely controlled wheeled or tracked device equipped with a television camera. Viewing a television monitor in a location removed from potential radiation from the waste, an operator uses the device to scan all areas of the walls and roof of each disposal vault, and all visible areas of the vault floor. Any anomalous conditions observed are investigated further. The estimated cost for this inspection process does not include costs for investigations of anomalous conditions, since their frequency and nature are difficult to predict.

If in the future it is decided to convert the assured isolation facility into a disposal facility, and if the facility meets the regulatory requirements in effect for disposal at that time, closure features that ensure continued protection of public health and safety will be designed based on the actual record of the facility's performance. These features could be significantly different from anything now conceived of; however, for the purpose of this cost comparison, it was assumed that the spaces between the waste canisters and the interior vault walls would be filled with pea gravel, and that the inspection access portals from the central aisle into the vaults would be replaced with concrete walls. It also was assumed that the covers over the

isolation units would be improved to be the same as the covers for the disposal facility (see Figure 2-6) and that the assured isolation facility would have to be licensed as a disposal facility.

The assured isolation facility design uses a single vault design for all three classes of LLRW. The interior of this vault is high enough to accommodate three layers of concrete canisters. If all of the waste is shipped in 55-gallon drums, the vault can accommodate almost 16,000 cubic feet of waste. To satisfy regulatory requirements in the event a decision is made to convert the assured isolation facility into a disposal facility, Class B and C wastes are only put in the lowest layer of canisters.

To allow future reductions in the inspection and preventive maintenance effort for certain vaults which may be justified after Class A waste has undergone radioactive decay for 100 years, the Class B and C wastes are used to fill the entire lowest layers of a few vaults. Because there is so little Class B and Class C waste, placing the waste this way allows some vaults to be used only for isolation of Class A waste. Should the assured isolation facility be converted into a disposal facility some day, placing Class B and C wastes in the lowest layer of canisters will ensure that the disposal depth requirement for Class C wastes will be satisfied. Also, the combination of vaults and canisters will provide the 300 years of structural stability required for Class B and C wastes.

Each vault contains a sump at a low point in the floor to collect any water that may enter the vault. The sumps are normally dry. If any water is found in a sump during inspection of the vault interior, it is sampled and analyzed for all potential contaminants.

Figure 2-8 is a perspective drawing of the vaults used in the assured isolation facility. Figure 2-9 is a plan view that shows the arrangement of the vaults in the larger of the two isolation units in the facility. This unit contains 52 vaults. The vaults are separated by a 20-foot-wide aisle into 2 rows of 26 vaults each. Note that the vaults are constructed in pairs that are isolated from one another by an expansion joint.

Figure 2-10 is a vertical cross section of an assured isolation facility vault. The exterior of this vault measures about 99 feet long, 35 feet wide, and 37 feet high from the bottom of the foundation to the top of the lowest point on the roof. The interior of each vault is about 93 feet long, 50 feet wide, and 28 feet high. Each vault can contain up to 150 concrete canisters configured in 3 layers of 50 each. These layers are placed in the center of the cell to create the 3.5-foot-wide aisles needed for the inspection equipment. Additionally, rather than being placed on a gravel bed (as is done in the disposal vaults), the bottom layer of canisters is placed directly on the cell floor. The assured isolation vaults do not have a gravel bed because any water on the cell floor would be detected during inspection and the conditions causing it would be quickly corrected.

Figure 2-11 shows the layout for the assured isolation facility. As in the design for the disposal facility, the vaults are arranged in two isolation units, one larger than the other. Also as with the disposal facility, the larger unit contains 2 rows of 26 vaults each, while the smaller unit contains 2 rows with 20 vaults each. The design reserves enough land to accommodate the larger earthen covers for conversion to disposal. The total site area is about 136 acres.

Earthen Covers—Figure 2-12 shows the cover system for the assured isolation units. The layers of this system and their functions, starting at the bottom and proceeding upward, are as follows:

- At least 6 inches of gravelly sand. The gravelly sand serves as a lower drainage layer to help divert away from the vaults any water that comes through the clay layer above. It also serves as bedding for the clay layer.

Not to Scale

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Figure 2-8. Perspective drawing of assured isolation vaults.

Figure 2-9. Plan view of the larger assured isolation unit.

Figure 2-10. Vertical cross section of an assured isolation unit.

Figure 2-11. Layout of the assured isolation facility.

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Figure 2-12. Cover system for the assured isolation units.

- Three feet of carefully compacted clay. The clay acts as a barrier that keeps precipitation from reaching the vaults.
- Four feet of native soil. The soil allows growth of short-rooted plants, such as grass, that prevent wind or water erosion of the cover. It also protects the clay from freeze-thaw cycles. The vegetation on top of the cover also reduces, through transpiration, the amount of precipitation that the clay and sand layers of the cover have to divert away from the vaults.

The cover shown in Figure 2-12 is sufficiently deep to protect the concrete vaults from freeze-thaw temperature cycles in Connecticut and to help prevent intrusion of precipitation and burrowing animals into the vaults, canisters, and waste. The slope of the covers over the isolation vaults is 3 percent, the same as the slope of the covers over the disposal vaults. The 50-percent cover slope at the sides of the isolation vaults is the same as that at the sides of the disposal vaults when the interim covers are in place. In case it is later decided to convert the assured isolation facility to a disposal facility, the site design leaves enough space to build covers over the isolation vaults that have the same thickness and slopes as those in the disposal facility design.

The assured isolation facility includes a runoff retention pond and 400-foot-wide buffer and security zone similar to the disposal facility. Water collected in the pond is analyzed, and if found to be uncontaminated, released to the environment. If the water in the retention pond is found to be contaminated, it is treated to remove the contaminants and then released. As with the disposal facility design, administrative and other support facilities are located in the buffer and security zone.

Life Cycle—The life cycle of the assured isolation facility includes 5-year preoperations and 50-year operations phases identical to those for disposal. As waste is accumulated in the isolation units, inspection of emplaced waste canisters and their surrounding vaults begins. Any potential impairment of the integrity of the canisters or vaults is remedied. Also, monitoring for any releases of radioactivity from the canisters, primarily by analyzing any water in the vaults, is conducted. The environment around the isolation units and the facility is also monitored for any releases of radionuclides. Because this monitoring is less important in demonstrating that the facility is performing as desired, however, it is generally conducted at a lower intensity than at the disposal facilities.

Since the assured isolation facility is not closed when waste receipt ends, its life cycle has no phase comparable to the closure and postclosure phase for disposal. Support facilities not needed for continued inspection and preventive maintenance are removed at the end of the operations phase.

For the purpose of the cost analyses, inspection and preventive maintenance at the assured isolation facility were assumed to continue at some level after waste stops arriving. As occurs in disposal, the radioactivity in the waste continues to diminish due to radioactive decay during the post-operations inspection and preventive maintenance phase (see Figure 2-7). Initially, inspection and preventive maintenance are assumed to continue at half the level maintained prior to the end of operations. One hundred years after the end of operations, inspection and preventive maintenance at vaults containing only Class A waste are discontinued, and the corresponding effort at the other vaults is reduced by half. At the same time, it was assumed that the level of effort for site monitoring and all other site efforts is also reduced by about half. (Note that these intervals are significantly longer than those for a disposal facility.) Later, if it can be demonstrated that public health and safety will be protected and if all appropriate regulatory agencies approve, inspection and preventive maintenance can end. Two durations of inspection and preventive maintenance were analyzed: 300 years and 500 years. While inspection and preventive maintenance could continue longer, the cost analyses did not cover durations beyond 300 years or 500 years.

Table 2-3 lists the major phases of the assured isolation facility life cycle.

Table 2-3. Major life cycle phases of the assured isolation facility.

Phase	Duration (yr)	Major Activities
Preoperations	5	Site selection Site characterization Design Licensing
Operations	50	Waste placement Cover placement Inspection Monitoring
Inspection and preventive maintenance	300 or 500	Inspection Preventive Maintenance Monitoring

2.4 Options Analyzed

In conjunction with the conceptual designs for disposal and assured isolation, options related to the development and operation of the waste management facilities were analyzed. Generally, these options included:

- For the preoperations phase, different levels of effort expended to characterize the site and obtain licenses.
- For the disposal facility, different durations of institutional control.
- For the assured isolation facility, different durations of inspection and preventive maintenance following the end of waste receipt.

Present value cost estimates are given in this report for many distinct cases. Each case is designated by an alpha-numeric code which indicates whether a disposal facility or an assured isolation facility is represented, what life cycle phase is represented, and which of the several options, if applicable, for that life cycle phase is represented. For example, the code D1B indicates that the case is for a disposal facility, for the first (preoperations) phase, and for costing option B.

The cases analyzed are as follows:

DISPOSAL

Preoperations Phase

- Case D1A: This case is based on the methods used in NY 1995 and RAE 1992. The costs tend to be optimistically low compared to recent experience.
- Case D1B: This case is based on an estimate of the average recent experience for preoperations costs in the U.S. Full characterization of a single site is assumed.
- Case D1C: This case is also based on recent experience, but with full characterization of two sites.

Operations Phase

- Case D2: This case represents operations at the disposal facility.

Closure and Postclosure Phase

- Case D3: This case represents closure and postclosure activities at the disposal facility.

Institutional Control Phase

- Case D4A: This case represents institutional control lasting 100 years.
- Case D4B: This case represents institutional control lasting 300 years.

ASSURED ISOLATION

Preoperations Phase

- Case I1A: This case represents preoperations activities that do not include site characterization because the assured isolation inspection system is designed to preclude release of contamination to the site.
- Case I1B: This case is the same as Case I1A, except that limited or confirmatory drilling and groundwater characterization at the site are added.
- Case I1C: In this case, the costs for several preoperations cost elements from Case D1A are used for the site development and for the licensing and permitting cost elements. They include costs for site development, environmental assessment and license application, licensing, and permits. This case represents a full site characterization and licensing process comparable to that for a disposal facility, as represented by the preoperations cost in Case D1A. (The licensing process, however, need not depend on site characteristics.)

Operations Phase

- Case I2A: This case represents operations at the assured isolation facility, without groundwater monitoring.
- Case I2B: This case is the same as for Case I2A, except that a cost for groundwater monitoring is added.

Inspection and Preventive Maintenance Phase

- Case I3A: The case represents inspection and preventive maintenance with cost estimation ending 300 years after the end of operations.
- Case I3B: This case represents inspection and preventive maintenance with cost estimation ending 500 years after the end of operations.

Figures 2-13 and 2-14 indicate which combinations of the preceding situations are plausible for disposal and assured isolation, respectively. The combinations joined by a series of arrows are plausible. There are six plausible combinations for disposal and six plausible combinations for assured isolation.

Figure 2-13. Cases for disposal.

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Figure 2-14. Cases for assured isolation.

3. PRESENT VALUE ANALYSIS

3.1 General Present Value Calculations

There are generally three methods for calculating estimates of costs of multi-year projects:

- Constant Value, which is the cost if the entire project was executed and paid for in a certain year, usually the current year. Costs are calculated for each year of the project as though the expenses are being paid in the designated year and then summed.
- Current Dollar, in which the effect of future inflation is accounted for on a year-by-year basis before summing the estimates of annual costs.
- Present Value, in which the effects of both inflation and the time value of money are accounted for on a year-by-year basis before summing the estimates of annual costs.

The first two methods ignore important aspects of the effects of time on long projects, so the present value method is used in this analysis of life cycle costs. It is the method usually chosen for use in comparing costs of alternative approaches to a specific objective where the magnitudes or timing of expenditures differ depending on the alternative.

Present value analysis determines the amount of money that would have to be put aside now to have enough to pay for all activities anticipated to take place during a project's life cycle. The effect of inflation is one of the factors that must be taken into account when considering the cost of an activity that will not take place until a significant amount of time has elapsed. Another factor that must be considered is the net potential earnings on deferred expenses or on money put aside now for paying expenses well into the future, called the return on investment. The following paragraphs help illustrate the interaction between inflation and return on investment and how they influence the present value of any activity that will take place in the future.

The return on investment has a significant impact on the results of present value analyses. The 7.5-percent annual return on investment used in these analyses to calculate the present value of costs incurred during the preoperations and operations phases is considered consistent with the cost of public borrowing during a period when inflation is at the 4-percent annual level that was also assumed for the analyses. A different return on investment, 6 percent, was used in calculating the present value of activities after the end of waste receipt. This lower return was chosen to be consistent with rules proposed by the U.S. Nuclear Regulatory Commission for funding of post-operations activities at commercial power reactors (NRC 1997). The lower return on investment represents a conservative approach to estimating how much money must be collected to ensure there will be sufficient funds for later activities. The net effect of using the 6-percent return on investment is to raise the present values of activities conducted after the end of operations, compared to what would have been calculated if the 7.5-percent rate of return had been used.

Suppose it is known that a certain item at the assured isolation or disposal facility, such as a wrench, must be purchased 30 years in the future. (The item could just as well be a bulldozer, a truck, an hour of the time of a watchperson, or the cost of a laboratory analysis of a groundwater sample.) If the present cost (in 1996 dollars) of the wrench is \$10, the cost 30 years from now, in the year 2026, can be expected to be higher due to inflation. At the assumed rate of inflation of 4 percent per year, the wrench, when purchased 30 years from 1996, will cost about \$32.40 in 2026 dollars. Figure 3-1 illustrates the effect of inflation on the cost of the wrench. However, if the \$10 that could be used to purchase the wrench in 1996 is invested in

**Assumptions: 4-percent inflation
7.5-percent return on investment**

**A wrench that costs \$10 now will cost \$32.40 in 30 years.
\$3.70 invested now will be worth \$32.40 in 30 years.**

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Figure 3-1. Present value illustration.

something that will yield a return on investment of 7.5 percent a year over the next 30 years, that \$10 will be worth about \$87.50 in 2026. Using an assumed 4-percent inflation and 7.5-percent return on investment, the 1996 present value of the wrench to be purchased in 2026 is the projected cost in 2026 (\$32.40) divided by the value in 2026 of the \$10 invested in 1996 (\$87.50), times the present cost of the wrench (\$10). This calculation gives a present value of about \$3.70. Figure 3-1 illustrates that the present value of the wrench to be purchased in 2026 is the amount that would have to be invested in 1996 at a 7.5-percent rate of return to be able to buy the wrench 30 years later if the price of the wrench were to increase at 4 percent per year.

If it had been assumed that the facilities were privately funded, the return on investment for the preoperations and operations phases would have been assumed to be higher because private companies generally have to borrow money at higher interest rates and have to pay corporate income taxes on profits. The result of an assumption of private funding would be to exaggerate the effects of the present value analysis on costs for those phases, further reducing the present values of costs expected to be incurred in the distant future. For example, with a 10 percent return on investment the preceding calculation would yield a present value for the wrench of about \$1.90.

Present value analysis is used to compare life cycle costs of projects to help identify projects that are economically most favorable over a defined period of time. For many projects, such as road improvements or harbor dredging, there is a readily identifiable monetary return for the money spent on the work. For other projects, such as those involving environmental protection or improvements in safety features, the monetary return may be harder to define. The enhanced protection of public health and safety that will result from building a LLRW disposal or assured isolation facility is a major benefit though, even if it is difficult to express in monetary terms. For this comparison, it was assumed that the disposal facility and the assured isolation facility would begin operations at the same time, and thus that the benefits they provide would be essentially the same. This assumption allowed the comparison to proceed solely on the basis of the present values of the costs of these two facilities.

One of the concerns sometimes expressed about present value analyses relates to uncertainties in the predicted inflation rate and return on investment. The last few decades have demonstrated that these parameters can vary widely over the time frames of interest in this comparison. However, it is the difference between these two parameters that determines the present value of a future cost for a particular project; that difference, known as the real rate of return, is much less volatile than either of its two individual components.

One characteristic of present value analysis is that, whenever the return on investment is greater than inflation (i.e., a positive real rate of return), the present value of an activity decreases the further that activity occurs in the future. If the wrench used in the example above is to be purchased 40 years in the future instead of 30 years, the present value of the wrench would be about \$2.70. Thus, for most analyses where the annual return on investment exceeds the annual inflation rate, costs that occur later make smaller contributions to the present value life cycle cost than those that are incurred early in the life cycle.

The higher the assumed real rate of return, the less impact expenditures in the distant future have on present value costs. Therefore, the assumed real rates of return used in the calculations can influence the relative present value life cycle costs of disposal and assured isolation, depending on when particular expenditures are made.

As noted above, for the present value calculations described in this report, the inflation rate used was assumed to be 4 percent and the return on investment was assumed to be 7.5 percent for costs incurred during the preoperations and operations phases. Figure 3-2 shows how this combination of return on investment and inflation reduces the impact of costs that are incurred in the future. The figure indicates the present value of a dollar spent at various times in the future. For example, a dollar spent 25 years in the future is equivalent to 44 cents spent now, a dollar spent 50 years in the future is equivalent to 19 cents now, and a dollar spent

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Figure 3-2. Effect of present value analysis.

100 years in the future is equivalent to less than 4 cents now. Beyond about 140 years in the future, the present value of a dollar is less than 1 cent spent now. This illustrates that the present values of the life cycle costs for the two waste management methods being compared will depend largely on the schedules of expenditures in the early years of their existence.

3.2 Present Value Calculation Of Unit Disposal Costs

A unit cost for placing waste in a disposal facility or an assured isolation facility (unit placement cost) is determined using the present values of the facility's life cycle costs and of the revenues required to meet those costs. The revenues required to meet life cycle costs are estimated using the projected annual rates of waste deliveries to the facility and a unit waste placement cost assumed to be constant in real terms (e.g., adjusted for inflation) over the facility's operating life.

The fundamental principal in determining the unit placement cost is the requirement that the present value of the facility's life cycle costs must equal the present value of revenues. The present value of life cycle costs is estimated as described in Section 3.1.

To calculate the present value unit placement costs, the following procedure was used: The amounts of waste to be emplaced annually were ascertained (see Page 2-3). A normalized present value of the waste revenue was calculated, assuming that one dollar of revenue is received for each cubic foot of waste, at the time the waste is emplaced. The present values of the facility life cycle costs were then divided by the normalized present value of all waste revenues.

Estimates of present value unit disposal costs are provided in Table 4-3.

4. COMPARISON OF PRESENT VALUE LIFE CYCLE COSTS

The present value life cycle costs for the conceptual disposal and assured isolation facilities were calculated using the cost estimates given in Appendix D. The annual costs for the preoperations phase were represented as being the same for each year. As illustrated in Figure 4-1, annual costs for the operations phases were represented as being the same year-by-year over three distinct intervals, based on the three different rates of waste receipt illustrated in Figure 2-1. Annual expenditures for monitoring and maintenance during the institutional control phase for the disposal facility also were assumed to be the same within each of the three distinct intervals for that phase. The annual expenditures for the inspection and preventive maintenance phase for the assured isolation facility were assumed to be the same within each of the two distinct intervals for that phase. The annual costs for each of those intervals reflect the decreasing levels of monitoring and maintenance that are presumed to result from growing confidence in the performance of the two facilities and the decay of radioactivity in the waste.

In the present value calculations, a 7.5-percent annual return on investment was assumed for all costs incurred up to and including the end of waste receipt. For all subsequent costs, the return on investment was assumed to be 6 percent. A 4-percent inflation rate was assumed for all present value calculations.

4.1 Costs for Individual Cases

Figure 4-1 illustrates the annual expenditures for the sets of cases described in Appendix C. It clearly shows the smaller costs associated with the preoperations phase for the assured isolation facility, followed by operations costs that are almost identical to those for the disposal facility. The figure also shows the extra costs required to close the disposal facility at the end of operations.

Table 4-1 lists the present value costs of the cases described in Section 2.4. Sets of present value costs from each phase in the life cycle of a disposal facility or an assured isolation facility can be added to obtain an estimate of the total life cycle cost. Any feasible combinations of cases, as described in Section 2.4, can be used.

4.2 Costs for Selected Combinations of Cases

The present value costs for two particular sets of cases (one set for disposal and one set for assured isolation) are given in Table 4-2. The approximate timing and expenditures for each set of cases are illustrated in Figure 4-1. Table 4-2 shows that, for the sets of cases chosen, the disposal method and assured isolation method of waste management have essentially the same present value life cycle costs. The present value of the preoperations cost for the disposal method is higher than for assured isolation, primarily because of the greater costs of site characterization and licensing. However, there is a greater cost for activities during the operations phase for the assured isolation facility, primarily due to greater construction costs.

The effect that present value analysis has on reducing the relative impact of expenses that occur later in the life cycle can be observed by comparing the relative magnitudes of the same major cost components in Table D-1 with their corresponding present values in Table 4-2. In Case D1A, for example, the present value analysis reduces the preoperations cost for the disposal facility from \$74 million in 1996 dollars to a present value of \$69 million (about a 7-percent reduction). However, in Case D3, the present value analysis reduces the cost of closure and postclosure from \$30 million in 1996 dollars to \$9.7 million (about a 68-percent reduction).

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Figure 4-1. Expenditure rates as a function of time; selected cases.

Table 4-1. Present value costs for the cases described in Section 2.4.^a

DISPOSAL		ASSURED ISOLATION	
5 Years of Preoperations			
D1A (optimistic)	69,000	I1A (no site groundwater characterization)	60,000
D1B (recent experience; one site characterized)	120,000	I1B (limited site groundwater characterization)	64,000
D1C (recent experience; two sites characterized)	140,000	I1C (site characterization comparable to D1A)	70,000
<u>50 Years of Operations</u>			
D2	250,000	I2A (no groundwater monitoring)	260,000
		I2B (groundwater monitoring)	260,000
<u>5 Years of Closure and Postclosure</u>			
D3	9,700	Not applicable	
100 or 300 Years of Institutional Control		300 or 500 Years of Inspection and Preventive Maintenance	
D4A (100 years of institutional control)	5,600	I3A (300 years of I&PM)	15,000
D4B (300 years of institutional control)	7,800	I3B (500 years of I&PM)	15,000

Table 4-2. Present value costs for the set of cases described in Appendix C.

Phase	Disposal Facility (thousands of dollars)		Assured Isolation Facility (thousands of dollars)	
Preoperations	69,000	(Case D1A)	60,000	(Case I1A)
Operations	250,000	(Case D2)	260,000	(Case I2A)
Closure and postclosure	9,700	(Case D3)	---	
Institutional control	5,600	(Case D4A)	---	
Inspection and preventive maintenance		---	15,000	(Case I3A)
	Total	340,000 ^a	330,000 ^a	

a. Total may not equal the sum of the cost elements because of rounding.

4.3 Costs for all Combinations of Cases

As noted in Section 2.4, there are 6 plausible combinations of cases, or scenarios, for disposal and 6 for assured isolation. Table 4-3 shows constant 1996 dollar life cycle costs, present value life cycle costs, and present value unit costs for the 12 plausible combinations of cases (i.e., scenarios) analyzed. For convenience, the definitions of the cases in the tables, originally given in Section 2.4, are repeated at the end of this chapter.

Table 4-3 is divided into three sections by dashed lines. The scenarios in each section are identical except for the preoperations case. The table shows that the present value life cycle costs for the plausible combinations range from \$330 million for assured isolation to \$410 million for disposal. The unit placement costs are directly proportional to the present value life cycle costs and scale accordingly. Life cycle costs for disposal are close to those for assured isolation only when the very low disposal preoperations costs in Case D1A are used. Whenever one of the other two disposal preoperations cases is used, disposal has a higher present value life cycle cost than assured isolation.

The largest life cycle costs for disposal involve preoperations Cases D1B or D1C, both of which incorporate costs based on recent experience in siting and developing disposal facilities, resulting in very high preoperations costs. Present value calculations weight costs at the beginning of the life cycle very heavily; consequently, the high experience-based costs for disposal preoperations cause disposal to have a higher present value life cycle cost. The lowest estimates for present value life cycle costs for both disposal and isolation, \$340M and \$330M respectively, occur when the cases with the lowest preoperations costs are used.

Table 4-3. Comparison of life cycle costs and unit costs.

DISPOSAL				ASSURED ISOLATION			
Scenario	Thousands of Constant (1996) Dollars	Present Value (thousands of dollars)	Present Value Unit Placement Cost (dollars per cubic foot)	Scenario	Thousands of Constant (1996) Dollars	Present Value (thousands of dollars)	Present Value Unit Placemen Cost (dollars per cubic foot)
D1A+D2+D3+D4A	710,000	340,000	520	I1A+I2A+I3A	810,000	330,000	510
D1A+D2+D3+D4B	780,000	340,000	520	I1A+I2A+I3B	880,000	330,000	510
D1B+D2+D3+D4A	760,000	390,000	590	I1B+I2B+I3A	820,000	340,000	520
D1B+D2+D3+D4B	830,000	390,000	590	I1B+I2B+I3B	900,000	340,000	520
D1C+D2+D3+D4A	780,000	410,000	620	I1C+I2B+I3A	830,000	350,000	530
D1C+D2+D3+D4B	850,000	410,000	630	I1C+I2B+I3B	900,000	350,000	530

When the preoperations costs used in the analyses for assured isolation are compared to those used for disposal, it can be seen that the former are generally much lower than the latter. Note that the highest preoperations cost for assured isolation (Case I1C) is equal to the lowest preoperations cost for disposal (Case D1A).

The effect of present value calculations on the importance of costs of activities that occur late in the life cycle is underscored by the fact that almost all of the life cycle costs in Table 4-3 occur as pairs of identical costs (when rounded to two significant digits). The two members of each pair differ only in the duration of the institutional control phase (for disposal) or of the inspection and preventive maintenance phase (for assured isolation). The fact that the different durations of those phases (which occur late in the life cycle) have little or no impact on the present value life cycle cost illustrates how the present value calculation greatly reduces the significance of such distant future expenditures. When the cost for inspection and preventive maintenance for assured isolation is expressed in 1996 dollars, it is about three or four times the cost in 1996 dollars for preoperations for assured isolation (see Table D-1). Table 4-2 shows that when that cost is converted to present value cost, it becomes only a fraction of the present value cost of preoperations.

The following describes the cases analyzed:

DISPOSAL

Preoperations Phase

- Case D1A: This case is based on the methods used in NY 1995 and RAE 1992. The costs tend to be optimistically low compared to recent experience.
- Case D1B: This case is based on an estimate of the average recent experience for preoperations costs in the U.S. Full characterization of a single site is assumed.
- Case D1C: This case is also based on recent experience, but with full characterization of two sites.

Operations Phase

- Case D2: This case represents operations at the disposal facility.

Closure and Postclosure Phase

- Case D3: This case represents closure and postclosure activities at the disposal facility.

Institutional Control Phase

- Case D4A: This case represents institutional control lasting 100 years.
- Case D4B: This case represents institutional control lasting 300 years.

ASSURED ISOLATION

Preoperations Phase

- Case I1A: This case represents preoperations activities that do not include site characterization because the assured isolation inspection system is designed to preclude release of contamination to the site.
- Case I1B: This case is the same as Case I1A, except that limited or confirmatory drilling and groundwater characterization at the site are added.
- Case I1C: In this case, the costs for several preoperations cost elements from Case D1A are used for the site development and for the licensing and permitting cost elements. They include costs for site development, environmental assessment and license application, licensing, and permits. This case represents a full site characterization and licensing process comparable to that for a disposal facility, as represented by the preoperations cost in Case D1A. (The licensing process, however, need not depend on site characteristics.)

Operations Phase

- Case I2A: This case represents operations at the assured isolation facility, without groundwater monitoring.
- Case I2B: This case is the same as for Case I2A, except that a cost for groundwater monitoring is added.

Inspection and Preventive Maintenance Phase

- Case I3A: The case represents inspection and preventive maintenance with cost estimation ending 300 years after the end of operations.
- Case I3B: This case represents inspection and preventive maintenance with cost estimation ending 500 years after the end of operations.

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Appendix A

Cost Elements

Appendix A

Cost Elements

This appendix provides some details of elements of the cost estimates that are given in Appendices C and D for the conceptual low-level radioactive waste (LLRW) disposal and assured isolation facilities. Most of the cost elements are used for both disposal and assured isolation, although the estimates of costs for the same elements are often different.

This appendix is divided into sections covering the four major phases of the facility life cycle. Section A.1 covers cost elements for the preoperations phase. These costs are associated with initial administration, design, and other preparatory activities. Elements of the construction and operating costs expected during facility operation are discussed in Section A.2. Section A.3 describes the cost elements for closure and postclosure of the disposal facility or closure of the assured isolation facility. Section A.4 deals with costs associated with institutional control for the disposal facility and inspection and preventive maintenance for the assured isolation facility.

Some of the estimates for specific cost elements were based on prior work involving cost projections for a LLRW disposal facility in Connecticut. Those earlier projections, originally made in 1994 dollars, were escalated to 1996 dollar costs for this study. If a cost is given in this appendix in 1994 dollars, it was adjusted to 1996 dollars for the analysis. Other cost estimates were stated directly in 1996 dollars.

A.1 PREOPERATIONS COSTS

Preoperations costs include costs related to the developmental process at the LLRW management facility. The cost estimates are for a volunteer site, and thus they do not include any costs associated with statewide screening. Included in the costs are site development, construction, administration and management, legal fees, design, and construction of support facilities. While construction of the first vaults will take place at the end of the preoperations phase, for simplicity the costs for those activities were included in operations costs. Unless otherwise indicated, the cost elements described below were used in developing cost estimates for both the disposal and assured isolation facilities.

Site Development—For disposal, this cost element includes the costs of characterizing the volunteer site (which may be accomplished in several increments), groundwater modeling, and performance assessment. For Case I1A for assured isolation, this cost was scaled from NYSERDA 1993 (see Section 3.1.2). For Case I1B, a cost for groundwater monitoring was added, and for Case I1C, the costs from Case D1A were used.

Environmental Assessment and License Application—For disposal, costs associated with preparing the license application, including preparing an environmental impact statement (EIS), were included in this cost element. Similar costs were included in the licensing and permitting cost element for assured isolation. While it is not known at this time whether an EIS would be required for building an assured isolation facility, it was assumed that one would be needed.

Licensing—For disposal, this element contains an estimate of the costs to obtain a license after submittal of the license application. For assured isolation, the licensing and permits elements were combined into a single cost element.

Permits—This is the estimated cost of obtaining permits other than the license to build and operate the facility.

Licensing and Permitting—For assured isolation, this cost element represents the sum of the environmental assessment and license application, licensing, and permits cost elements used for disposal.

Siting Agency Administration—This element represents costs incurred by a state siting agency that are attributable to the development of the facility.

Legal Fees—An estimated annual budget of \$300,000 in 1996 dollars for legal fees and legal service during the preoperations phase was included. This element does not include any legal fees that might be incurred if major opposition to the siting or operation of the facility were to arise. The size of those fees is largely unpredictable.

Engineering and Design—The cost of engineering and design activities to produce final construction drawings and specifications for the facility was estimated to be 12 percent of the sum of the costs for constructing support facilities, and 25 percent of the cost of constructing the waste disposal units.

Baseline Monitoring—For the disposal facility, baseline monitoring includes installing groundwater monitoring wells; taking samples of groundwater, surface water, soil, air, and vegetation; and analyzing the samples. For Case IIA for the assured isolation facility, this cost element includes the same activities, except those associated with groundwater monitoring. For Cases IIB and IIC, the cost of groundwater monitoring was included in this element.

Construction Management—The cost of managing all construction activities at the disposal and assured isolation facilities was estimated as a percentage of the cost of construction. Specifically, the construction management cost was estimated to be 4.5 percent of the cost of constructing support facilities and systems at the facility.

Consumables—This is the cost for fuel, utilities, and materials for the preoperations phase. This cost element is 10 percent of the payroll cost.

Payroll—The payroll element includes the cost of employing seven full-time personnel during the last two years of preoperations. These personnel supervise the construction of the support facilities, roadways, parking areas, and peripheral systems. The actual construction work during the preoperations phase was assumed to be performed by independent contractors.

Site Preparation and Support Facility Construction—Construction includes land purchase, relocation of personnel, mobilization and demobilization of equipment, initial land preparation, and construction of buildings, roads, drainage channels, parking areas, and the retention pond. Construction of drainage features and the lining of the retention pond was assumed to continue into the operations phase. Most peripheral systems or support facilities were assumed to be constructed during the preoperations phase.

Purchase of Equipment for Operations and Disposal or Isolation Unit Construction—Heavy equipment to be used during the operations phase, for both construction and operation, was assumed to be purchased at the end of the preoperations phase. Laboratory and office equipment required by facility personnel in the early years of operations also was included in this component. Dust control equipment for minimizing fugitive dust from construction activities was assumed to be purchased. Fire protection equipment, a pickup truck, pumps, forklifts, overhead cranes in a concrete canister fabrication and storage building, an equipment storage and maintenance building, and a waste receiving, storage, and handling building also were included in this cost element.

Incentive and Assistance Payments—This element is an estimate of the cost of assistance to the local community where the disposal or assured isolation facility is located. Some of the funds provided may be designated for use on specific aspects of the facility development. A cost of two million dollars per year in 1996 dollars was assumed for this element.

Contingencies—A contingency was provided for the costs during the preoperations phase. Because of the preliminary nature of the facility description and design, the contingency was estimated to be 20 percent of all costs for Cases D1A, I1A, I1B, and I1C. For Cases D1B and D1C, see the text in Appendix D.

A.2 OPERATIONS COSTS

The bases for cost elements associated with facility operations are described in this section. It was assumed that the operations phase will last for 50 years and that disposal or assured isolation activities will be conducted by full-time facility employees. During the period of highest average waste receipt, on the order of 50 to 100 trucks per year of waste will arrive at the facilities, depending on the modes of waste packaging and any need for waste shielding casks. Operating equipment was assumed to be either purchased or leased while operations are being conducted. Unless otherwise indicated, the cost elements described below were used in developing cost estimates for both disposal and assured isolation facilities.

Start-Up of Facilities—The facility start-up cost was assumed to be incurred during the first year of operation. This cost was estimated as 10 percent of the average annual payroll for the operations phase. Costs associated with personnel hiring, personnel relocation, and programs to train all personnel that will work at the facility were included in this cost element.

Construction of Disposal or Assured Isolation Units—Included in this element were all items associated with constructing disposal or assured isolation vaults, drainage features, and cover systems during the operations phase. Construction activity was divided into several individual elements, and material costs for each element were calculated based on the conceptual designs presented in Chapter 2.

Costs for each element of disposal or assured isolation unit construction were based on the amounts of construction materials needed. Personnel costs, and most of the cost of equipment used for the construction and operating activities, were included in the cost components for construction and operations payroll, and in those for construction and operations equipment.

Equipment Maintenance—The equipment maintenance costs were estimated to be 10 percent of the total equipment lease or purchase costs.

Building and Facilities Maintenance—This cost element includes costs involved in maintaining roads and the grounds for all support facilities. That portion of the cost was estimated to be 10 percent of the total construction cost of support facilities over the operations phase. Disposal unit or isolation unit

maintenance costs associated with minor repairs to the concrete at the time of construction, and the costs for maintaining earthen covers and on-site drainage features, were assumed to equal 1 percent of the total construction cost of the disposal units.

Construction and Operations Payroll—Payroll costs account for the cost of all personnel at the facility. In developing the estimates of personnel requirements, some employees were assumed to be capable of performing more than one function to improve the cost-effectiveness of the facility. All personnel used during the operations phase were assumed to be full-time employees. The operations payroll cost element includes all personnel costs, such as salaries and fringe benefits.

Management Agency Administration—Like the siting agency administration element in the preoperations phase, this element is an estimate of costs incurred by a state agency for overseeing the operation of the disposal facility or assured isolation facility.

Legal Fees—The annual budget for legal fees and legal services was estimated to be \$300,000 in 1996 dollars for both disposal and assured isolation. This item does not include any legal fees that might be incurred if major opposition to the siting or operation of the facility were to arise. The size of those fees is essentially unpredictable.

Environmental Monitoring—This cost element represents the monitoring and sampling conducted during the operations phase, including, in the case of assured isolation, inspection of the vault interiors. Since sampling will take place both around the facility and within the sumps in the vaults, the cost associated with it depends in part on the size of the site and the number of vaults. For assured isolation, the cost for sampling also depends on the degree of groundwater monitoring assumed, if any, and includes inspection of the vault interiors. This cost element does not include personnel costs for environmental monitoring. They are included in the Construction and Operations Payroll cost element.

Regulatory Costs—The regulatory costs element was included to cover costs associated with periodic license renewal, license amendments, and payments to cover the cost of a state inspector. Relicensing was assumed to be necessary every 5 years following the initial facility licensing action. The relicensing fee was assumed to be \$300,000 in 1994 dollars for both disposal and assured isolation. Also, two persons working full time on site (at \$120,000 per year in 1996 dollars) were assumed to be part of this cost element.

Consumables—This element represents costs for supplies needed to conduct operations at the facility. It was estimated to be 10 percent of the payroll cost.

Office Equipment—This component includes costs for desks, chairs, typewriters, computer systems, file cabinets, etc. that will be used in the buildings on site. Most required office equipment was assumed to be purchased during the preoperations phase. It was assumed that the majority of this equipment will be replaced every 10 years during the 50 years of operations.

Construction and Operations Equipment—The costs of leased equipment and the annual average depreciation of purchased equipment were assumed to be equivalent. In other words, it was assumed that there is no cost advantage between leasing and purchasing equipment. The unit costs used for this cost element were based on the purchase of equipment. The frequency with which purchased equipment is replaced was assumed to be the standard depreciation time under normal full-time use, multiplied by the ratio of actual use to full-time use.

Financial Assurance—A surety bond was assumed to be maintained through the operations phase to ensure that money will be available to cover costs for all activities that will or could occur after the end of operations. The collection of funds for that purpose during the operations period as part of the fees charged for disposal or assured isolation at the facility was also included in the financial assurance cost element. The activities covered include closure, postclosure, and institutional control for disposal, and inspection and preventive maintenance for assured isolation. Also, as part of the financial assurance cost element, sufficient monies were assumed to be collected to cover retrieval, remediation of portions of the site (for disposal), and redisposal or reisolation of some of the waste at any time following 100 years after the end of operations, or to close the assured isolation facility as early as 100 years after operations end. Throughout the operations period, and for all time thereafter, the funds collected were assumed to earn 6 percent in the presence of a 4 percent inflation rate. This is consistent with proposed U.S. Nuclear Regulatory Commission rules for similar funding for postclosure activities at commercial nuclear power reactors (NRC 1997). The uncollected portion of those funds, which diminishes as operations continue and more money is received from generators sending waste for disposal, was assumed to be covered by the surety bond. The annual cost of that bond was assumed to be 1 percent of the value of the bond.

Liability insurance was assumed to be maintained throughout the operations phase of both facilities at an estimated annual premium of \$50,000 in 1994 dollars. This liability insurance is meant to cover injuries to persons or damage to property during everyday activities. The cost used is based on a survey of LLRW disposal sites presently operating. Although potentially expensive, remediation of the facility to clean up a release of radionuclides may be required at some time in the future; however, the probability of such an occurrence was considered remote. Remedial action costs were not included because of the difficulty of estimating how much would be needed to pay for remedial activities when the site and design details are not known.

Incentive and Assistance Payments—This element is an estimate of the cost of incentives and compensation to the local community where the disposal or assured isolation facility is located. Some of the funds provided may be designated for assistance on specific aspects of facility operations. A cost of two million dollars per year in 1996 dollars was assumed for this element.

Payments in Lieu of Taxes—It was assumed that during the operations phase, payments in lieu of annual property taxes for land, buildings, and equipment will be 1.75 percent of asset values.

Contingencies—A contingency amount of 20 percent of the total of all costs for the operations phase was assumed.

A.3 DISPOSAL FACILITY CLOSURE AND POSTCLOSURE COSTS

Following the operations phase, the disposal facility will be closed. The closure interval was assumed to last 2 years, during which the last disposal units will be closed and the final cover systems will be placed. All decontamination and dismantling of support buildings and systems were assumed to occur during this time. A 3-year postclosure interval was assumed to follow the closure interval. Environmental monitoring and minor custodial care will continue throughout the closure and postclosure intervals.

It may, at some time, be decided to convert the assured isolation facility into a disposal facility. To do this, the facility, when converted, will have to meet the regulatory requirements for disposal in effect at that time, and approval for such a conversion will have to be given by the appropriate regulatory agency. Should it be decided to convert the assured isolation facility to a disposal facility, the empty spaces in the

vaults will be filled, the vault and cell accesses will be sealed, and earthen covers similar to the final covers for the disposal facility will be installed.

Facility Closure—Disposal facility closure activities will be conducted during the first 2 years following the end of operations. Activities that have major cost impacts and which will be performed during this phase are described below. Construction labor and equipment were assumed to be contracted out during this phase. A radiological survey will be performed to document that satisfactory conditions exist. Existing buildings and structures on site will be razed after any residual contamination has been removed. Any contaminated materials will be packaged for disposal, and the entire site will be graded to its final configuration. The upper part of the interim cover will be removed and replaced with the appropriate part of the final cover. Radiological surveys will be conducted, and the cover and the remainder of the site will be vegetated. In estimating the costs of placing the final earthen cover system, contract labor and equipment were assumed to be used. Following closure, a survey crew will be contracted to survey and place permanent monuments at appropriate locations around the site.

Payroll—This element includes the cost of employing full-time personnel needed to ensure proper and safe closure, monitoring, and security. These personnel include a site manager, receiving clerk, quality assurance supervisor, bookkeeper, and security personnel, health physics technicians, laboratory technicians, and laborers to perform decontamination and final waste placement.

Equipment—Since it was assumed that most of the work during closure will be contracted out, purchase or lease of construction equipment will be minimal during this phase. It was assumed that the pickup trucks and small equipment used for ongoing activities such as monitoring will be replaced as needed during the closure and postclosure phase. Some of the equipment purchased, such as compactors, backhoes, and graders, will also be used during institutional control.

Environmental Monitoring—Monitoring during the closure and postclosure phase will be performed on a continuous basis. In addition to sample collection, costs for detailed visual monitoring to identify any evidence of settlement or other undesirable conditions at the site were included.

Consumables—Costs for fuel, utilities, and materials for the closure and postclosure phase were estimated to be 10 percent of payroll.

Equipment Maintenance—Equipment maintenance costs were estimated to be 10 percent of the total equipment lease or purchase costs.

Custodial Agency Administration—This element is an estimate of costs incurred by a state agency for overseeing the closure of the disposal or assured isolation facility.

Regulatory Costs—A one-time fee of \$300,000 in 1994 dollars for license renewal was assumed to be required during the closure and postclosure phase for the disposal facility or during closure for the assured isolation facility. This fee was assumed to include the cost of reviewing the closure plan. The regulatory costs were assumed to be significantly reduced after facility closure.

Financial Assurance—Liability insurance coverage was assumed to be maintained throughout the closure and postclosure phase. The estimated cost of the coverage is \$50,000 per year in 1994 dollars.

Licensing—Closure of the assured isolation facility (not assumed to take place until at least 100 years after the end of operations, if ever) includes an additional cost element. This additional element represents the cost of licensing the assured isolation facility as a disposal facility.

Payments in Lieu of Taxes—It was assumed that during the closure and postclosure phase, payments in lieu of taxes will be 1.75 percent of the land and equipment values. No property taxes for buildings were included because essentially no buildings will remain on site.

Contingencies—A contingency amount of 20 percent of all closure costs was assumed.

The financial assurance cost element for operations at an assured isolation facility includes collection of monies and bonding to cover the unaccumulated portion of a fund to pay for closure of the facility at any time after 100 years following the end of operations. The cost estimate for closure of an assured isolation facility is based on the same cost elements described above for disposal facility closure and postclosure costs. The element is called "assured isolation facility closure" rather than "disposal facility closure."

In calculating the cost of closing an assured isolation facility 100 years or more after the end of operations, it was assumed that only assured isolation vaults containing Class B and C wastes will receive final covers like those placed on disposal vaults. All of the spaces within the vaults will be filled with pea gravel, however, and inspection accesses to the vaults will be sealed.

A.4 INSTITUTIONAL CONTROL OR INSPECTION AND PREVENTIVE MAINTENANCE

The institutional control phase will follow closure of the disposal facility. The inspection and preventive maintenance phase will follow the operations period for the assured isolation facility. During either phase, sampling of the surrounding environment will continue. Because this monitoring is less important to demonstrating that the assured isolation facility is performing as desired, however, it will generally be conducted at a lower intensity at the assured isolation facility, compared to the disposal facility. At the assured isolation facility, inspection of the vault interiors will continue. For both facilities, periodic checks for uneven settling or any other damage to the covers will be made, and fences and on-site vegetation will be maintained. The estimates of costs during these periods do not include costs for remediation of any significant unsatisfactory conditions discovered. Those costs are, however, covered by the fund created to cover the cost of retrieving all the waste and repositioning it (see the financial assurance discussion in Section A.2).

Unless otherwise indicated, the cost elements described below were used in developing cost estimates for both the disposal and assured isolation facilities.

Payroll—The personnel required during the institutional control phase for a disposal facility include a security guard, a health physics technician, and several laborers. Assumptions made about the use of these personnel are outlined in the following paragraphs.

The cost estimates assume one full-time security employee working an 8-hour shift during the first interval of institutional control. This person was assumed to be contracted.

During the subsequent second interval, security was assumed to be performed by a half-time employee, and for the third interval, security was assumed to be limited to site visits of about 2 hours per day.

The health physics technician will periodically perform monitoring, check for settlement, and be present when other workers are on site.

For the assured isolation facility, these personnel were assumed to be supplemented by two personnel who operate the robot cameras to inspect the insides of the vaults during the first 100 years of inspection and preventive maintenance. After the first 100 years are over, the inspections are discontinued at the vaults that contain only Class A waste. For costing purposes, even with this reduction in effort it was assumed that one person is needed full time to conduct inspections for the final 200 or 400 years. All other site staffing levels for the first 100 years were assumed to be the same as for disposal and to then be reduced by half for the remaining 200 or 400 years of inspection and preventive maintenance.

Equipment—Construction equipment was assumed to be purchased or leased throughout the institutional control or inspection and preventive maintenance phases on an as-needed basis. This equipment will be used to inspect the vault walls (for assured isolation only), to remediate any cover settlement that may occur, and to address any other undesirable conditions that may develop. Such equipment could include a farm tractor, a vibrating roller compactor, and a pickup truck, as well as the robot camera used in vault wall inspection.

Consumables—This cost element is similar to that of the operations and closure phases. It was estimated to constitute 10 percent of the payroll costs.

Environmental Monitoring—It was assumed that all analyses of samples will be conducted off site. The monitoring effort for the disposal facility was assumed to decrease by half at the start of each of the three intervals of institutional control and to then remain constant until the end of that interval.

The monitoring effort for the assured isolation facility during the inspection and preventive maintenance phase is described in Section 2.3. For the first 100 years, this effort continues at half of the annual level expended at the end of operations. It is halved again 100 years after the end of operations.

Equipment and Vehicle Maintenance—Equipment and vehicle maintenance were assumed to be 10 percent of equipment costs. This quantity was estimated to provide for maintenance and upkeep of the purchased and leased equipment and vehicles used on site.

Custodial Agency Administration—Administration costs are those incurred by a state agency to administer the institutional control or inspection and preventative maintenance programs. They were estimated to be 5 percent of the payroll for each of the intervals.

Regulatory Costs—Regulatory cost estimates were based on the assumption that relicensing of the disposal or assured isolation facility will occur throughout the institutional control or inspection and preventive maintenance phase at 5-year intervals. Current regulations require that a disposal facility remain under license at least until the end of institutional control. For disposal, the 5-year cost of relicensing was assumed to be \$100,000 in 1994 dollars during the first interval of institutional control, \$50,000 in 1994 dollars during the next interval, and \$25,000 in 1994 dollars during the final interval. For assured isolation, the 5-year cost was assumed to be \$100,000 in 1994 dollars for the first 100 years, and \$50,000 in 1994 dollars for the remainder of the inspection and preventive maintenance phase.

Financial Assurance—Payment of an annual premium of \$50,000 in 1994 dollars for liability insurance was assumed to continue for the facility through the duration of the institutional control or inspection and preventive maintenance phases.

Payments in Lieu of Taxes—It was assumed that payments in lieu of taxes will be 1.75 percent of the land and equipment value. No property taxes for buildings were included because essentially no buildings will remain on site.

Contingencies—Contingencies were based on 20 percent of the total costs incurred for each of the intervals of institutional control or inspection and preventive maintenance.

Appendix B

Scaling Certain Cost Elements

Appendix B

Scaling Certain Cost Elements

The cost analyses for this report are all based on detailed cost estimates for a reference disposal facility, whose capacity is identical to that of the facilities examined in this study. The primary differences between that facility and those analyzed here are as follows: The vaults for the reference facility each contained two interior walls that divided them into three cells, and the reference facility used separate vaults for Class A waste and Class B and C waste. Many of the costs for the assured isolation facility and the disposal facility design analyzed here are the same as those developed for the reference disposal facility. Others were scaled from those for the reference facility based on such factors as the volume of concrete used, volume of backfill or earthen cover material, and disposal facility area. This appendix identifies the cost elements that were scaled and the manner in which the scaling occurred.

B.1 SCALING USED IN DERIVING THE DISPOSAL FACILITY COST ESTIMATES

For the preoperations phase, the site development cost element was scaled from the corresponding cost element for the reference disposal facility by the ratio of the facility land areas. Two cost elements—site preparation and support facility construction, and baseline monitoring—were scaled by holding half of the cost constant and scaling the remaining half according to the ratio of facility areas. The half held constant represents essentially those costs associated with waste receipt, waste processing, and administration facilities at the site.

For the operations phase, a review of the details of the cost estimate for constructing disposal units for the reference disposal facility revealed that about 60 percent of those costs is related to building the concrete vaults, that about 6 percent is related to the placement of soil, and that the remainder is relatively independent of those two activities. Consequently, for the disposal facility design analyzed, 60 percent of that cost element was scaled by the ratio of the volume of concrete used, 6 percent was scaled proportional to the volume of soil placed during operations, and the rest was left unchanged from the amount used in the reference facility cost element.

A similar review of the construction and operations payroll cost element resulted in scaling 30 percent of that element proportional to the volume of concrete used; the rest of the cost element was identical for both disposal facilities. The construction and operations equipment cost element was developed by scaling 15 percent of the comparable element for the reference disposal facility proportional to the volume of earthen cover material and 10 percent proportional to the concrete volume. The remainder of this element was not changed. Finally, half of the environmental monitoring cost element was scaled according to the ratio of the area of the disposal facility analyzed to that of the reference facility. This was done to account for the need for more monitoring at a larger site.

For the closure and postclosure phase, the disposal facility closure cost element was scaled from the costs for the reference disposal facility according to the ratio of the volumes of soil used in closing the two facilities. Thirty percent of the payroll, equipment, and monitoring cost elements was scaled in proportion to the facility areas, while the other 70 percent was fixed.

For all three intervals of the institutional control phase, the payroll, equipment, and monitoring cost elements were scaled in the same way as described above for the closure and postclosure phase: 30 percent proportional to facility area, and 70 percent fixed.

B.2 SCALING USED IN DERIVING THE ASSURED ISOLATION COST ESTIMATES

Cost estimates for the assured isolation design were developed by scaling some cost elements from those estimated in considerable detail for the reference disposal facility. The following describes which cost elements were estimated using scaling and how that scaling was accomplished.

For the preoperations phase, only the construction cost element was scaled from the corresponding cost element for the reference disposal facility. That cost element was changed by assuming that half of the cost is the same for the assured isolation and reference facilities (this half represents essentially all costs associated with waste receipt, waste processing, and administration facilities on the site). The other half was calculated by assuming that it is proportional to the areas of the facilities.

As with the disposal facility, for the operations phase 60 percent of the construction cost element was scaled proportional to the volume of concrete used, 6 percent was scaled proportional to the volume of soil placed during operations, and the rest was left unchanged from the amount used in the corresponding reference facility cost element.

Thirty percent of payroll costs for construction and operations was scaled according to the ratio of the volume of concrete used in the reference disposal facility and the assured isolation facility; the rest of the cost element was identical for both facilities. The construction and operations equipment cost elements for the assured isolation design were developed by scaling 15 percent of the comparable element for the reference disposal facility proportional to the earthen cover material volume and 10 percent proportional to the concrete volume; the remainder of this element was not changed.

For "closure" of the assured isolation facility, the closure cost elements were scaled from the closure cost elements for the reference disposal facility by the ratios of the volumes of backfill soil needed. Thirty percent of payroll and equipment costs was assumed to vary according to the areas of the facilities, and the rest of those cost elements were assumed to be fixed. Of course, any closure of an assured isolation facility (i.e., conversion to a closed disposal facility) will have to be done in accordance with regulations for disposal that are in effect at that time.

For all three intervals of the inspection and preventive maintenance phase, the payroll and equipment cost elements were scaled in the same way as described above for the "closure" phase: 30 percent proportional to facility area, and 70 percent fixed.

Appendix C

Examples of Detailed Cost Estimates

Appendix C

Examples of Detailed Cost Estimates

This appendix provides examples of detailed estimates of costs for the several life cycle phases of the disposal and assured isolation facilities. Brief descriptions of what each cost element involves are given in Appendix A. A reader familiar with the information in Appendix A will better understand the makeup of the cost elements.

The costs for a reference disposal facility were developed in detail using standard cost estimating procedures. The reference facility is similar to the disposal facility analyzed here, except its vaults each have two interior walls that divide them into three cells and it has separate vaults for Class A waste and Class B and C waste. The costs for the disposal facility and the assured isolation facility analyzed were derived from the reference disposal facility costs whenever possible. For example, the costs of concrete and reinforcing steel, labor, and equipment needed to construct vaults for the facilities analyzed were scaled from the corresponding costs for the reference disposal vaults using the relative volumes of reinforced concrete used in the facility's two types of vaults (Appendix B describes this scaling in some detail). For many other cost elements, such as the cost of materials, labor, and equipment needed to build the earthen covers over the vaults, the cost estimates were developed more directly.

To illustrate how cost estimates for each phase of the facility life cycle were developed, this appendix details one of the cases described in Section 2.4 for each life cycle phase of the disposal and assured isolation facilities. Details of the costs for the remainder of the cases described in Section 2.4 are given in Appendix D.

C.1 DISPOSAL FACILITY COSTS

For illustrative purposes, Tables C-1 through C-4 list the disposal facility cost elements for Cases D1A, D2, D3, and D4A, respectively, and their corresponding estimated costs in constant 1996 dollars. The institutional control phase in Case D4A is divided into three intervals during which different levels of care are exercised. Together, the combination of these four cases represents only one of 6 plausible combinations for disposal facility costs (see Figure 2-13). When the costs for Cases D1A, D2, D3, and D4A are combined, the life cycle cost of the disposal facility totals about \$710 million. Table C-5 shows the costs in 1996 dollars by life cycle phase for this set of cases. Of the \$710 million, \$570 million, or 80 percent, is spent during the 50-year operations phase, when waste is being received.

Part of the financial assurance cost for the operations phase is related to collecting enough money to pay for retrieval of waste from the disposal facility, cleaning up contamination from a release from the facility, and redisposal of some of the waste. Section A.2 of Appendix A describes how the estimates of costs for these activities are used. Retrieval of waste from the disposal facility would involve removing the earthen covers from the vaults, breaking the vault roofs and removing the resulting concrete rubble, and removing the backfill around the concrete canisters. It was assumed in developing the retrieval cost estimate that the canisters would be structurally sound and therefore could be removed intact. Using a crane, the waste would be retrieved through the vault roofs, in a procedure that would be essentially the reverse of how it was placed in the vaults initially. It was further assumed that the disposal facility site

Table C-1. Cost elements and estimates for Case D1A: Five years of preoperations at the disposal facility (optimistic estimate).

Cost Element	Estimated Cost (thousands of 1996 dollars)
Site development	8,600
Environmental assessment and license application	2,000
Licensing	2,800
Permits	820
Siting agency administration	5,300
Legal fees	1,500
Engineering and design	5,100
Baseline monitoring	2,100
Construction management	630
Consumables	86
Payroll	860
Site preparation and support facility construction	14,000
Purchase of equipment for operations and disposal unit construction	7,700
Incentive and assistance payments	10,000
Contingencies	12,000
TOTAL	74,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table C-2. Cost elements and estimates for Case D2: 50 years of operations at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Start-up of facilities	230
Construction of disposal units	110,000
Equipment maintenance	1,500
Building and facilities maintenance	2,600
Construction and operations payroll	110,000
Management agency administration	15,000
Legal fees	15,000
Environmental monitoring	32,000
Regulatory costs	9,200
Consumables	11,000
Office equipment	470
Construction and operations equipment	15,000
Financial assurance	30,000
Incentive and assistance payments	100,000
Payments in lieu of taxes	15,000
Contingencies	<u>95,000</u>
TOTAL	570,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table C-3. Cost elements and estimates for Case D3: Five years of closure and postclosure at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Disposal facility closure	15,000
Payroll	3,000
Equipment	150
Monitoring	4,400
Consumables	300
Equipment maintenance	15
Management agency administration	1,500
Regulatory costs	320
Financial assurance	270
Payments in lieu of taxes	47
Contingencies	<u>5,000</u>
TOTAL	30,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table C-4. Cost elements and estimates for Case D4A: 100 years of institutional control at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
<u>Years 1 through 10</u>	
Payroll	1,400
Equipment	75
Consumables	140
Monitoring	4,000
Equipment and vehicle maintenance	8
Custodial agency administration	74
Regulatory costs	210
Financial assurance	530
Payments in lieu of taxes	82
Contingencies	<u>1,300</u>
TOTAL	7,900^a
<u>Years 11 through 25</u>	
Payroll	1,100
Equipment	120
Consumables	110
Monitoring	3,000
Equipment and vehicle maintenance	12
Custodial agency administration	55
Regulatory costs	160
Financial assurance	800
Payments in lieu of taxes	140
Contingencies	<u>1,100</u>
TOTAL	6,600^a
<u>Years 26 through 100</u>	
Payroll	3,300
Equipment	260
Consumables	340
Monitoring	7,700
Equipment and vehicle maintenance	26
Custodial agency administration	170
Regulatory costs	400
Financial assurance	4,000
Payments in lieu of taxes	580
Contingencies	<u>3,400</u>
TOTAL	20,000^a
GRAND TOTAL	35,000^a
a. Total may not equal the sum of cost elements because of rounding.	

Table C-5. Summary of disposal facility costs for one plausible combination of cases, by phase.

Phase	Case	Estimated Costs (thousands of 1996 dollars)
Preoperations	D1A (optimistic)	74,000
Operations	D2	570,000
Closure and postclosure	D3	30,000
Institutional control	D4A (100 years)	35,000
TOTAL		710,000^a

a. Total may not equal sum of phase costs because of rounding.

would be physically restored to a condition approximating its natural state (in other words, the empty vaults would be filled with soil, and the site would be graded and revegetated). The vault walls and floors, however, would not be broken up and removed, except for those parts of the vaults that may have become contaminated (see below for a description of remediation at the disposal site). Site restoration only contributes about 2 percent of the total cost of retrieval.

Table C-6 shows the major cost elements, with corresponding cost estimates in 1996 dollars, for retrieving all waste from the disposal facility. The estimates were derived from detailed estimates of retrieval costs prepared for a similar conceptual design for the New York State Low-Level Radioactive Waste Siting Commission. This was done through scaling by volume and adjusting to account for two years of inflation (the estimates for the Siting Commission were for 1994 dollars).

It was assumed that waste retrieval will take place no sooner than 100 years after the end of operations. This is conservatively early, and it is unlikely that such retrieval would be needed at all, much less so soon. Nonetheless, for the purpose of estimating costs associated with retrieval, it was assumed that all Class B and C wastes, and the two Class A waste streams that provide about 85 percent of the ingestion toxicity in Class A waste, would be redispersed at a new facility developed for that specific purpose. The high-toxicity Class A waste will be placed in specially marked canisters prior to disposal so it can be identified for just that reason. It was estimated that 377,000 cubic feet of waste would have to be redispersed.

It was assumed that the triggering event for retrieval of waste from the disposal facility would be detection of contamination released from a single disposal vault. Therefore, a cost for removing the soil below a single vault and disposing of that soil and the rubble from the floor of the vault was added to the retrieval cost. Table C-6 shows the cost items used to produce that estimate. The cost items indicated differ from the cost elements used for most activities in this report. The unit costs for developing these estimates were taken from Means 1996. It was estimated that 113,000 cubic feet of contaminated concrete rubble from the vault floor and soil from below the vault would have to be disposed of as Class A waste.

Table C-6. Retrieval, remediation, and redisposal costs for the disposal facility.

RETRIEVAL OF WASTE	
Cost Element	Estimated Cost (thousands of 1996 dollars)
Planning	620
Construction and demolition	21,000
Personnel	2,000
Equipment	310
Utilities	90
Custodial agency administration	98
Contingencies	<u>4,700</u>
Total retrieval cost	28,000 ^a
REMEDICATION OF CONTAMINATION	
Cost Item	Estimated Cost (thousands of 1996 dollars)
Cutting and removing the concrete vault floor	210
Excavating contaminated soil	82
Backfilling	<u>6</u>
Total remediation cost	290 ^a
REDISPOSAL	
	Estimated Cost (thousands of 1996 dollars)
Waste 377,000 ft ³ @ \$760/ft ³	290,000
Contaminated material 113,000 ft ³ @ \$510/ft ³	<u>57,000</u>
Total redisposal cost	340,000 ^a
GRAND TOTAL:	370,000^a
<hr/>	
a.	Total may not equal the sum of cost elements because of rounding.

The average unit cost for redisposal of retrieved radioactive waste and remediation waste 100 years after the end of operations was determined by estimating the cost of developing a new disposal facility based on the disposal facility design analyzed. Then, the present value of anticipated disposal revenues was set equal to the present value of life cycle costs. (See Section 3.2). In this manner the average unit cost for redisposal after waste retrieval was estimated to be about \$510 per cubic foot (in 1996 dollars). Since much of the waste retrieved from the vaults for redisposal will be Class B and Class C waste, the unit cost for retrieved waste was increased by 50 percent, to about \$760 per cubic foot, to account for the generally higher cost of disposing of Class B and C waste and for the disposal of the remainder of the Class A waste in a regulated landfill. This increase is believed to be conservative, since no one knows what it might cost to dispose of this waste 155 or more years from now. The disposal cost for waste from remediation was assumed to be about \$510 per cubic foot. Table C-6 shows that the total estimated cost of redispersing of the Class B, Class C, and high-toxicity Class A wastes is about \$290 million, and that the cost for disposing of remediation waste is about \$57 million. Both of these costs are considerably more than the cost of just retrieving the waste or remediating contaminated media.

C.2 ASSURED ISOLATION FACILITY COSTS

For illustrative purposes, assured isolation facility cost estimates are shown in Tables C-7 through C-9 for Cases I1A, I2A, and I3A, respectively. Together, this combination of cases represents only one of 6 plausible combinations for assured isolation costs (see Figure 2-14). Almost all of the cost elements in Tables C-7 through C-9 are the same as those in Tables C-1, C-2, and C-4, allowing easy comparison between the elements for disposal and assured isolation.

For the **preoperations** phase, the following costs were assumed to be identical for Case I1A and Case D1A: siting agency administration, legal fees, payroll, and purchase of equipment for operations and isolation (or disposal) unit construction.

Site development was estimated to cost \$2,200,000. This estimate is based on the estimated cost of \$500,000 for site characterization for an LLRW storage facility in New York (NYSERDA 1993), adjusted for inflation at about 3 percent per year from 1993 to 1996 and then quadrupled to account for the fact that the site for the conceptual assured isolation facility requires about eight times the area of the temporary storage facility in the New York study. The New York estimate was not adjusted directly in proportion to site area because it was felt that some of the site characterization costs are relatively fixed and that some economies of scale could be achieved with a larger site. The cost estimate used is felt to be appropriate for the studies that will be required under good engineering practices for a facility of this size. The licensing and permitting cost element in Table C-7 represents an aggregate of the environmental assessment and license application, licensing, and permits cost elements for disposal.

Several of the cost elements were linked to other elements as percentages of those elements in the same manner as for the disposal facility cost estimates. These "linked" elements are construction management, consumables (proportional to payroll), engineering and design, and contingencies. Those proportionalities are described in Appendix A.

Half of the site preparation and support facility construction costs were assumed to be the same as for Case D1A (this half represents preparation and construction of essentially all the waste receipt, waste processing, and administration facilities at the site). The other half of this cost element for the assured isolation facility was scaled up from Case D1A by the ratio of the total areas of the two sites to account for the greater costs of site preparation at the larger assured isolation facility. An additional cost was also added to account for the need to acquire more land.

Table C-7. Cost elements and estimates for Case IIA: Five years of preoperations at the assured isolation facility without site groundwater characterization.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Site development	2,200
Licensing and permitting	3,800
Siting agency administration	5,300
Construction management	670
Consumables	86
Legal fees	1,500
Payroll	860
Site preparation and support facility construction	15,000
Purchase of equipment for operations and isolation unit construction	7,700
Engineering and design	5,600
Baseline monitoring	580
Incentive payments	10,000
Contingencies	11,000
TOTAL	64,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table C-8. Cost elements and estimates for Case I2A: 50 years of operations at the assured isolation facility without groundwater monitoring.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Start-up of facilities	230
Construction of isolation units	130,000
Equipment maintenance	1,600
Building and facilities maintenance	2,800
Construction and operations payroll	120,000
Management agency administration	15,000
Legal fees	15,000
Environmental monitoring	29,000
Regulatory costs	9,200
Consumables	12,000
Office equipment	470
Construction and operations equipment	16,000
Financial assurance	25,000
Incentive and assistance payments	100,000
Taxes or payments in lieu of taxes	15,000
Contingencies	<u>97,000</u>
TOTAL	580,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table C-9. Cost elements and estimates for Case I3A: 300 years of inspection and preventive maintenance at the assured isolation facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
<u>Years 1 through 100</u>	
Payroll	15,000
Equipment	780
Consumables	1,500
Monitoring	51,000
Equipment and vehicle maintenance	78
Custodial agency administration	740
Regulatory costs	2,100
Financial assurance	5,300
Payments in lieu of taxes	890
Contingencies	<u>15,000</u>
TOTAL	91,000^a
<u>Years 101 through 300</u>	
Payroll	15,000
Equipment	780
Consumables	1,500
Monitoring	29,000
Equipment and vehicle maintenance	78
Custodial agency administration	740
Regulatory costs	2,100
Financial assurance	11,000
Payments in lieu of taxes	1,700
Contingencies	<u>12,000</u>
TOTAL	74,000^a
GRAND TOTAL	170,000^a

a. Total may not equal the sum of cost elements because of rounding.

Monitoring costs (part of the site development cost element) were reduced from those in Case D1A to reflect the assumption that no baseline monitoring of groundwater would be conducted for Case I1A because the assured isolation facility is designed so that inspection and preventive maintenance will preclude the release of any radionuclides outside the vaults. However, monitoring of soil, surface water, vegetation, and air during the preoperations and operations phases was assumed to be the same as for Cases D1A and D2.

For the **operations** phase (Case I2A), the following cost elements were assumed to be identical to those in Case D2: start-up of facilities, management agency administration, legal fees, regulatory costs, office equipment, incentive and assistance payments, and payments in lieu of taxes. The costs of equipment maintenance, building and facilities maintenance, consumables, and contingencies were related to other cost elements using the same approach employed to develop the cost estimates for the corresponding elements of the disposal facility.

The cost estimates for disposal unit construction, construction and operations payroll, and construction and operations equipment were scaled from the reference disposal facility cost estimates as described in Section B.1.

For the assured isolation facility, the same environmental monitoring used for the disposal facility was assumed, except that groundwater monitoring was excluded. This exclusion reduces the cost for environmental monitoring. Consistent with the concept for assured isolation presented in Newberry 1995, the environmental monitoring was assumed to be augmented during the operations phase with quarterly inspections of the interiors of the assured isolation vaults using a robotic device equipped with a television camera. To estimate the cost of this activity, it was assumed that the inspection equipment would cost \$200,000, have a 5-year replacement life, and require one person for operation. It was also assumed that it would take about six hours per vault to conduct the inspection. Any drainage water from the assured isolation cells was also assumed to be sampled and analyzed quarterly during the operations phase. The frequency of vault inspection and drainage water sampling was assumed to be reduced after the end of the operations phase, as described below.

The phase **following operations** was divided into two intervals: the first 100 years of inspection and preventive maintenance, followed (for Case I3A) by a 200-year interval of reduced inspection and preventive maintenance. Table C-9 contains cost estimates for those two intervals. For the first 100 years after the end of operations, monitoring of the interiors of the vaults and sampling of any water collected from the isolation cells continues at half the frequency of the operations phase. Environmental monitoring also continues at half the level of the operations phase, and the fence around the facility is maintained. When comparing the cost estimates given in Table C-9 with those for comparable intervals given in Table C-4, it is important to note that the costs shown are totals for the entire interval and that the intervals are generally much longer for assured isolation than for disposal.

For the last 200 years of the 300-year inspection and preventive maintenance phase, it was assumed that the Class A waste would no longer present a hazard. Thus, during this interval, only the condition of the interiors of the vaults containing Class B and C waste is monitored, and only drainage water from those vaults is sampled. The level of environmental monitoring during this interval also is reduced to half of that for the first 100 years, and the fence around the facility continues to be maintained.

Table C-10 shows the cost estimate for closure of the assured isolation facility. Sufficient funds must be collected from generators sending waste to the facility to pay for closure of the assured isolation facility any time following 100 years after the end of operations (i.e., 100 years following the end of waste receipt). The cost estimates for closure of the assured isolation facility given in Table C-10 were scaled from the comparable costs for disposal facility closure by the relative volumes of earthen materials

Table C-10. Cost elements and estimates for closure of the assured isolation facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Assured isolation facility closure	3,500
Payroll	3,100
Equipment	150
Monitoring	0
Consumables	310
Equipment maintenance	15
Custodial agency administration	1,500
Regulatory costs	320
Financial assurance	270
Licensing	5,600
Contingencies	<u>2,900</u>
TOTAL	18,000^a

a. Total may not equal the sum of cost elements because of rounding.

that need to be placed at the facility. The scaling was based on the assumption that closure of the assured isolation facility 100 years or more after the end of waste receipt would only require adding the upper half of the disposal facility earthen cover over the vaults that contain Class B and C wastes.

Several cost elements for closure of the assured isolation facility were assumed to be the same as those for the disposal facility. These elements include payroll, equipment, custodial agency administration, regulatory costs, and financial assurance. Consumables, equipment maintenance, and contingencies were related to other cost elements in the same manner as for disposal. Environmental monitoring costs were omitted from the cost estimate of assured isolation closure because it was assumed that at closure the monitoring program would be ongoing and funded by the part of the monies collected during operations that was intended for monitoring during the inspection and preventive maintenance phase terminated by the closure.

When the costs for Cases I1A, I2A, and I3A are combined, the life cycle cost of the assured isolation facility totals about \$810 million in 1996 dollars. Table C-11 shows the costs in 1996 dollars by phase in the facility life cycle. Of the \$810 million, about \$580 million, or about 72 percent, is spent during the phase when waste is being received. The total cost is about \$100 million more than the corresponding estimate for the disposal facility. The isolation facility is expected to cost more than the disposal facility for two major reasons: the extra cost of constructing larger vaults to allow inspection of the vault interiors, and the longer (300 years versus 105 years) duration of activities following the end of operations.

Costs for retrieving and placing all Class B and C waste, and the high-toxicity Class A waste, in another assured isolation facility are given in Table C-12. It was assumed that if retrieval is necessary, a new assured isolation facility of a similar design will be built to take this waste. Unlike the disposal facility, however, it was assumed that no remediation of soil under the assured isolation facility will be

Table C-11. Summary of assured isolation facility costs for one plausible combination of cases, by phase.

Phase	Case	Estimated Costs (thousands of 1996 dollars)
Preoperations	I1 A (no groundwater characterization)	64,000
Operations	I2 A (no groundwater monitoring)	580,000
Inspection and preventive maintenance	I3 A (300 years)	170,000
TOTAL		810,000^a

a. Total may not equal sum of phase costs because of rounding.

Table C-12. Retrieval and reisolation costs for the assured isolation facility.

RETRIEVAL OF WASTE	
Cost Element	Estimated Cost (thousands of 1996 dollars)
Planning	130
Construction	4,400
Personnel	2,500
Equipment	380
Utilities	250
Custodial agency administration	120
Contingencies	<u>1,600</u>
Total retrieval cost	9,300^a
REISOLATION	
Waste	
377,000 ft ³ @ \$750/ft ³	280,000
GRAND TOTAL:	290,000^a
a. Total may not equal the sum of cost elements because of rounding.	

necessary; it was presumed that the systems designed to detect loss of containment integrity would trigger retrieval before any release to the soil could occur. Major retrieval costs include costs for removing enough of the cover over the vaults to safely access the tunnels between rows of vaults, entering the isolation vaults with essentially the same equipment used to place the waste, removing the intact waste canisters, backfilling the empty vaults, and physically restoring the assured isolation facility site by grading and revegetating as necessary.

As with the disposal facility, it was assumed that when retrieval takes place (at least 100 years after the end of operations) the portion of the Class A waste that contributes about 15 percent of the ingestion toxicity of all Class A waste would no longer be a potential threat to human health and the environment and that, consequently, it could be sent to a regulated landfill. No explicit cost for disposal of that waste was included in this estimate. To estimate the cost of managing the rest of the retrieved waste, an estimate of the cost of placing the Class B, C, and high-toxicity Class A wastes in another assured isolation facility similar to the one analyzed (reisolation) was developed. The average unit cost for that activity was estimated to be about \$500 per cubic foot (in 1996 dollars). As with the analysis of the disposal facility, the unit cost was increased by an assumed factor of 50 percent, to about \$750 per cubic foot, to account for disposal of the low-toxicity Class A waste and a generally higher cost of placing Class B and C waste in assured isolation. Table C-12 shows that the estimated cost of reisolating the Class B, C, and high-toxicity Class A wastes is about \$280 million, which is much more than the cost of retrieving the waste. The total cost for retrieving and reisolating waste from the assured isolation facility, in 1996 dollars, is about \$290 million.

Comparing the retrieval cost estimate in Table C-12 with that for the disposal facility (see Table C-6) shows that the cost for retrieving waste from the assured isolation facility is much lower than for retrieving it from the disposal facility. This difference results primarily from the fact that, with assured isolation, it is not necessary to cut through the concrete vaults and remove backfill from around the waste canisters before retrieving them. Also, the volume of earthen cover material that must be removed is much smaller for isolation than for disposal; only enough of the cover to access the tunnels between vaults must be removed to retrieve waste from assured isolation.

Since sufficient funds for retrieving and placing the Class B and C wastes, and high-toxicity Class A wastes, in another assured isolation facility or for closing the facility are required to be available by 100 years after the end of operations, the financial assurance cost element for assured isolation is based on the larger of the cost estimates for those two situations (retrieval or closure), rather than on the sum of the two. Consequently, the retrieval and reisolation cost estimates given in Table C-12 were used in determining the portion of the financial assurance element that represents monies that must be available 100 years after the end of operations to cover costs of possible closure or retrieval and reisolation.

Appendix D

Details of Cost Estimates

Appendix D

Details of Cost Estimates

This appendix provides details of the cost buildups for the 14 cases (7 for disposal and 7 for assured isolation) that form the basis for the present value life cycle costs given in Chapter 4. The cost buildups for the seven cases given in Appendix C are repeated here to present all cases together for easy comparison.

Tables D-1 and D-2 summarize the information presented in this appendix. For information purposes, Table D-1 presents the cost in 1996 dollars and the present value cost for waste retrieval, remediation (disposal only), and redisposal or reisolation. These costs are imbedded in the financial assurance cost element for the operations period and should not be added to the other cost estimates shown in Tables D-1 and D-2.

To emphasize the uncertainties that are inherent in all the cost estimates, all costs in this appendix, as elsewhere in the report, are rounded to two significant digits. One consequence of this rounding is the seemingly identical total costs in 1996 dollars and in present value for preoperations Case D1B (see Table D-1). Because the preoperations phase is assumed to occur soon after 1996, the present value cost and the cost in 1996 dollars are not very different. For case D1B, that difference is entirely obscured by the roundoff.

Table D-1. Summary of cost information

(Costs in thousands of 1996 dollars, unless they are present value costs)

<u>Preoperations</u>	CASES					
	<u>D1A</u>	D1B	<u>D1C</u>	<u>I1A</u>	<u>I1B</u>	<u>I1C</u>
Site Development	8,600	Detailed Breakdown Not Used		2,200	5,100	8,600
EA and License Application	2,000			--	--	--
Licensing	2,800			--	--	--
Permits	820			--	--	--
Licensing and Permitting	--			3,800	3,800	5,600
Siting Agency Administration	5,300			5,300	5,300	5,300
Legal Fees	1,500			1,500	1,500	1,500
Engineering and Design	5,100			5,600	5,600	5,600
Baseline Monitoring	<u>2,100</u>			<u>580</u>	<u>1,300</u>	<u>1,300</u>
Costs Through Licensing	28,000	84,000	106,000	19,000	23,000	28,000
Construction Management	630	630	630	670	670	670
Consumables	86	86	86	86	86	86
Payroll	860	860	860	860	860	860
Site Prep. and Support Fac. Const.	14,000	14,000	14,000	15,000	15,000	15,000
Purchase Equip. for Ops. and Const.	7,700	7,700	7,700	7,700	7,700	7,700
Incentive and Assistance Payments	10,000	10,000	10,000	10,000	10,000	10,000
Contingencies	<u>12,000</u>	<u>6,700</u>	<u>6,700</u>	<u>11,000</u>	<u>11,000</u>	<u>12,000</u>
1996 Dollars (Preoperations) ^a	<u>74,000</u>	<u>120,000</u>	<u>150,000</u>	<u>64,000</u>	<u>68,000</u>	<u>75,000</u>
Present Value (Preoperations)	69,000	120,000	140,000	60,000	64,000	70,000
Operations		D2		I2A	I2B	
Start-Up of Facilities		230		230	230	
Construction of Waste Units		110,000		130,000	130,000	
Equipment Maintenance		1,500		1,600	1,600	
Building and Facilities Maintenance		2,600		2,800	2,800	
Construction and Operations Payroll		110,000		120,000	120,000	
Management Agency Administration		15,000		15,000	15,000	
Legal Fees		15,000		15,000	15,000	
Environmental Monitoring		32,000		29,000	36,000	
Regulatory Costs		9,200		9,200	9,200	
Consumables		11,000		12,000	12,000	
Office Equipment		470		470	470	
Construction and Operations Equip.		15,000		16,000	16,000	
Financial Assurance		30,000		25,000	25,000	
Incentive and Assistance Payments		100,000		100,000	100,000	
Taxes or Payments in Lieu of Taxes		15,000		15,000	15,000	
Contingencies		<u>95,000</u>		<u>97,000</u>	<u>98,000</u>	
1996 Dollars (Operations) ^a		<u>570,000</u>		<u>580,000</u>	<u>590,000</u>	
Present Value (Operations)		250,000		260,000	260,000	

Table D-1. (continued)

<u>Closure and Postclosure</u>		<u>D3</u>		<u>No case designation assigned; part of financial assurance costs</u>	
Facility Closure		15,000		3,500	
Payroll		3,000		3,100	
Equipment		150		150	
Environmental Monitoring		4,400		0	
Consumables		300		310	
Equipment Maintenance		15		15	
Custodial Agency Administration		1,500		1,500	
Regulatory Costs		320		320	
Financial Assurance		270		270	
Licensing		--		5,600	
Payments in lieu of taxes		47		51	
Contingencies		<u>5,000</u>		<u>2,900</u>	
1996 Dollars (Closure & Postclosure) ^a		<u>30,000</u>		<u>18,000</u>	
Present Value (Closure & Postclosure)		9,700			
<u>Institutional Control/Inspection & Preventive Maintenance</u>					
<u>Interval (Years)</u>	<u>D4A 1-10</u>	<u>D4B 1-30</u>		<u>I3A 1-100</u>	<u>I3B 1-100</u>
Payroll	1,400	4,300		15,000	15,000
Equipment	75	230		780	780
Consumables	140	430		1,500	1,500
Environmental Monitoring	4,000	12,000		51,000	51,000
Equipment and Vehicle Maintenance	8	23		78	78
Custodial Agency Administration	74	220		740	740
Regulatory Costs	210	640		2,100	2,100
Financial Assurance	530	1,600		5,300	5,300
Payments in lieu of taxes	82	250		890	890
Contingencies	<u>1,300</u>	<u>4,000</u>		<u>15,000</u>	<u>15,000</u>
Subtotal ^a	<u>7,900</u>	<u>24,000</u>		<u>92,000</u>	<u>92,000</u>
Per Year	790	790		920	920
<u>Interval (years)</u>	<u>11-25</u>	<u>31-75</u>		<u>101-300</u>	<u>101-500</u>
Payroll	1,100	3,300		15,000	30,000
Equipment	120	370		780	1,600
Consumables	110	330		1,500	3,000
Environmental Monitoring	3,000	9,100		29,000	59,000
Equipment and Vehicle Maintenance	12	37		78	160
Custodial Agency Administration	55	170		740	1,500
Regulatory Costs	160	480		2,100	4,200
Financial Assurance	800	2,400		11,000	21,000
Payments in lieu of taxes	140	400		1,700	3,400
Contingencies	<u>1,100</u>	<u>3,300</u>		<u>12,000</u>	<u>25,000</u>
Subtotal ^a	<u>6,600</u>	<u>20,000</u>		<u>74,000</u>	<u>150,000</u>
Per Year	440	440		370	370

Table D-1. (continued)

<u>Interval (years)</u>	<u>26-100</u>	<u>76-300</u>		
Payroll	3,300	10,000		
Equipment	260	770		
Consumables	340	1,000		
Environmental Monitoring	7,700	23,000		
Equipment and Vehicle Maintenance	26	77		
Custodial Agency Administration	170	520		
Regulatory Costs	400	1,200		
Financial Assurance	4,000	12,000		
Payments in lieu of taxes	580	1,700		
Contingencies	<u>3,400</u>	<u>10,000</u>		
Subtotal ^a	<u>20,000</u>	<u>61,000</u>		
Per Year	270	270		
 1996 Dollars^a (Institutional Control/ Inspection and Preventive Maintenance)	 35,000	 100,000	 170,000	 240,000
 Present Value (Institutional Control/ Inspection and Preventive Maintenance)	 5,600	 7,800	 15,000	 15,000
Retrieval	DISPOSAL	ASSURED ISOLATION		
Planning	620	130		
Construction and Demolition	21,000	4,400		
Personnel	2,000	2,500		
Equipment	310	380		
Utilities	90	250		
Custodial Agency Administration	98	120		
Contingencies	4,700	1,600		
Subtotal ^a	28,000 ^a	9,300 ^a		
Remediation of Contamination				
Cutting and removing the concrete vault floor	210			
Excavating contaminated soil	82			
Backfilling	6			
Subtotal ^a	290			
Redisposal or Reisolation				
	340,000	280,000		
GRAND TOTAL	370,000^a	290,000^a		
Present Value (If conducted 100 years after end of operations)	17,000	14,000		

a. Total may not equal the sum of cost elements because of rounding.

Table D-2. Comparison of costs for disposal and assured isolation (Thousands of Dollars)

Disposal											
Scenario	Pre-Operations	Operations	Post-Closure and	Institutional Control	TOTAL	Retrieval, Remediation, & Redisposal	Pre-Operations	Operations	Inspection and Preventive Maintenance	TOTAL	Retrieval & Redisposal ^b
D1A+D2+D3+D4A	74,000	570,000	30,000	35,000	710,000	370,000	64,000	580,000	170,000	810,000	290,000
D1A+D2+D3+D4B	74,000	570,000	30,000	100,000	780,000	370,000	64,000	580,000	240,000	880,000	290,000
D1B+D2+D3+D4A	120,000	570,000	30,000	35,000	760,000	370,000	68,000	590,000	170,000	820,000	290,000
D1B+D2+D3+D4B	120,000	570,000	30,000	100,000	830,000	370,000	68,000	590,000	240,000	900,000	290,000
D1C+D2+D3+D4A	150,000	570,000	30,000	35,000	780,000	370,000	75,000	590,000	170,000	830,000	290,000
D1C+D2+D3+D4B	150,000	570,000	30,000	100,000	850,000	370,000	75,000	590,000	240,000	900,000	290,000
Assured Isolation											
Scenario	Pre-Operations	Operations	Post-Closure and	Institutional Control	TOTAL	Retrieval, Remediation, & Redisposal	Pre-Operations	Operations	Inspection and Preventive Maintenance	TOTAL	Retrieval & Redisposal ^b
D1A+D2+D3+D4A	69,000	250,000	9,700	5,600	340,000	17,000	60,000	260,000	15,000	330,000	14,000
D1A+D2+D3+D4B	69,000	250,000	9,700	7,800	340,000	17,000	60,000	260,000	15,000	330,000	14,000
D1B+D2+D3+D4A	120,000	250,000	9,700	5,600	390,000	17,000	64,000	260,000	15,000	340,000	14,000
D1B+D2+D3+D4B	120,000	250,000	9,700	7,800	390,000	17,000	64,000	260,000	15,000	340,000	14,000
D1C+D2+D3+D4A	140,000	250,000	9,700	5,600	410,000	17,000	70,000	260,000	15,000	350,000	14,000
D1C+D2+D3+D4B	140,000	250,000	9,700	7,800	390,000	17,000	70,000	260,000	15,000	350,000	14,000
D1C+D2+D3+D4B	140,000	250,000	9,700	7,800	400,000	17,000	70,000	260,000	15,000	350,000	14,000

Present Value

Retrieval, Remediation, & Redisposal
After End of
100 Years
Operations^b

Scenario

Pre-Operations

Operations

Inspection and Preventive Maintenance

TOTAL

Retrieval & Redisposal
After End of
100 Years
Operations^b

a. Total may not equal the sum of cost elements because of rounding.

b. Imbedded in operations phase financial assurance costs. Present value indicated is at the end of operations, when sufficient money must be on hand to fund these activities any time after 100 years later.

D.1 DISPOSAL

D.1.1 Preoperations

Case D1A—This case represents preoperations at the disposal facility, with cost estimates derived in a manner similar to recent cost studies for other facilities (e.g., RAE 1992, NY 1995, and DOE 1993). The cost elements and estimates for Case D1A are given in Table D-3.

Case D1B—This case represents, in part, an estimate of the average recent experience for preoperations costs in the U.S. It was assumed that only one site is fully characterized. As representative of that scenario, the history of expenditures at the disposal facility being developed in North Carolina was used. The total expenditure for developing the North Carolina facility up to the submittal of a license application was about \$64 million. Of that, roughly two-thirds was spent in characterizing two sites, one-sixth in selecting a site, and one-sixth in preparing two license applications. Only one facility design was prepared, however. It was assumed that one-third of the license application preparation cost was for preparing the design and that the other two-thirds was split evenly between the preparations for the two license applications. The cost through license application submittal if a volunteer site was found (assumed here at no cost), only one site was characterized, and only one license application was prepared was estimated to be one-third (for characterizing one site) of \$64 million, plus two-thirds of one-sixth (for one design and one license application) of \$64 million, or about \$28 million.

Projections of the amount needed to complete the licensing process in North Carolina have been around \$120 million, including the \$64 million described above. In other words, it is estimated that about \$56 million will be spent in the preoperations phase after submission of the license application. To date, most of this money has been spent on additional characterization of the proposed site.

Combining the pre-license application and post-license application estimates described in the preceding paragraphs yields an estimate of \$84 million to successfully complete the licensing process for a disposal facility at a volunteer site in a humid climate, when only one site is characterized. Because this estimate (and all such estimates) includes a large uncertainty, it was not adjusted to account for inflation. The estimate is somewhat consistent, however, with the experience in Illinois, where about \$70 to 80 million apparently were spent in an unsuccessful attempt to license a disposal facility. There is no strong reason to expect that the disposal facility that is the subject of this comparison will be any less expensive to license just because it is smaller than the North Carolina and Illinois facilities.

Certain other preoperations costs that were used in the analysis of Case D1A but which were not part of the cost incurred in North Carolina were incorporated in the total preoperations cost for this case. Table D-4 lists the cost elements for this case. Note that an amount for contingencies was only added for cost elements not derived from the North Carolina experience because the North Carolina costs represent relatively known expenses and not projections.

Case D1C—This case is similar to Case D1B because it represents an estimate of the average recent experience in the U.S. However, for this case it was assumed that two sites are fully characterized. In keeping with the discussion for the development of costs for Case D1B, it was estimated that the cost up to license application is two-thirds (for characterizing two sites) of \$64 million, plus two-thirds (for one design and one license application) of one-sixth of \$64 million, or about \$50 million.

Table D-3. Cost elements and estimates for Case D1A: Five years of preoperations (optimistic estimate).

Cost Element	Estimated Cost (thousands of 1996 dollars)
Site development	8,600
Environmental assessment and license application	2,000
Licensing	2,800
Permits	820
Siting agency administration	5,300
Legal fees	1,500
Engineering and design	5,100
Baseline monitoring	2,100
Construction management	630
Consumables	86
Payroll	860
Site preparation and support facility construction	14,000
Purchase of equipment for operations and disposal unit construction	7,700
Incentive and assistance payments	10,000
Contingencies	12,000
TOTAL	74,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-4. Cost elements and estimates for Case D1B: Five years of preoperations costs based on recent experience in the U.S.; full characterization of a single site.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Costs through licensing (see text)	84,000
Construction management	630
Consumables	86
Payroll	860
Site preparation and support facility construction	14,000
Purchase of equipment for operations and disposal unit construction	7,700
Incentive and assistance payments	10,000
Contingencies (on all but the first item)	<u>6,700</u>
TOTAL	120,000^a

a. Total may not equal the sum of cost elements because of rounding.

Presumably, there will not be any additional expense for characterizing the second site after the license application is submitted because the application will involve only one site, even though two sites were fully characterized. Therefore, this case incorporates the same post-license application cost used in Case D1B. Combining the pre-license application cost estimate with the \$56 million estimate for post-license application costs used in Case D1B yields an estimate of \$106 million to successfully complete the licensing process for this case.

In addition to the \$106 million to complete the licensing process, this case includes several other preoperations cost elements that were used in Case D1A but which were not part of the North Carolina experience. Table D-5 lists the cost elements for this case. As with Case D1B, an amount for contingencies was only added for those cost elements that are not based on the North Carolina experience.

D.1.2 Operations

Case D2 represents operations at the disposal facility. The cost elements and estimates for this case are given in Table D-6.

D.1.3 Closure and Postclosure

Case D3 represents closure and postclosure activities at the disposal facility. The cost elements and estimates for this case are given in Table D-7.

D.1.4 Institutional Control

Case D4A—This case represents 100 years of institutional control at the disposal facility. The cost elements and estimates for the three intervals of institutional control for this case—the first 10 years, the next 15 years, and the final 75 years—are given in Table D-8.

Case D4B—This case is for 300 years of institutional control at the disposal facility. The 300-year institutional control phase is divided into different intervals than those used in Case D4A. Those intervals are the first 30 years, the next 45 years, and the final 225 years. The cost elements and estimates for Case D4B are given in Table D-9.

When comparing the cost estimates in Tables D-8 and D-9, note that the entries for each interval represent the total cost for that interval and that the intervals in the two tables have different lengths. Therefore, even if corresponding costs are the same on an annual basis, the numbers in the tables will differ. In fact, for the same interval of institutional control, the annual costs for each cost element are the same for Cases D4A and D4B; differences between the two sets of costs stem only from the different lengths of the intervals.

Table D-5. Cost elements and estimates for Case D1C: Five years of preoperations costs based on recent experience in the U.S.; full characterization of two sites.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Costs through licensing (see text)	106,000
Construction management	630
Consumables	86
Payroll	860
Site preparation and support facility construction	14,000
Purchase of equipment for operations and disposal unit construction	7,700
Incentive and assistance payments	10,000
Contingencies (on all but the first item)	<u>6,700</u>
TOTAL	150,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-6. Cost elements and estimates for Case D2: 50 years of operations at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Start-up of facilities	230
Construction of disposal units	110,000
Equipment maintenance	1,500
Building and facilities maintenance	2,600
Construction and operations payroll	110,000
Management agency administration	15,000
Legal fees	15,000
Environmental monitoring	32,000
Regulatory costs	9,200
Consumables	11,000
Office equipment	470
Construction and operations equipment	15,000
Financial assurance	30,000
Incentive and assistance payments	100,000
Payments in lieu of taxes	15,000
Contingencies	<u>95,000</u>
TOTAL	570,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-7. Cost elements and estimates for Case D3: Five years of closure and postclosure at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Disposal facility closure	15,000
Payroll	3,000
Equipment	150
Environmental monitoring	4,400
Consumables	300
Equipment maintenance	15
Custodial agency administration	1,500
Regulatory costs	320
Financial assurance	270
Payments in lieu of taxes	47
Contingencies	<u>5,000</u>
TOTAL	30,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-8. Cost elements and estimates for Case D4A: 100 years of institutional control at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
<u>Years 1 through 10</u>	
Payroll	1,400
Equipment	75
Consumables	140
Environmental monitoring	4,000
Equipment and vehicle maintenance	8
Custodial agency administration	74
Regulatory costs	210
Financial assurance	530
Payments in lieu of taxes	82
Contingencies	<u>1,300</u>
TOTAL	7,900^a
<u>Years 11 through 25</u>	
Payroll	1,100
Equipment	120
Consumables	110
Environmental monitoring	3,000
Equipment and vehicle maintenance	12
Custodial agency administration	55
Regulatory costs	160
Financial assurance	800
Payments in lieu of taxes	140
Contingencies	<u>1,100</u>
TOTAL	6,600^a
<u>Years 26 through 100</u>	
Payroll	3,300
Equipment	260
Consumables	340
Environmental monitoring	7,700
Equipment and vehicle maintenance	26
Custodial agency administration	170
Regulatory costs	400
Financial assurance	4,000
Payments in lieu of taxes	580
Contingencies	<u>3,400</u>
TOTAL	20,000^a
GRAND TOTAL	35,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-9. Cost elements and estimates for Case D4B: 300 years of institutional control at the disposal facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
<u>Years 1 through 30</u>	
Payroll	4,300
Equipment	230
Consumables	430
Environmental monitoring	12,000
Equipment and vehicle maintenance	23
Custodial agency administration	220
Regulatory costs	640
Financial assurance	1,600
Payments in lieu of taxes	250
Contingencies	<u>4,000</u>
TOTAL	24,000^a
<u>Years 31 through 75</u>	
Payroll	3,300
Equipment	370
Consumables	330
Environmental monitoring	9,100
Equipment and vehicle maintenance	37
Custodial agency administration	170
Regulatory costs	480
Financial assurance	2,400
Payments in lieu of taxes	400
Contingencies	<u>3,300</u>
TOTAL	20,000^a
<u>Years 76 through 300</u>	
Payroll	10,000
Equipment	770
Consumables	1,000
Environmental monitoring	23,000
Equipment and vehicle maintenance	77
Custodial agency administration	520
Regulatory costs	1,200
Financial assurance	12,000
Payments in lieu of taxes	1,700
Contingencies	<u>10,000</u>
TOTAL	61,000^a
GRAND TOTAL	100,000^a

a. Total may not equal the sum of cost elements because of rounding.

D.2 ASSURED ISOLATION

D.2.1 Preoperations

Case I1A—This case represents one set of preoperations costs for the assured isolation facility. The cost elements and estimates for Case I1A are given in Table D-10. Section C.2 in Appendix C discusses how the estimates for the cost elements were derived from those for Case D1A for the disposal facility. Most of the cost elements for the preoperations phase are identical to the elements for the same phase for the disposal facility design. A comparison of the total cost for the preoperations phase of the life cycle for an assured isolation facility (for Case I1A) with that in Table D-3 for the disposal facility (for Case D1A) shows that the assured isolation facility costs significantly less (about 9 percent less) than the disposal facility during this phase. The lower cost is primarily due to the assumption used in Case I1A that there will be no characterization or baseline monitoring of groundwater at the site for the assured isolation facility, and that licensing and permitting for the assured isolation facility will cost considerably less than environmental assessment and license application, licensing, and permits for the disposal facility. Those assumptions, in turn, are based on assumptions that the public will accept the concept that inspection of the vault interiors and preventive maintenance will prevent releases of contaminants from the vaults and that, therefore, groundwater characterization and monitoring are not necessary to protect public health and safety. It was also assumed that regulatory agencies would accept this concept, which would make licensing and permitting an assured isolation facility less complicated than for a disposal facility.

Case I1B—This case is similar to Case I1A, except that it includes costs for significant characterization and baseline monitoring of groundwater at the site during the preoperations phase. Specifically, quarterly monitoring at 22 wells was assumed to develop the cost estimate for the additional groundwater monitoring. The cost elements are the same as for Case I1A, and the estimates of costs for those elements are given in Table D-11. Comparing Tables D-10 and D-11 shows that the total preoperations cost estimate for this case is about \$4 million, or about 6 percent, greater than that for Case I1A due to the addition of groundwater characterization and monitoring.

Case I1C—This case represents a situation where the cost of site characterization and licensing for an assured isolation facility is the same as that for a disposal facility. For this case, the cost estimates for the site development, environmental assessment and license application, licensing, and permits cost elements for Case D1A were used in cost elements for site development, and licensing and permitting. Of course, these costs for preoperations at an assured isolation facility are still much lower than those used for similar activities in the cost analyses of Cases D1B and D1C. This substitution raised the total preoperations cost for Case I1C by about \$7 million, or about 10 percent, relative to that for Case I1B. The cost elements and estimates for Case I1C are given in Table D-12.

D.2.2 Operations

Case I2A—This case involves costs for operations at the assured isolation facility without groundwater monitoring. The cost elements and estimates are given in Table D-13.

Note that the cost elements are the same as those used for the operations phase for the disposal facility cost estimates. Many of the cost *estimates*, however, are different. Appendix B describes how many of the cost estimates were derived from the reference design that was used to develop corresponding cost estimates for the disposal facility (Case D2). Comparison of Tables D-6 and D-13 shows that operations at the assured isolation facility cost about \$10 million more than at the disposal

Table D-10. Cost elements and estimates for Case II A: Five years of preoperations at the assured isolation facility without site groundwater characterization.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Site development	2,200
Licensing and permitting	3,800
Siting agency administration	5,300
Construction management	670
Consumables	86
Legal fees	1,500
Payroll	860
Site preparation and support facility construction	15,000
Purchase of equipment for operations and disposal unit construction	7,700
Engineering and design	5,600
Baseline monitoring	580
Incentive and assistance payments	10,000
Contingencies	11,000
TOTAL	64,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-11. Cost elements and estimates for Case IIB: Five years of preoperations for the assured isolation facility with limited site groundwater characterization.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Site development	5,100
Licensing and permitting	3,800
Siting agency administration	5,300
Construction management	670
Consumables	86
Legal fees	1,500
Payroll	860
Site preparation and support facility construction	15,000
Purchase of equipment for operations and disposal unit construction	7,700
Engineering and design	5,600
Baseline monitoring	1,300
Incentive and assistance payments	10,000
Contingencies	11,000
TOTAL	68,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-12. Cost elements and estimates for Case IIC: Five years of preoperations for the assured isolation facility with certain costs identical to those in Case D1A.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Site development	8,600
Licensing and permitting	5,600
Siting agency administration	5,300
Construction management	670
Consumables	86
Legal fees	1,500
Payroll	860
Site preparation and support facility construction	15,000
Purchase of equipment for operations and disposal unit construction	7,700
Engineering and design	5,600
Baseline monitoring	1,300
Incentive and assistance payments	10,000
Contingencies	12,000
TOTAL	75,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-13. Cost elements and estimates for Case I2A: 50 years of operations at the assured isolation facility without groundwater monitoring.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Start-up of facilities	230
Construction of assured isolation units	130,000
Equipment maintenance	1,600
Building and facilities maintenance	2,800
Construction and operations payroll	120,000
Management agency administration	15,000
Legal fees	15,000
Environmental monitoring	29,000
Regulatory costs	9,200
Consumables	12,000
Office equipment	470
Construction and operations equipment	16,000
Financial assurance	25,000
Incentive and assistance payments	100,000
Payments in lieu of taxes	15,000
Contingencies	<u>97,000</u>
TOTAL	580,000^a

a. Total may not equal the sum of cost elements because of rounding.

facility, primarily because of the higher cost of construction. The higher construction costs largely result from the need to have inspection aisles around the insides of the vault and cell walls. This feature significantly increases the amount of concrete needed in construction.

Case I2B—This case represents operations at the assured isolation facility, but with groundwater monitoring conducted during operations. The same 22 wells that were added in Case I1B were added to the design for Case I2A at the start of operations. The number of wells grows to 34 as the vaults are constructed and built over the operating phase. The cost elements and estimates for this case are given in Table D-14. Comparison of Tables D-13 and D-14 shows that the increase in monitoring costs over the operating phase, and associated contingencies, raises the cost of the assured isolation facility by about \$10 million.

D.2.3 Inspection and Preventive Maintenance

Case I3A—This case represents 300 years of inspection and preventive maintenance at the assured isolation facility. The cost elements and estimates for this case are given in Table D-15 for the two intervals of this phase and for the entire phase. Note that the cost elements are the same as for the institutional control phase for the disposal facilities. Many of the values of the cost *estimates* are different, however.

Case I3B—This case is for the assured isolation facility with 500 years of inspection and preventive maintenance. Table D-16 gives the cost estimate for this case. Comparison of Tables D-15 and D-16 shows that extending this phase for an additional 200 years increases the cost for the phase by about \$70 million, or about 40 percent.

Table D-14. Cost elements and estimates for Case I2B: 50 years of operations at the assured isolation facility with groundwater monitoring.

Cost Element	Estimated Cost (thousands of 1996 dollars)
Start-up of facilities	230
Construction of assured isolation units	130,000
Equipment maintenance	1,600
Building and facilities maintenance	2,800
Construction and operations payroll	120,000
Management agency administration	15,000
Legal fees	15,000
Environmental monitoring	36,000
Regulatory costs	9,200
Consumables	12,000
Office equipment	470
Construction and operations equipment	16,000
Financial assurance	25,000
Incentive and assistance payments	100,000
Payments in lieu of taxes	15,000
Contingencies	<u>98,000</u>
TOTAL	590,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-15. Cost elements and estimates for Case I3A: 300 years of inspection and preventive maintenance at the assured isolation facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
<u>Years 1 through 100</u>	
Payroll	15,000
Equipment	780
Consumables	1,500
Environmental monitoring	51,000
Equipment and vehicle maintenance	78
Custodial agency administration	740
Regulatory costs	2,100
Financial assurance	5,300
Contingencies	<u>15,000</u>
TOTAL	91,000^a
<u>Years 101 through 300</u>	
Payroll	15,000
Equipment	780
Consumables	1,500
Environmental monitoring	34,000
Equipment and vehicle maintenance	78
Custodial agency administration	740
Regulatory costs	2,100
Financial assurance	11,000
Contingencies	<u>13,000</u>
TOTAL	77,000^a
GRAND TOTAL	170,000^a

a. Total may not equal the sum of cost elements because of rounding.

Table D-16. Cost elements and estimates for Case I3B: 500 years of inspection and preventive maintenance at the assured isolation facility.

Cost Element	Estimated Cost (thousands of 1996 dollars)
<u>Years 1 through 100</u>	
Payroll	15,000
Equipment	780
Consumables	1,500
Environmental monitoring	51,000
Equipment and vehicle maintenance	78
Custodial agency administration	740
Regulatory costs	2,100
Financial assurance	5,300
Contingencies	<u>15,000</u>
TOTAL	91,000^a
<u>Years 101 through 500</u>	
Payroll	30,000
Equipment	1,600
Consumables	3,000
Environmental monitoring	65,000
Equipment and vehicle maintenance	160
Custodial agency administration	1,500
Regulatory costs	4,200
Financial assurance	21,000
Contingencies	<u>25,000</u>
TOTAL	150,000^a
GRAND TOTAL	240,000^a

a. Total may not equal the sum of cost elements because of rounding.