Projected Costs for Mined Geologic Repositories for Disposal of Commercial Nuclear Wastes

Technical Report

December 1982

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**Engineering Economics Program Office
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1.0 SUMMARY

This document reports cost estimates for (1) the exploration and development activities preceding the final design of terminal isolation facilities for disposal of commercial high-level waste and (2) the design, construction, operation, and decommissioning of such facilities. Exploration and development costs also include a separate cost category for related programs such as subseabed research, activities of the Transportation Technology Center, and waste disposal impact mitigation activities.

1.1 Approach

This document contains brief descriptions of cost estimates for the programs required to develop terminal isolation facilities given current policies of the U.S. Department of Energy (DOE) to satisfy regulations of the U.S. Nuclear Regulatory Commission (NRC) and of the U.S. Environmental Protection Agency (EPA). Changes in national policies and programs or changes in safety or environmental requirements would change the estimated costs.

Cost estimates for exploration and development are projected to the end of the program for various cost centers using past experience and available near-term estimates. Estimated costs for the waste preparation and repository systems are based on a combination of conceptual designs and design modifications in order to reflect current program guidance. Principal references for these estimates include the salt conceptual designs,(1,2,3) the Westinghouse waste package design studies,(4,5) and the Environmental Impact Statement (EIS)(6).

1.2 Estimated Costs

Figure 1 presents the projected cumulative exploration and development costs. The estimates are in mid-82 dollars with no discounting.

Table 1 summarizes the waste preparation and repository costs for eight repository waste preparation/repository cases. These cases cover four

FIGURE 1. ESTIMATED NWTs PROGRAM EXPLORATION AND DEVELOPMENT COSTS; 1982 DOLLARS

TABLE 1. COST SUMMARY OF REFERENCE CASES
(Billions of 1982 \$)

ID No.	Title	Total Costs	Capital Costs			Operations Costs			Decommissioning Costs		
			Waste Preparation	Repository	Subtotal	Waste Preparation	Repository	Subtotal	Waste Preparation	Repository	Subtotal
82-66	Domed Salt, Spent Fuel	5.23	0.331	1.27	1.60	1.20	2.13	3.33	0.050	0.251	0.301
82-67	Bedded Salt, Spent Fuel	5.35	0.331	1.38	1.71	1.20	2.13	3.33	0.050	0.267	0.317
82-68	Tuff, Spent Fuel	5.59	0.331	1.29	1.62	1.20	2.43	3.63	0.050	0.286	0.336
82-69	Granite, Spent Fuel	5.76	0.331	1.37	1.70	1.20	2.50	3.70	0.050	0.308	0.358
82-70	Domed Salt, Reprocessing Waste	4.86	0.293	1.24	1.53	1.00	2.08	3.08	0.044	0.211	0.255
82-71	Bedded Salt, Reprocessing Waste	4.98	0.293	1.34	1.63	1.00	2.08	3.08	0.044	0.227	0.271
82-72	Tuff, Reprocessing Waste	5.35	0.293	1.37	1.66	1.00	2.41	3.41	0.044	0.227	0.271
82-73	Granite, Reprocessing Waste	5.45	0.293	1.44	1.73	1.00	2.43	3.43	0.044	0.240	0.384

host geologies (domed salt, bedded salt, tuff, and granite) and two waste forms (spent fuel and reprocessing waste). Note that for the spent fuel cases the costs for certain waste form preparation items -- spent fuel disassembly and close packing -- are included in the total costs. For the reprocessing waste cases, vitrification costs are not included in the total costs.

Several of the key assumptions used in arriving at these estimates are given in Table 2.

1.3 Limitation of These Estimates

The cost estimates reported in this study represent the compilation of many estimates. Although the waste preparation and repository costs are based on available conceptual designs, these designs are not fully applicable to or consistent with current program guidance and thus major adjustments had to be made. Hence, the estimates in this report should be considered as "expected values" with a large uncertainty margin. Many of the source documents which had to be modified are "venture-type" estimates with uncertainties in the range of 30 percent or greater.

While no separate cost estimates for basalt repositories are included in this report, the cost summaries do include the exploration and development costs for the Basalt Waste Isolation Program (BWIP).

TABLE 2. KEY ASSUMPTIONS AND GROUND RULES

-
1. Number of Repositories -- 2
 2. Repository Start-up Dates -- The first in 1998 (October)
The second in 2002 (October)
 3. Repository Capacity - 72,000 MT
 4. Waste Age -- Designs based on a minimum cooling period of 10 years
 5. Waste Packages -- Long-lived "Westinghouse Package" design for commercial high-level waste and spent fuel (end fittings and intermediate-level waste are not placed in long-lived packages)
 - Spent fuel disassembly at repository
 - Spent fuel packaging at repository; commercial high-level waste (CHLW) packaging at repository
 - Transuranic contaminated waste (TRU) (100 nCi/g) in thin-walled packages
 - No tailored backfill around the waste package canister
 - TRU incinerated for volume reduction
 6. Waste Emplacement -- Borehole for spent fuel and high-level waste
 - No hole liners
 - Commingling of RHTRU(a) package with other waste packages
 7. Retrievability -- Designs include provision to maintain retrievability for as long as 50 years from date of emplacement of first waste package
 - Early backfilling not precluded (5 years)
 - Retrieval costs not included
 - Decommissioning after the last waste emplacement
 8. Repository (Design) Receipt Rates -- First 5 years = 1,800 MT/year
Next 21 years = 3,000 MT/year
-

(a) RHTRU = remote-handled transuranic (contaminated waste).

2.0 COST ESTIMATES: SITE EXPLORATION AND DEVELOPMENT ACTIVITIES

In this section the planned National Waste Terminal Storage (NWTs) program activities to the year 2006 are briefly described and the estimated costs of carrying out such activities are presented. The estimated total projected NWTs exploration and development program costs through the year 2006 are about 4.1 billion dollars.

Costs for research prior to FY 82 are discussed in Section 2.2.3.

2.1 NWTs Program Strategy

The basic NWTs program strategy is specified in the NWTs program Major Systems Acquisition (MSA) Plan⁽⁷⁾ which was approved by the Under Secretary of the U.S. Department of Energy, April 15, 1982. In this plan the program is divided into four phases: the Advanced Development Phase, the Engineering Development Phase, the Operation Phase, and the Decommissioning Phase. The major schedule milestones during each of these phases are shown in Table 3. The major activities during each of the phases are briefly described below.

2.1.1 Advanced Development Phase

The objectives of the Advanced Development Phase are:

- To conduct geologic studies to identify potential repository sites in varied geographic regions, considering alternative combinations of surface and geologic/hydrologic environments,
- To provide the capability to analyze behavior mechanisms for radioactive waste placed in such candidate environments, and
- To develop other technologies, such as waste handling and packaging and repository sealing, necessary to support the design, construction, operation, and decommissioning of repositories.

The NWTs program began the Advanced Development Phase in 1976 and is presently planning and conducting efforts in this phase.

TABLE 3. MAJOR SCHEDULE MILESTONES

Begin Exploratory Shaft (ES) Construction	
Basalt	4/83
Tuff	9/83
Salt	4/84
Complete ES Phase I Testing	7/85
Complete ES Phase II Testing	3/87
Issue DOE Site Recommendation Report	9/87
Issue DOE Site Selection Report and Final EIS(a)	4/88
Start Construction	10/92
Begin Operations	10/98

(a) EIS = environmental impact statement.

2.1.2 Engineering Development Phase

The objectives of the Engineering Development Phase are:

- To finalize repository site selection
- To perform at-depth testing and the engineering design and development to derive site-specific designs needed for the repository facilities and waste packages, and
- To construct the repository in accordance with approved designs, procedures, and the NRC construction authorization, and to license it for operations.

This phase of the project will involve the systematic use of the knowledge and understanding gained from the previous phase to achieve the detailed design, construction, and checkout of the repository, and licensing by NRC.

2.1.3 Operation Phase

The objective of the Operation Phase is:

- To operate a nuclear waste repository to receive and emplace waste, thereby providing a capability for isolation of existing and future high-level and TRU radioactive waste generated by civilian activities from the environment so that it will not pose any significant threat to public health and safety.

Activities in this phase start after a key decision to initiate repository operations. During this phase, wastes will be emplaced, monitored, and maintained retrievable for some period of time. Following filling of the repository, preparation of documentation to decommission the facility will be initiated.

2.1.4 Decommissioning Phase

The objectives of the Decommissioning Phase are:

- To successfully isolate the emplaced nuclear waste by sealing the repository and restoring the site at the surface, and

- To take whatever additional measures are needed to assure that the sealed repository will not constitute a threat to future generations.

Activities in this phase start after a key decision to decommission the facility has been made. This final phase covers the operations for the closure and sealing of the repository and implementation of monitoring plans. This phase ends with the restoration of the surface environment to its near original state, the imposition of long-term institutional controls, and the initiation of any postclosure surveillance or monitoring systems which might be required.

2.2 NWTS Program Site Exploration and Development Costs

The Major Systems Acquisition Plan presents a schedule for starting operations of the first 72,000 MTU capacity repository in October 1998. Consistent with the Nuclear Waste Management Reference Scenario, the costs presented in this section are based on the start-up of the first repository in October 1998 and the second in October 2002. The site exploration and development costs for both repositories are summarized in Table 4. The costs itemized in this section do not include land acquisition costs should a non-government-owned site be selected as one of the first two repository sites; neither do the cost schedules include Title II and III repository design costs for the two selected sites. Both of these costs are included in the repository construction costs described in Section 3.0.

In addition, the estimates do not include costs associated with waste vitrification process development. TRU treatment and packaging technology are similarly excluded.

The costs contained under the Exploration and Development category are broken into two major headings: Exploration and Development, and Related Programs. The Exploration and Development category is further subdivided into five subcategories: Site Identification, Site Characterization, Site Approval and Construction Authorization, Test and Evaluation Facility, and Technology for Development of Repositories. The costs and a description of the major

TABLE 4 - ESTIMATED NMTS PROGRAM EXPLORATION AND DEVELOPMENT COSTS \$
REFERENCE CASE
(R1 STARTUP - 98, R2 STARTUP - 02)
(MILLIONS-\$2)

EXPLORATION & DEVELOPMENT	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	TOTAL	CATEGORY TOTAL			
SITE IDENTIFICATION																									332					
- FIRST THREE SITES	85	98																							183					
- NATIONAL SCREENING		12	39	50	48																				149					
SITE CHARTACTERIZATION																									708					
- FIRST THREE SITES		17	142	120	55	32	17	10	10	10	10														423					
- OTHER SITES			6	5	6	70	73	80	15	15	15														285					
SITE APPROVAL & CONSTRUCTION AUTHORIZATION	8	9	12	15	20	18	8	8	7	9	9	12	6	6	6	6	4	4	4	4	4						179	179		
T&E FACILITY																									176					
- R&D/CONSTRUCTION/OPERATIONS	2	2	8	22	27	15	7	3	3	2	2	2	2	3	3	3											106			
- CASK ACQUISITION			10	20	10																								40	
- TRANSPORTATION							5	5	5											5	5	5								30
TECHNOLOGY DEVELOPMENT FOR REPOSITORIES																									1458					
- SYSTEMS	8	9	12	12	12	11	8	8	8	8	8	8	8	8	8	8	8	8	4	4	4						172			
- PACKAGE	12	12	12	12	12	12	11	10	7	5	10	8	7	6	5	5	5	6	5	6	5						173			
- REPOSITORY	25	26	33	34	35	21	18	17	15	14	18	12	11	9	12	23	25	17	9	9	9						392			
- AT DEPTH TESTING						20	35	25	4	24	39	28	4	4	4	3												190		
- OTHER TEST FACILITIES	24	20	28	29	10	8	8	8	8	7	7	7	7															171		
- MANAGEMENT	17	19	21	21	21	21	21	21	21	21	21	21	16	14	12	12	12	12	12	12	12						360			
SUBTOTAL ABOVE CATEGORIES																									2853					
RELATED PROGRAMS																									1238					
- RELATED R&D	7	7	16	19	25	25	21	21	21															162						
- IMPACT MITIGATION										60	60	60	64	64	64	64	64	68	68	8	8	8	8	8	8	684				
- FUND MANAGEMENT		4	8	10	10	10	15	15	15	15	15	15	20	20	20	20	20	20	20	20	20	20	20	20	20	392				
TOTAL	188	235	347	369	291	263	247	231	139	190	214	173	145	139	139	149	138	135	122	63	62	28	28	28	28	4091				

* THESE FIGURES SHOULD NOT BE USED FOR BUDGET PURPOSES. THEY ARE ONLY ESTIMATES AND MAY VARY FROM ACTUAL BUDGET FIGURES. OFFICAL BUDGET DOCUMENTS SHOULD BE CONSULTED IF DETAILED COST INFORMATION IS NEEDED ON ANY OF THE SUBELEMENTS SHOWN IN THIS TABLE.

activities falling under each category and subcategory are presented in the following paragraphs.

2.2.1 Exploration and Development

The estimated total exploration and development costs associated with identifying and characterizing five sites, selecting and approving two of these sites for repository construction, and developing and demonstrating the technology to construct and operate a repository at these two sites is 2.85 billion dollars. The costs associated with each of the subcategories are shown in Table 4 and described below.

Site Identification. The estimated cost of site identification activities between FY 82 and FY 86 is about 330 million dollars. The costs associated with the screening of enough sites so that five candidate sites will have been identified in FY 86 are included in this estimate. Site screening consists of a set of decisions made sequentially to identify sites favorable for waste disposal from vast land areas. The cost estimate also includes costs for summarizing the screening activities and for the preparation of appropriate National Environmental Policy Act (NEPA) documents. Of the 330 million dollar estimate, about 180 million dollars is the remaining cost associated with identifying a site in basalt on the Hanford Reservation in the State of Washington, in tuff on or adjacent to the Nevada Test Site, and in salt in one of three regions of the country: the Gulf Coast Region containing dome salt formations, the Paradox Basin Region of southeastern Utah containing bedded salt formations, or the Permian Basin Region in Texas containing bedded salt formations. The remainder of the siting budget, approximately 150 million dollars, includes the costs of crystalline rock investigations, investigations of geologic Province 9, and national screening leading to the identification of two additional sites.

Site Characterization. The site characterization costs for the five sites that will be identified as sites for the first two repositories are estimated to total approximately 710 million dollars. Site characterization

costs, as described in reference (8), include the costs of scientifically collecting and evaluating information about the physical, chemical, geologic, and human environment necessary to judge site suitability. Detailed surface and subsurface studies will be performed at each of the five sites. The studies will include the construction of an exploratory shaft and testing of rock at repository depth as required by the procedural rules (10 CFR 60) of the NRC⁽⁹⁾. Not included under the site characterization heading are all the at-depth tests needed to provide repository licensing data for the two selected sites. The costs for these tests are included under the category, "Technology for Development of Repositories" (p. 13).

Site Approval and Construction Authorization. The site approval and construction authorization costs total approximately 180 million dollars. Siting costs after the detailed siting studies that precede the final site selection decision are included under this category. Included are those costs associated with the comparison of alternative sites, associated with the preparation of documents recommending two sites for a repository, and those costs incurred during the public review period. Also included are the costs of preparing all the appropriate NEPA and licensing documents for the selected repository sites. Although approval and construction authorization are needed only at the two selected sites, these costs are incurred at all candidate sites because of the need for site comparisons and because schedule constraints require simultaneous preparation of licensing and environmental documents at all sites. License applications will be submitted only for the approved sites.

Test and Evaluation Facility. The research and development budget includes approximately 180 million dollars allocated to the development and operation of a Test and Evaluation Facility (TEF). The purpose of the TEF is to refine repository construction methods and operation and safety procedures, and to evaluate waste handling and emplacement equipment under real-time, at-depth prototypical conditions. Placement of up to 300 packages of solidified high-level waste will take place in the TEF. Included in the 180 million dollar cost is 40 million dollars needed for cask acquisition in order

to transport the waste to the TEF site, and 30 million dollars in actual transport costs. The balance of the TEF cost, approximately 110 million dollars, is associated with the research and development (R&D), construction, and operation of the TEF.

Technology for Development of Repositories. The remaining estimated costs associated with technology development for potential repository host media and sites are approximately 1.5 billion dollars. Included under this heading are system studies aimed at developing and applying performance assessment models, developing an isolation system description for each host medium and potential repository site, developing and maintaining a baseline of information containing relevant data on the isolation systems being developed, and performing the trade studies for selecting among alternatives. The total cost of such studies is estimated at approximately 170 million dollars. The technology development category also projects future expenditures in the waste package area of approximately 170 million dollars. This cost includes the activities directed at developing the basic data needed to design and evaluate waste package concepts for each host medium to provide preliminary designs for each candidate site and to develop final designs for the two selected repository sites. Repository development costs are projected to total approximately 390 million dollars. Major technology development activities in the repository area include the development of a data base containing relevant site-specific data needed to complete site-specific repository designs, the development of equipment and instrumentation required to safely and efficiently operate and maintain a waste isolation system, the development of constitutive relationships describing performance of the repository system both during operations and following closure, the development and testing of seals and plugs, the development of site-specific conceptual design for each candidate site for a repository, and the development and application of performance assessment models needed to evaluate preliminary and final isolation system designs.

Test facility construction and operating costs totalling approximately 360 million dollars are also included under the Technology for Development of Repositories cost category. Of that figure, 190 million dollars has been allocated to at-depth testing at the two selected repository sites. The

remainder, 170 million dollars, is for the continued operation of currently existing facilities that provide relevant test data.

Management costs totalling 360 million dollars represent the costs for managing the entire NWTS Research and Development Program. Management costs for the four existing NWTS projects - the Office of Nuclear Waste Isolation (ONWI), the Basalt Waste Isolation Project (BWIP), the Nevada Nuclear Waste Storage Investigations (NNWSI), and the Office of NWTS Integration (ONI) - are included in this estimate.

2.2.2 Related Program Costs

There are several categories of costs which usually are considered part of the NWTS program, but are separate from the estimates discussed previously. These include research for the subseabed program, part of the research at the Transportation Technology Center, and socioeconomic impact mitigation costs.

Related research is projected at just over 160 million dollars (1982 dollars) spread between now and 1990. In order to estimate the range of potential impacts, a scoping analysis of the costs involved in mitigating the socioeconomic impacts related to a repository development was recently prepared by ONWI.

Three scenarios were created. Each scenario differed with respect to demographic composition, size and location of existing population centers, available labor force, and other characteristics which affect levels of project-related in-migration. Factors such as public sector revenues and existing infrastructure capacity were not considered in this initial cost estimate. For this analysis, a computer model was developed to project levels of in-migration for different scenarios and to assess the cost of mitigating socioeconomic impacts created by in-migration. These costs relate to the need for expanding community service facilities and personnel in impacted areas. Housing costs were also included. However, revenues from their resale were not considered.

The model produced rather large infrastructure costs during the construction phase, which highlights the revenue-cost squeeze that communities are likely to incur during the initial stages of the project.

The costs of impact mitigation are extremely site-specific and could vary considerably. Furthermore, it is not clear which of these mitigation costs will be incurred by the repository developer and which will be the responsibility of local governments and the private sector. For this analysis, it is assumed that 300 million dollars will be provided for socioeconomic impact mitigation during the initial phase of the project (60 million dollars per year for 5 years starting prior to the start of construction) plus 4 million dollars per year throughout the Operation Phase. This is applied to each repository for this estimate.

2.2.3 Costs for Exploration and Development Prior to FY 82

The costs for previous exploration and development are part of the total program costs which are to be recovered through the collection of a fee for disposal services. The exact costs that should be included are somewhat uncertain because many of the DOE waste management programs support multiple objectives. The costs are shown in Table 5. These costs represent actual expenses in as-spent dollars. A separate column gives these costs in equivalent 1982 dollars. These were developed by inflating with the Gross National Product (GNP) deflator.

TABLE 5. COSTS FOR COMMERCIAL WASTE DISPOSAL EXPLORATION
AND DEVELOPMENT PRIOR TO FY 82

<u>Fiscal Year</u>	<u>Outlay for Exploration and Development; 1000s of as-spent Dollars</u>	<u>Outlay Adjusted to 1000s of 1982 Dollars^(a)</u>
1981	170,900	184,100
1980	161,400	184,400
1979	126,400	157,500
1978	70,300	94,900
1977	33,200	48,100
1976	6,000	9,200
Pre-1976	<u>5,000</u>	<u>8,800</u>
TOTAL	573,200	687,000

(a) The adjustment to 1982 dollars was made using the Gross National Product (GNP) deflator.

3.0 COST ESTIMATES: REPOSITORY AND WASTE PREPARATION SYSTEMS

3.1 Approach

3.1.1 The Cost Matrix

In order to avoid missing or double-counting costs, a "Cost Matrix" has been prepared. The matrix covers all the systems and activities relevant to waste isolation. The systems are divided into two major categories:

- Waste Preparation System Costs, and
- Repository System Costs.

The waste preparation costs cover the facilities, equipment, materials, and other operations required to prepare and package the waste form for disposal.

The repository costs cover the site, waste handling and emplacement, underground workings, ventilation, and support utilities required to dispose of the packaged waste. Separate entries for capital construction, operations, and decommissioning costs are indicated in the cost matrix. A sample cost matrix is reproduced as Table 6.

To complete the cost matrix, the costs of capital construction, operations, and decommissioning of the repository and waste preparation system are estimated by scaling and factoring previous conceptual design estimates. Because the current waste preparation and repository systems designs are not fully consistent with one another, several adjustments had to be made. The waste package costs are based on the conceptual designs for salt and on preliminary design information for tuff. The repository costs are based on the conceptual designs for salt, NWTSR1* and NWTSR2*(1,2) as well as cost data from the conceptual reference repository description (CRRD),(10) the final environmental impact statement designs,(6) the International Nuclear

*NWTSR1, which refers to NWTs Repository No. 1, is a conceptual design by Stearns-Roger Engineering Company for storing high-level waste in a dome. NWTSR2 refers to a conceptual design by Kaiser Engineers for storing spent fuel in bedded salt.

TABLE 6. SAMPLE WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE:

ID #:

COST UNITS:

DATE PREPARED:

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾										
Spent Fuel										
– Waste Package Components										
– Assembly Facility										
CHLW										
– Waste Package Components										
– Assembly Facility										
TRU										
– Waste Package Components										
– Assembly Facility										
Others										
– Waste Package Components										
– Assembly Facility										
• REPOSITORY SYSTEM										
Site										
– Land & Land Rights										
– On-Site Improvements										
– Off-Site Improvements										
Waste Handling & Emplacement										
– Receiving										
– Other Surface Facilities										
– Waste Shafts & Hoists										
– Transfer & Emplacement										
Rooms										
Boreholes										
Transfer Equipment										
Underground Workings/Rock Handling										
– Service Shaft										
– Shaft Pillar Zone										
– Corridors										
– Rock Handling & Disposal										
– Test Facilities										
Ventilation										
– Ventilation Structures										
– Ventilation Supply Shaft										
– Development Exhaust Shaft										
– Ventilation Flow Paths										
– Repository Exhaust Shaft										
Support & Utilities										
• TOTAL										

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(1) Waste solidification costs are not included in this category.

Fuel Cycle Evaluation (INFCE) designs,⁽¹¹⁾ and preliminary work from the Alternate Geologic Media Engineering Studies (AGMES) and Pacific Northwest Laboratory's studies⁽¹²⁾. The waste packaging facility costs are based on designs and estimates by Kaiser Engineers,⁽¹³⁾ Westinghouse,⁽⁴⁾ and E. R. Johnson Associates in a draft report on the assessment of impacts of spent fuel disassembly alternatives on the nuclear waste isolation system. For this study the capital construction and operations costs are reported at the subtotal level, and decommissioning is estimated as a fraction of capital construction costs plus the costs for rooms, corridors, and test facilities built during operations.

The definitions of the cost matrix categories used in this report are discussed below. The definitions are grouped into activity totals, waste preparation system totals, and repository system totals.

3.1.2 Cost Category Definitions: Activity Totals

Capital Construction: This includes the costs of all facilities, both above and below ground, which are required to provide an operational facility. This also includes the cost of the land, land rights, and site work. Title II design, Title III design, construction management, and capital equipment are included.

Facility Construction: This includes the costs for the purchases of land, improvement to the land, new buildings, structures, and excavations.

Capital Equipment Purchase and Installation: This includes the costs of equipment with a useful life of more than one year.

Operations: This includes all costs associated with the operation of the facility from the time it becomes operational until the Decommissioning Phase. Room backfilling and capital equipment replacement are included.

Labor: This includes the costs of salaries, wages, and fringe benefits.

Materials: This includes the costs of travel, communications, supplies, and all equipment with a useful life of less than one year. The costs of package component parts are included in this account.

Equipment Replacement: This includes the costs of replacement of equipment with a useful life of more than one year.

Utilities: This includes the purchase of fuel, electricity, and water from offsite sources. The costs of facilities and equipment to produce electricity and water on site are included as part of the support and utilities subsystem.

Decommissioning: This includes all costs associated with returning the facility to its original state. This phase begins after the last storage room has been backfilled.

3.1.3 Cost Category Definitions: Waste Preparation System Totals

Waste Preparation System: This includes the costs of placing the waste into a package suitable for disposal. It includes the costs of the components - 55-gallon drums, titanium overpacks, etc. - and the facilities and activities (including spent fuel disassembly) necessary to encapsulate the waste forms prior to final disposal.

Spent Fuel: This category contains the costs of preparing and packaging spent fuel.

CHLW: This category contains the costs of packaging the commercial high-level waste form. Vitrification costs are not included.

TRU: This category contains the costs of packaging remote-handled transuranic wastes. TRU preparation costs are not included in this study.

Other: This category contains the costs of packaging other wastes. In this study other wastes include end fittings and hardware for spent fuel cases, and the drums of contact-handled waste for the reprocessing cases.

Note that in this study the cost of facility construction for the TRU and other waste categories is not separated from the cost of facility construction for spent fuel and CHLW categories. That is, only one assembly facility is costed which handles all waste for a specific repository.

3.1.4 Cost Category Definitions: Repository System and Subsystem Totals

Repository System: This includes the costs of receiving, handling, and disposing of waste. Packaging costs are not included even if the packaging facility is integrated into the repository facilities.

Site: This includes the costs of land and land rights, site preparation such as grading, draining, paving, fencing, and landscaping, and offsite improvements such as highways, railroads, and power transmission lines.

Waste Handling and Emplacement: This includes all facilities, equipment, and activities required to move the waste from the top of the waste shaft to and into the emplacement hole in the repository. Waste packaging is not included even if the facility is colocated. The excavation and backfilling of the individual rooms are included.

Underground Workings/Rock Handling: This includes the costs of excavating and backfilling the shaft pillar zone, the main corridors, any test areas, the service shaft, and ventilation passageways. The transfer, storage, and disposal of all excess rock from all sources are also included.

Ventilation: This includes the costs of ventilation structures, mechanical systems, ventilation shafts, and flow paths.

Support and Utilities. This includes the costs of all other repository systems. Specifically, administration, maintenance, warehouse, sewage treatment, pump houses, steam generation, cooling towers, holding ponds, storage tanks, visitors' center, substation, and standby power systems are included.

3.1.5 Cost Category Definitions: Special Terms

Waste Package-Related Costs: Although not specifically shown, costs can, of course, be aggregated in a variety of other ways. For instance, total waste package-related costs can be interpreted to include all of the waste preparation system costs plus all of the waste handling and emplacement subsystem costs. These are categories which are directly affected by changes in the waste package design. Categories which are indirectly affected, e.g., ventilation, would not be included as part of the "Waste Package-Related Costs" in this interpretation of terms.

This concept of waste package-related costs is often employed in discussions of waste package economics.

3.2 Description of Waste Isolation System "Cases"

3.2.1 General Description

In this report, estimates are prepared for eight "cases" which cover four media (domed salt, bedded salt, tuff, and granite) and two waste types (spent fuel and reprocessing waste). The four "spent fuel" cases include the

costs of preparing the spent fuel for disposal, i.e., disassembly and packaging. The four reprocessing waste cases include the costs of packaging the HLW glass, the cladding hulls, and the other TRU waste but not the costs of liquid waste solidification. In all cases, unless otherwise noted, TRU wastes are packaged in thin-walled (approximately 1 cm thick) packages and the packages commingled with the high-level wastes.

For all cases, repository capacity is taken to be 72,000 MT of spent fuel or the equivalent waste produced from reprocessing 72,000 MT of spent fuel. The receipt rate is 1,800 MT/yr equivalent for the first five years and 3,000 MT/yr equivalent for the next 21 years. The reference packages are the long-lived borehole packages described in the reports by Westinghouse^(4,5). Since specific sites and repository horizons have not been selected, these estimates assume a generic site with the repository facilities about 2,000 feet underground. Similarly, these estimates do not reflect differences in the requirements for air conditioning, foundations, regional labor rates, or other site-specific factors. However, the estimates do reflect an increase in offsite improvements for bedded salt as compared with the other three media. Tuff may also require some additional offsite improvements. However, these are not included in the current estimates.

The key parameters which describe the emplacement configurations are shown in Table 7. The differences are due mainly to differences in strength and thermal properties among the host rocks considered. Because the granite designs have not been completed, the tuff configuration was used as a substitute for granite. This substitution is considered acceptable since the thermal conductivity for granite is higher than that for tuff (2.56 versus 1.85 W/m·C @ 100 C). This assumption somewhat penalizes the granite in terms of mining costs, but does allow the use of the larger packages designed by Westinghouse for estimating purposes.

The contents of the assumed repositories are shown in Table 8. Note that the packages for end fittings, cladding, and TRU account for a significant fraction of the total number of packages.

Since specific construction schedules have not been developed, the same construction schedule is used for all cases. The costs of land and land rights are projected to be incurred during the 1980s. The remaining capital

TABLE 7. EMPLACEMENT CONFIGURATIONS USED AS THE BASIS FOR THE COST ESTIMATES

	<u>Room Height (meters)</u>	<u>Room Width (meters)</u>	<u>Room Spacing (meters)</u>	<u>Borehole Pitch (meters)</u>	<u>Package Outside Dimensions Diameter X Length (meters)</u>	<u>Package Contents (MT of fuel)*</u>
Domed & Bedded Salt/Spent Fuel	7.2	4.0	27.5	10.0	.61 x 4.31	2.96
Domed & Bedded Salt/End Fittings	7.2	4.0	27.5	2.0	.48 x 4.15	N/A
Tuff/Spent Fuel	7.2	4.0	25.0	9.4	.61 x 4.31	2.96
Tuff/End Fittings	7.2	4.0	25.0	2.0	.48 x 4.15	N/A
Granite	← The values for tuff were used →					
Domed & Bedded Salt/HLW Glass	6.1	5.45	23.8	2.50	.475 x 3.38	2.28
Domed & Bedded Salt/Cladding Waste	** 6.1	5.45	23.8	2.5	.76 x 3.07	N/A
Domed & Bedded Salt/Remote Handled TRU						
Tuff/HLW Glass	6.0	5.45	25.0	5.9	.475 x 3.38	2.28
Tuff/Cladding Waste	** 6.1	5.45	25.0	2.5	.76 x 3.07	N/A
Tuff/Remote Handled TRU						
Granite	← The values for tuff were used →					

*This is the weight of the fuel in the spent fuel. For HLW glass this is the weight of the spent fuel which was reprocessed which generated the waste in the glass.

**Two rows per room.

TABLE 8. CONTENTS OF THE 72,000 MTU^(a) REPOSITORIES USED
AS A BASIS FOR THE COST ESTIMATES

	<u>Number of Packages</u>	<u>Contents of a Single Package Volume</u>
Reprocessing Waste Repositories		
HLW Glass	31,560	0.19 m ³
Cladding	66,000	1.31 m ³
Remote-Handled TRU		
Spent Fuel Repositories		
Disassembled Spent Fuel Pins	24,374	0.57 m ³
End Fittings	5,010	0.68 m ³

(a) MTU = metric tons of uranium.

construction costs are assumed distributed over a six-year period as follows: 5, 15, 20, 22, 23, 15 percent per year. Operations costs are assumed 100 percent variable on a \$/MTU basis. This is not totally accurate, but will introduce only insignificant errors compared to other uncertainties. Decommissioning is assumed distributed over a five-year period as follows: 10, 15, 25, 30, 20 percent per year.

3.2.2 Case 82-66: Domed Salt/Spent Fuel*

The basis for capital construction cost estimates is described first, followed by operations cost estimates and decommissioning estimates. The estimates are summarized in Table 9.

Capital Construction Subtotals

Waste Preparation System. The waste package component costs for all package types are assigned entirely to operations. The spent fuel waste package designs and costs are based upon Westinghouse data⁽⁴⁾. The assembly facility costs are based upon a design by Kaiser Engineers⁽¹³⁾. The Kaiser design accommodates 3,300 MTU per year which is close to the 3,000 MTU per year assumed for this study. Additional costs have been added to the estimate to account for facilities for disassembly and close packing of the spent fuel, an activity not included in the Kaiser design. After reviewing data developed by E. R. Johnson Associates in their draft assessment of impacts of spent fuel disassembly alternatives on the nuclear waste isolation system, it was estimated that the disassembly facility would increase the costs by 44 million dollars over the Kaiser estimate.

Site. The site costs are very dependent upon the exact location. Since this location is not currently known, the costs for onsite improvements are based on the NWTSR1 values and are assigned to all cases. The land and land rights estimate of 41 million dollars is assigned to salt and granite cases (the tuff site is on government-owned land). Offsite improvements of

* "Case" designations refer to the sequence in which certain calculations were carried and are of significance only to the authors.

TABLE 9. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE: Domed Salt/Spent Fuel
 COST UNITS: 1982 \$, thousands

ID #: 82-66
 DATE PREPARED: 10/1/82

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾			330980					1201221	49647	1581848
Spent Fuel										
- Waste Package Components			0					595528		
- Assembly Facility			330980					599993		
CHLW										
- Waste Package Components										
- Assembly Facility										
TRU										
- Waste Package Components										
- Assembly Facility										
Others										
- Waste Package Components								5700		
- Assembly Facility										
• REPOSITORY SYSTEM			1270301					2128700	250900	3649901
Site										
- Land & Land Rights			41000					0		
- On-Site Improvements			105656					0		
- Off-Site Improvements			20000					0		
Waste Handling & Emplacement										
- Receiving			165490					299997		
- Other Surface Facilities			0					0		
- Waste Shafts & Hoists			46175					48402		
- Transfer & Emplacement										
Rooms			52160					242426		
Boreholes			0					40500		
Transfer Equipment			16611					61208		
Underground Workings/Rock Handling										
- Service Shaft			87088					80675		
- Shaft Pillar Zone			44378					0		
- Corridors			221388					158717		
- Rock Handling & Disposal			133292					84596		
- Test Facilities			0					0		
Ventilation										
- Ventilation Structures			101793					302435		
- Ventilation Supply Shaft			24104					12908		
- Development Exhaust Shaft			4560					0		
- Ventilation Flow Paths			5802					218		
- Repository Exhaust Shaft			7861					0		
Support & Utilities			192943					796618		
• TOTAL			1601281					3329921	300547	5231749

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(1) Waste solidification costs are not included in this category.

20 million dollars are assigned to all cases except for bedded salt (125 million dollars is added in the bedded salt cases since some of the bedded sites are quite remote). Onsite improvements are over 100 million dollars.

Waste Handling and Emplacement. The packaging facility design by Kaiser is used in this exercise as a basis for packaging facility costs, including receiving costs(13). Receiving costs are obtained by allocating one-third of the total packaging facility cost estimate to receiving. The waste shaft and hoist costs are based on NWTSR1. The room dimensions as designed by Westinghouse are used with a unit mining cost to calculate the costs of rooms. Twenty percent of the room costs are capital construction and the remaining 80 percent are considered part of operations.

Underground Workings/Rock Handling. The service shaft and the shaft pillar zone costs are based on NWTSR1. The corridors (including ventilation passageways) and the rock handling and disposal costs are scaled from the NWTSR1 estimates; the scaling is proportional to the total amount of emplacement rooms.

Ventilation. The ventilation costs depend strongly on the ambient temperature at the mine horizon and the total number of rooms being ventilated at any one time. Without specific designs these costs are not known. Therefore capital construction costs for ventilation are based on NWTSR1. Operations costs for ventilation are scaled by the operating period.

Support and Utilities. These costs are based on NWTSR1.

Operations Subtotals

Waste Preparation. The waste package components are assumed to be fabricated off site and shipped to the waste preparation facility. The individual package component costs are based on the long-lived waste package conceptual designs for spent fuel pins prepared by Westinghouse. These designs are used directly for the spent fuel packages. The packages for end

fittings assume a thin-walled (approximately one centimeter thick) steel canister with no titanium overpack. The same assembly facility costs are used for all spent fuel cases. The peak annual operating costs estimated by Kaiser are used in this exercise to account for the addition of spent fuel disassembly and close packing to the packaging operation.

There are about 24,000 packages of spent fuel pins for which package materials cost about 600 million dollars. In addition there are about 5,000 packages of end fittings for which package materials cost about 6 million dollars.

Site. There are no site operations costs.

Waste Handling and Emplacement. The receiving facility's operation costs are based on the same sources as its capital construction. Borehole costs and backfilling costs are based upon estimates made by Westinghouse. Westinghouse estimates that 60 person hours are required to emplace one package.

Underground Workings/Rock Handling. The operations costs are estimated in a manner similar to capital construction plus backfilling costs. Based on Westinghouse estimates, backfilling is assumed to cost 25 percent of the mining costs.

Ventilation. Operations costs for ventilation are scaled from NWTSR1 in direct proportion to the operating period.

Support and Utilities. Operations costs are scaled from NWTSR1 in direct proportion to the operating period.

Decommissioning Totals

The costs of decommissioning are assumed to be 15 percent of the sum of all capital construction plus the costs of rooms and corridors constructed during operations.

3.2.3 Case 82-67: Bedded Salt/Spent Fuel

The bedded salt/spent fuel estimate is identical with the domed salt/spent fuel estimate, Case 82-66, except for offsite improvements. Because many of the bedded sites are quite remote, additional costs are included for roads, railroads, transmission lines, etc. The cost estimate is shown in Table 10.

Since specific sites have not been selected, differences in depth to the salt horizon, air conditioning requirements, and salt physical properties between domed salt and bedded salt are not reflected in the cost estimates.

This approach is considered quite reasonable for estimates which will be used to support the disposal fee update. However, until site-specific estimates are prepared one cannot and should not draw conclusions as to the relative costs of bedded versus domed salt deposits. For example, some preliminary work indicates that for particular sites the estimated costs of bedded salt repositories range from cheaper to more expensive than for a particular domed salt site.

3.2.4 Case 82-68: Tuff/Spent Fuel

The cost estimate for tuff/spent fuel is shown in Table 11. Although the tuff repository location is limited to a small geographic area, there is still a great deal of uncertainty concerning the design configuration. Potential repository horizons range in depth from 1,400 to 2,900 feet and include both welded and unwelded tuff. Furthermore, although the areal extent of the horizons being considered is limited it was assumed that adequate area could be found to emplace 72,000 MT of waste. In addition, several other ground rules were established which may bias the estimate to the low side:

- (1) The spent fuel package has internal compartments for the fuel pins which act as heat transfer fins and allow the designer to reduce the pitch between packages. However, no additional waste preparation costs are included for this design feature.

TABLE 10. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE: Bedded Salt/Spent Fuel

ID #: 82-67

COST UNITS: 1982 \$, thousands

DATE PREPARED: 10/1/82

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾			330980					1201221	49647	1581848
Spent Fuel										
– Waste Package Components			0					595528		
– Assembly Facility			330980					599993		
CHLW										
– Waste Package Components										
– Assembly Facility										
TRU										
– Waste Package Components										
– Assembly Facility										
Others										
– Waste Package Components								5700		
– Assembly Facility										
• REPOSITORY SYSTEM			1375401					2128700	266500	3770601
Site										
– Land & Land Rights			41000					0		
– On-Site Improvements			105656					0		
– Off-Site Improvements			125000					0		
Waste Handling & Emplacement										
– Receiving			165490					299997		
– Other Surface Facilities			0					0		
– Waste Shafts & Hoists			46175					48402		
– Transfer & Emplacement										
Rooms			52160					242426		
Boreholes			0					40500		
Transfer Equipment			16611					61208		
Underground Workings/Rock Handling										
– Service Shaft			87088					80675		
– Shaft Pillar Zone			44378					0		
– Corridors			221388					158717		
– Rock Handling & Disposal			133392					84596		
– Test Facilities			0					0		
Ventilation										
– Ventilation Structures			101793					302435		
– Ventilation Supply Shaft			24104					12908		
– Development Exhaust Shaft			4560					0		
– Ventilation Flow Paths			5802					218		
– Repository Exhaust Shaft			7861					0		
Support & Utilities			192943					796618		
• TOTAL			1706381					3329921	316147	5352449

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(1) Waste solidification costs are not included in this category

TABLE 11. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE Tuff/Spent Fuel
 COST UNITS: 1982 \$, thousands

ID #: 82-68
 DATE PREPARED: 10/1/82

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾			330980					1201221	49647	1581848
Spent Fuel										
- Waste Package Components			0					595528		
- Assembly Facility			330980					599993		
CHLW										
- Waste Package Components										
- Assembly Facility										
TRU										
- Waste Package Components										
- Assembly Facility										
Others										
- Waste Package Components								5700		
- Assembly Facility										
• REPOSITORY SYSTEM			1289988					2427316	286300	4003604
Site										
- Land & Land Rights			0					0		
- On-Site Improvements			105656					0		
- Off-Site Improvements			20000					0		
Waste Handling & Emplacement										
- Receiving			165490					299997		
- Other Surface Facilities			0					0		
- Waste Shafts & Hoists			46175					48402		
- Transfer & Emplacement										
Rooms			74541					369064		
Boreholes			0					162200		
Transfer Equipment			16611					61208		
Underground Workings/Rock Handling										
- Service Shaft			87088					80675		
- Shaft Pillar Zone			51922					0		
- Corridors			316381					249437		
- Rock Handling & Disposal			69061					44154		
- Test Facilities			0					0		
Ventilation										
- Ventilation Structures			101793					302435		
- Ventilation Supply Shaft			24104					12908		
- Development Exhaust Shaft			4560					0		
- Ventilation Flow Paths			5802					218		
- Repository Exhaust Shaft			7861					0		
Support & Utilities			192943					796618		
• TOTAL			1620968					3628537	335947	5585452

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(1) Waste solidification costs are not included in this category.

- (2) Some estimates indicate that mining costs in tuff may exceed mining costs in salt by as much as 500 percent. However, the EIS(6) and ONWI-110(14) state that the mining costs in hard rock are only about 30 percent greater than the mining costs in salt. Thus, the hard rock mining costs in this study are assumed 1.3 times the unit mining cost for salt. Note that tuff mining costs will be less than granite in terms of $\$/m^3$ since the density of tuff is less than the density of granite.
- (3) The estimates do not include potential costs for extra depth shafts, special ventilation, or extensive offsite improvements due to rough terrain.

Waste Preparation System Costs

The waste preparation system costs are identical for all four spent fuel cases. See Case 82-66, Domed Salt/Spent Fuel, for details.

Repository System Costs

The repository system estimates for Case 82-68 are similar to those for Case 82-66, except that the room and pillar dimensions are different (see Table 7), the excavation costs are increased about 30 percent, and the bore-hole drilling costs are about four times larger.

Since air temperatures and emplacement rates are similar, no differences in the ventilation requirements are reflected in the estimates. Similarly the same basic shaft sizes and configuration are assumed for this case as are assumed for the salt/spent fuel cases.

3.2.5 Case 82-69: Granite/Spent Fuel

Conceptual waste package designs for granite are not available. Therefore, to be conservative the tuff package design and emplacement configuration were used for the granite estimate. The cost estimate is shown in Table 12.

TABLE 12. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE: Granite/Spent Fuel

ID #: 82-69

COST UNITS: 1982 \$, thousands

DATE PREPARED: 10/1/82

	Capital Construction			Operations				Decom-	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	missioning	
• WASTE PREPARATION SYSTEM ⁽¹⁾			330980				1201221	49647	1581848
Spent Fuel									
– Waste Package Components			0				595528		
– Assembly Facility			330980				599993		
CHLW									
– Waste Package Components									
– Assembly Facility									
TRU									
– Waste Package Components									
– Assembly Facility									
Others									
– Waste Package Components							5700		
– Assembly Facility									
• REPOSITORY SYSTEM			1366873				2500961	308114	4175948
Site									
– Land & Land Rights			41000				0		
– On-Site Improvements			105656				0		
– Off-Site Improvements			20000				0		
Waste Handling & Emplacement									
– Receiving			165490				299997		
– Other Surface Facilities			0				0		
– Waste Shafts & Hoists			41068				48402		
– Transfer & Emplacement									
Rooms			82823				410079		
Boreholes			0				162200		
Transfer Equipment			16611				61208		
Underground Workings/Rock Handling									
– Service Shaft			78967				80675		
– Shaft Pillar Zone			57691				0		
– Corridors			351534				277161		
– Rock Handling & Disposal			76734				49060		
– Test Facilities			0				0		
Ventilation									
– Ventilation Structures			101793				302435		
– Ventilation Supply Shaft			20066				12908		
– Development Exhaust Shaft			3192				0		
– Ventilation Flow Paths			5802				218		
– Repository Exhaust Shaft			5503				0		
Support & Utilities			192943				796618		
• TOTAL			1697853				3702182	357761	5757796

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(1) Waste solidification costs are not included in this category.

Waste Preparation System Costs

The waste preparation system costs are identical for all four spent fuel cases. See Case 82-66, Domed Salt/Spent Fuel, for details.

Repository System Costs

The repository system estimates are similar to Case 82-66 except that room and pillar dimensions are different (see Table 7), excavation costs are increased about 30 percent, and the borehole drilling costs are about four times larger.

3.2.6 Case 82-70: Domed Salt/Reprocessing Wastes

The cost estimate for Domed Salt/Reprocessing Wastes is shown in Table 13.

Waste Preparation System Costs

The waste preparation costs for the CHLW in domed salt consist of two components: the waste package material costs, and the waste package assembly facility costs. The waste package material costs are based upon waste package designs and costs provided by Westinghouse⁽⁴⁾. The packages for TRU are assumed to be thin-walled (approximately 1 centimeter thick) steel without the titanium overpack. The costs of the TRU packages are scaled from the Westinghouse package design costs. The waste package facility costs are based upon the Kaiser packaging facility design⁽¹³⁾. It is assumed that the Kaiser design, although designed for spent fuel, is approximately consistent with the annual throughput of CHLW and remote-handled TRU packages. Consequently, the capital costs for the CHLW packaging facility are assumed to be the same as for the original design. Because the cost of receiving is included as part of the packaging facility cost, the packaging costs allocated to waste preparation are arbitrarily set at two-thirds of the original facility cost estimate.

TABLE 13. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE. Domed Salt/Reprocessing Waste

ID #: 82-70

COST UNITS: 1982 \$, thousands

DATE PREPARED: 10/1/82

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾			292900					1000300	43900	1337100
Spent Fuel										
– Waste Package Components										
– Assembly Facility										
CHLW										
– Waste Package Components								438800		
– Assembly Facility			292900					441000		
TRU										
– Waste Package Components								100700		
– Assembly Facility										
Others										
– Waste Package Components								19800		
– Assembly Facility										
• REPOSITORY SYSTEM			1239181					2075119	210900	3525200
Sits										
– Land & Land Rights			41000					0		
– On-Site Improvements			105656					0		
– Off-Site Improvements			20000					0		
Waste Handling & Emplacement										
– Receiving			146400					220700		
– Other Surface Facilities			0					0		
– Waste Shafts & Hoists			89195					72253		
– Transfer & Emplacement										
Rooms			34056					110691		
Boreholes			0					121900		
Transfer Equipment			69500					182500		
Underground Workings/Rock Handling										
– Service Shaft			87088					80675		
– Shaft Pillar Zone			53254					0		
– Corridors			144547					56036		
– Rock Handling & Disposal			90055					57576		
– Test Facilities			0					0		
Ventilation										
– Ventilation Structures			122000					363000		
– Ventilation Supply Shaft			24104					12908		
– Development Exhaust Shaft			4560					0		
– Ventilation Flow Paths			6962					262		
– Repository Exhaust Shaft			7861					0		
Support & Utilities			192943					796618		
• TOTAL			1532081					3075419	254800	4862300

BPMD 134 (10-82)

(1) Waste solidification costs are not included in this category.

The facility's operating costs are assumed to be two-thirds of the Kaiser design operating costs. This scaling is made since the CHLW and remote-handled TRU packages can be accommodated at approximately the original design rate of throughput with two shifts per day rather than three shifts. In addition, only two-thirds of the operating cost is allocated to the waste packaging facility. The other one-third is allocated to the operation of the receiving facility.

Repository System Costs

Site improvements and support and utilities are assumed to cost the same as for the spent fuel repository.

The receiving facility cost is assumed to be one-third of the packaging facility cost. The volume of rooms mined is based upon the dimensions given in Table 7. The volume of main corridors, branch corridors, and ventilation ducts is based upon the same ratio of corridors to rooms as in available designs (i.e., a detailed layout was not prepared). The costs for a low-level waste shaft are included in this case. Rock-handling costs are scaled from the total amount of salt mined. Ventilation structures and flow path cost estimates are 20 percent greater than the spent fuel case because the additional TRU waste requires more rooms be open at any given time and consequently requires more ventilation.

3.2.7 Case 82-71: Bedded Salt/Reprocessing Wastes

The bedded salt/reprocessing wastes estimate is identical with the domed salt/reprocessing estimate except for offsite improvements. See Case 82-67, Bedded Salt/Spent Fuel, for details. The cost estimate is shown in Table 14.

3.2.8 Case 82-72: Tuff/Reprocessing Wastes

Refer to Case 82-68, Tuff/Spent Fuel, for general limitations on the tuff estimates. The cost estimate is shown in Table 15.

TABLE 14. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE: Bedded Salt/Reprocessing Waste
 COST UNITS: 1982 \$, thousands

ID #: 82-71
 DATE PREPARED: 10/1/82

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾			292900					1000300	43900	1337100
Spent Fuel										
- Waste Package Components										
- Assembly Facility										
CHLW										
- Waste Package Components								438800		
- Assembly Facility			292900					441000		
TRU										
- Waste Package Components								100700		
- Assembly Facility										
Others										
- Waste Package Components								19800		
- Assembly Facility										
• REPOSITORY SYSTEM			1344127					2075119	226600	3645846
Site										
- Land & Land Rights			41000					0		
- On-Site Improvements			105656					0		
- Off-Site Improvements			125000					0		
Waste Handling & Emplacement										
- Receiving			146400					220700		
- Other Surface Facilities			0					0		
- Waste Shafts & Hoists			89195					72253		
- Transfer & Emplacement										
Rooms			34056					110691		
Boreholes			0					121900		
Transfer Equipment			69500					182500		
Underground Workings/Rock Handling										
- Service Shaft			87088					80675		
- Shaft Pillar Zone			53254					0		
- Corridors			144547					56036		
- Rock Handling & Disposal			90055					57576		
- Test Facilities			0					0		
Ventilation										
- Ventilation Structures			122000					363000		
- Ventilation Supply Shaft			24104					12908		
- Development Exhaust Shaft			4560					0		
- Ventilation Flow Paths			6962					262		
- Repository Exhaust Shaft			7861					0		
Support & Utilities			192943					796618		
• TOTAL			637027					3075419	270500	4982946

BPMD-134 (10-82)

(1) Waste solidification costs are not included in this category.

TABLE 15. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE: Tuff/Reprocessing Waste
 COST UNITS: 1982 \$, thousands

ID #: 82-72
 DATE PREPARED: 10/1/82

	Capital Construction			Operations				Decom- missioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal	
• WASTE PREPARATION SYSTEM(1)			292900					1000300	43900
Spent Fuel									
- Waste Package Components									
- Assembly Facility									
CHLW									
- Waste Package Components								438800	
- Assembly Facility			292900					441000	
TRU									
- Waste Package Components								100700	
- Assembly Facility									
Others									
- Waste Package Components								19800	
- Assembly Facility									
• REPOSITORY SYSTEM			1370358					2412813	226746
Site									
- Land & Land Rights			0					0	
- On-Site Improvements			105656					0	
- Off-Site Improvements			20000						
Waste Handling & Emplacement									
- Receiving			146400					220700	
- Other Surface Facilities			0					0	
- Waste Shafts & Hoists			89195					72253	
- Transfer & Emplacement									
Rooms			75590					109522	
Boreholes			0					487300	
Transfer Equipment			69500					182500	
Underground Workings/Rock Handling									
- Service Shaft			87088					80675	
- Shaft Pillar Zone			62300					0	
- Corridors			320834					31759	
- Rock Handling & Disposal			35365					55316	
- Test Facilities			0					0	
Ventilation									
- Ventilation Structures			122000					363000	
- Ventilation Supply Shaft			24104					12908	
- Development Exhaust Shaft			4560					0	
- Ventilation Flow Paths			6962					262	
- Repository Exhaust Shaft			7861					0	
Support & Utilities			192943					796618	
• TOTAL			1663258					3413113	270646
									5347017

BPMD-134 (10-82)

(1) Waste solidification costs are not included in this category

Waste Preparation System Costs

Waste preparation costs for all reprocessing cases in tuff are identical to the costs of waste preparation in salt.

Repository System Costs

The repository cost estimates are similar to Case 82-70, Domed Salt/Reprocessing Wastes, except that room and pillar dimensions are different (see Table 7), excavation costs are greater by about 30 percent, and borehole drilling costs are about four times larger.

3.2.9 Case 82-73: Granite/Reprocessing Wastes

Refer to Case 82-69, Granite/Spent Fuel, for general limitations on the granite estimates. The cost estimate is shown in Table 16.

Waste Preparation System Costs

Waste preparation costs for all reprocessing cases in granite are identical to the costs of waste preparation in salt.

Repository System Costs

The repository cost estimates are similar to Case 82-70, Domed Salt/Reprocessing Waste, except that room and pillar dimensions are different (see Table 7), excavation costs are greater by about 30 percent, and borehole drilling costs are about four times larger.

TABLE 16. WASTE PREPARATION/REPOSITORY COST MATRIX

TITLE Granite/Reprocessing Waste
 COST UNITS 1982 \$, thousands

ID # 82-73
 DATE PREPARED 10/1/82

	Capital Construction			Operations					Decommissioning	Total
	Facility Construction	Capital Equipment Purchase & Installation	Subtotal	Labor	Materials	Equipment Replacement	Utilities	Subtotal		
• WASTE PREPARATION SYSTEM ⁽¹⁾			292900					1000300	43900	1337100
Spent Fuel										
- Waste Package Components										
- Assembly Facility										
CHLW										
- Waste Package Components								438800		
- Assembly Facility			292900					441000		
TRU										
- Waste Package Components								100700		
- Assembly Facility										
Others										
- Waste Package Components								19800		
- Assembly Facility										
• REPOSITORY SYSTEM			1440971					2434647	239691	4115309
Site										
- Land & Land Rights			41000					0		
- On-Site Improvements			105656					0		
- Off-Site Improvements			20000					0		
Waste Handling & Emplacement										
- Receiving			146400					220700		
- Other Surface Facilities			0					0		
- Waste Shafts & Hoists			79786					72253		
- Transfer & Emplacement										
Rooms			83989					121686		
Boreholes			0					487300		
Transfer Equipment			69500					182500		
Underground Workings/Rock Handling										
- Service Shaft			78967					80675		
- Shaft Pillar Zone			69229					0		
- Corridors			356483					35283		
- Rock Handling & Disposal			39295					61462		
- Test Facilities			0					0		
Ventilation										
- Ventilation Structures			122000					363000		
- Ventilation Supply Shaft			20066					12908		
- Development Exhaust Shaft			3192					0		
- Ventilation Flow Paths			6962					262		
- Repository Exhaust Shaft			5503					0		
Support & Utilities			192943					796618		
• TOTAL			1733871					3434947	283591	5452409

BPMD 134 (10-82)

(1) Waste solidification costs are not included in this category

4.0 COMPARISON OF CURRENT COST ESTIMATES WITH PREVIOUS ESTIMATES

4.1 Exploration and Development Estimate Comparison

Two previous estimates of the total R&D expenditures have been published^(15,16). In the 1978 report R&D was estimated to total, in 1978 dollars, 560 million dollars. In the 1980 report the total estimated R&D cost between 1980 and 2003 is shown, in 1980 dollars, to be 4.1 billion dollars. The current estimate, in 1982 dollars, is 4.1 billion dollars.

In the 1978 report the R&D costs stopped in 1986 and salt was considered as the only disposal medium. Soon after that report was issued, the siting program was expanded to include investigations in other media such as granite, basalt, tuff, and shale. R&D was initiated on the development of a long-lived waste package, and predictive modeling was recognized as a key licensing requirement. The thrust for most of these changes was the Inter-agency Review Group (IRG)⁽¹⁷⁾ and Confidence Rulemaking⁽¹⁸⁾ documents of 1979 and 1980. The 1980 estimate incorporated most of the changes identified above. The closeness of the 1982 and 1980 estimates is perhaps misleading because major shifts in emphasis have occurred. The finalization of the procedural rule by the U.S. Nuclear Regulatory Commission (NRC)⁽⁹⁾ specified that exploratory shafts be constructed at sites prior to their selection as a repository site. Previously the exploratory shaft was planned after site selection. Increased estimates of impact mitigation costs are included in the 1982 estimate. Both these changes would tend to make the 1982 estimate higher. On the other hand, the new strategy described in Section 3.1 streamlines the R&D process, carrying fewer concepts and media into the later design phases.

4.2 Repository and Waste Preparation Estimate Comparison

Tables 17 and 18 highlight the comparison between the estimates given in this report and estimates prepared for previous reports by DOE on the estimated fee for disposal services. As one would expect, because the estimate is given in current year dollars the estimated costs have increased.

TABLE 17. COMPARISON OF KEY PARAMETERS

1978: DOE/ET-0055(15)

- Encapsulation separate but colocated with repository
- Salt/spent fuel the only case
- Receipt rate of 1,800 MT/yr for 5 yrs then 6,000 MT/yr
- Repository capacity of 45,000 MT
- Simple carbon steel borehole waste packages
- Intact assemblies in the waste package

1980: DOE/SR-0006(16)

- Encapsulation separate but colocated with the repository
- Generic cost average that represents bedded salt, domed salt, basalt, and granite for spent fuel
- Receipt rate of 6,000 MT/yr
- Repository capacity of 68,000 MT
- Simple carbon steel borehole waste packages with adsorbent package backfill

1982: This report

- Waste preparation integrated into repository facility for spent fuel and for reprocessing waste
 - Cases for bedded salt, domed salt, tuff, and granite for both spent fuel and reprocessing waste
 - Receipt rate of 1,800 MT/yr for 5 years then 3,000 MT/yr
 - Repository capacity of 72,000 MT
 - Large long-lived borehole waste package
 - Disassembled spent fuel and borosilicate glass
 - Thin-walled TRU packages
 - TRU commingled with high-level waste
-

TABLE 18. COMPARISON OF ESTIMATED COSTS FOR SPENT FUEL REPOSITORIES
(millions of dollars, various years dollars)

	<u>Capital con- struction Costs</u>	<u>Operations Costs</u>	<u>Decommissioning Costs</u>	<u>Total Costs (capacity varies)</u>	<u>Total/kg* (\$/kg)</u>	
<u>1978: DOE/ET-0055</u>						
Encapsulation	350	21/yr fixed costs plus 0.0087/MT variable cost	--	990	22	
Repository	500	50/yr fixed costs plus 0.011/MT variable costs	200 (includes encap- sulation)	1300	<u>29</u> 51	
<u>1980: DOE/SR-0006</u>						
Encapsulation	460	29/yr fixed costs plus 0.014/MT variable costs	40	1900	28	44
Repository	980	18/yr fixed costs plus 0.02/MT variable costs	150	2800	<u>41</u> 69	
<u>1982: This report</u>						
Waste Preparation	330	0.017/MT	50	1600	23	
Repository	1270-1370	0.031-0.036/MT	250-310	3700-4200**	<u>52-58</u> 75-81	

*This is the total cost of the design throughput divided by the total kg of heavy metal disposed. This is not discounted and does not represent a fee of any sort.

**This range covers the reference cases.

In addition, the costs have increased because of the incorporation of long-lived packages. However, some of the increases have been offset by using larger packages and thus fewer packages and by incorporating the waste preparation facilities into the repository facilities. Moreover, the size of a single repository has increased, which decreases the cost per unit of waste. The receipt rate has decreased, which also leads to lower costs.

5.0 REFERENCES

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APPENDIX A: SENSITIVITY CASES

Summary

Estimates were prepared for over fifty additional cost cases to indicate how the reference costs may change under certain conditions. The estimates fall into two general categories. The first category highlights the sensitivity of the reference case costs to uncertainties in some of the cost data. The second category indicates the sensitivity of the reference case costs to potential variations in the repository/waste package designs. The cost estimates are summarized in Tables A-1 and A-2.

Cost Data Uncertainty

The first group of additional cases described are cases which indicate how the total repository costs for the reference cases change when uncertainties are assigned to the two major sets of cost data, mining costs and waste preparation costs.

High and Low Mining Costs. Cases 82-74 to 82-81 show the effect of high (+50 percent) and low (-25 percent) mining costs for salt. Mining costs cover shaft costs (excluding hoists and headframes), rooms, corridors, and the shaft pillar zone. Variations in cost could result from changes in design and operating procedures as well as changes in unit costs. This variation is based on current judgment as to the level of uncertainty applicable to this kind of preconceptual estimate.

Cases 82-100 to 82-107 show the effect of high and low mining costs for tuff and granite. Note that the uncertainty in hard rock mining costs is greater than the uncertainty for salt mining. Granite mining costs are varied from -25 percent to +100 percent. The tuff mining costs are varied from -25 percent to +200 percent. Several inquiries were made concerning tuff mining costs. The estimates received varied widely. However much of this variation was due to the use of definitions of mining costs different from those used in this study.

TABLE A-1. SUMMARY OF SENSITIVITY CASES FOR SALT

ID No.	TITLE	TOTAL	CAPITAL CONSTRUCTION			OPERATIONS			DECOMMISSIONING		
			Waste Preparation	Repository	Subtotal	Waste Preparation	Repository	Subtotal	Waste Preparation	Repository	Subtotal
82-74	Domed Salt, Spent Fuel, High Mining Costs	5683	331	1462	1793	1201	2330	3531	49	310	359
82-75	Domed Salt, Spent Fuel, Low Mining Costs	5006	331	1174	1505	1201	2029	3230	49	222	271
82-76	Domed Salt, Reprocessing Waste, High Mining Costs	5150	293	1406	1699	1000	2158	3158	44	249	293
82-77	Domed Salt, Reprocessing Waste, Low Mining Costs	4717	293	1155	1448	1000	2033	3033	44	192	236
82-78	Bedded Salt, Spent Fuel, High Mining Costs	5804	331	1567	1898	1201	2330	3531	49	326	375
82-80	Bedded Salt, Spent Fuel, Low Mining Costs	5127	331	1279	1610	1201	2029	3230	49	238	287
82-89	Bedded Salt, Reprocessing Waste, High Mining Costs	5271	293	1511	1804	1000	2158	3158	44	265	309
82-81	Bedded Salt, Reprocessing Waste, Low Mining Costs	4838	293	1260	1553	1000	2033	3033	44	208	252
82-82	Domed Salt, Spent Fuel, High Waste Preparation Costs	5816	463	1270	1733	1621	2129	3750	70	263	333
82-83	Domed Salt, Spent Fuel, Low Waste Preparation Costs	4672	199	1270	1469	781	2129	2910	30	263	293
82-84	Domed Salt, Reprocessing Waste, High Waste Prep. Costs	5330	410	1239	1649	1333	2075	3408	62	211	273
82-85	Domed Salt, Reprocessing Waste, Low Waste Prep. Costs	4395	176	1239	1415	668	2075	2743	26	211	237
86-86	Bedded Salt, Spent Fuel, High Waste Preparation Costs	5936	463	1375	1838	1621	2129	3750	70	278	348
82-87	Bedded Salt, Spent Fuel, Low Waste Preparation Costs	4792	199	1375	1574	781	2129	2910	30	278	308
82-88	Bedded Salt, Reprocessing Waste, High Waste Prep. Costs	5451	410	1344	1754	1333	2075	3408	62	227	289
82-89	Bedded Salt, Reprocessing Waste, Low Waste Prep. Costs	4516	176	1344	1520	668	2075	2743	26	227	253
82-90	Domed Salt, Spent Fuel, Separate TRU Rooms	5325	331	1270	1601	1201	2210	3411	50	263	313
82-91	Domed Salt, Reprocessing Waste, Separate TRU Rooms	5032	293	1239	1532	1000	2223	3223	44	233	277
82-92	Bedded Salt, Spent Fuel, Separate TRU Rooms	5446	331	1375	1706	1201	2210	3411	50	279	329
82-93	Bedded Salt, Reprocessing Waste, Separate TRU Rooms	5153	293	1344	1637	1000	2223	3223	44	249	293
82-94	Domed Salt, Reprocessing Waste, Optimum Package	4456	261	1246	1507	708	1985	2693	39	217	256
82-95	Bedded Salt, Reprocessing Waste, Optimum Package	4577	261	1351	1612	708	1985	2693	39	233	272
82-96	Domed Salt, Spent Fuel, Simple Package	4660	298	1254	1552	716	2099	2815	45	248	293
82-97	Domed Salt, Reprocessing Waste, Simple Package	4294	234	1210	1444	577	2031	2608	35	207	242
82-98	Bedded Salt, Spent Fuel, Simple Package	4781	298	1359	1657	716	2099	2815	45	264	309
82-99	Bedded Salt, Reprocessing Waste, Simple Package	4414	234	1315	1549	577	2031	2608	35	222	257

NOTE: The reference and optimum spent fuel package designs are the same. Costs of fabricating the glass logs are not included. Costs are in millions of '82 dollars.

TABLE A-2. SUMMARY OF SENSITIVITY CASES FOR TUFF AND GRANITE

ID No.	TITLE	TOTAL	CAPITAL CONSTRUCTION			OPERATIONS			DECOMMISSIONING		
			Waste Preparation	Repository	Subtotal	Waste Preparation	Repository	Subtotal	Waste Preparation	Repository	Subtotal
82-100	Tuff, Reprocessing Waste, High Mining Costs	7003	293	2527	2820	1000	2696	3696	44	443	487
82-101	Tuff, Reprocessing Waste, Low Mining Costs	5140	293	1225	1518	1000	2378	3378	44	200	244
82-102	Granite, Reprocessing Waste, High Mining Costs	6328	293	2045	2338	1000	2592	3592	44	354	398
82-103	Granite, Reprocessing Waste, Low Mining Costs	5234	293	1290	1583	1000	2396	3396	44	211	255
82-104	Tuff, Spent Fuel, High Mining Costs	8260	331	2379	2710	1201	3664	4865	50	635	685
82-105	Tuff, Spent Fuel, Low Mining Costs	5250	331	1154	1485	1201	2272	3473	50	242	292
82-106	Granite, Spent Fuel, High Mining Costs	7299	331	1941	2272	1201	3267	4468	50	509	559
82-107	Granite, Spent Fuel, Low Mining Costs	5373	331	1224	1555	1201	2309	3510	50	258	308
82-108	Tuff, Reprocessing Waste, High Waste Preparation Costs	5815	410	1370	1780	1333	2413	3746	62	227	289
82-109	Tuff, Reprocessing Waste, Low Waste Preparation Costs	4880	176	1370	1546	668	2413	3081	26	227	253
82-110	Granite, Reprocessing Waste, High Waste Preparation Costs	5921	410	1441	1851	1333	2435	3768	62	240	302
82-111	Granite, Reprocessing Waste, Low Waste Preparation Costs	4986	176	1441	1617	668	2435	3103	26	240	266
82-112	Tuff, Spent Fuel, High Waste Preparation Costs	6157	463	1290	1753	1621	2427	4048	70	286	356
82-113	Tuff, Spent Fuel, Low Waste Preparation Costs	5013	199	1290	1489	781	2427	3208	30	286	316
82-114	Granite, Spent Fuel, High Waste Preparation Costs	6330	463	1367	1830	1621	2501	4122	70	308	378
82-115	Granite, Spent Fuel, Low Waste Preparation Costs	5186	199	1367	1566	781	2501	3282	30	308	338
82-116	Tuff, Reprocessing Waste, Simple Package	4778	234	1341	1575	577	2369	2946	35	222	257
82-117	Tuff, Spent Fuel, Simple Package	5013	298	1273	1571	716	2397	3113	45	284	329
82-118	Granite, Reprocessing Waste, Simple Package	4884	234	1412	1646	577	2391	2968	35	235	270
82-119	Granite, Spent Fuel, Simple Package	5186	298	1350	1648	716	2471	3187	45	306	351
82-120	Tuff, Reprocessing Waste, Separate TRU Rooms	5855	293	1370	1663	1000	2855	3855	44	293	337
82-121	Tuff, Spent Fuel, Separate TRU Rooms	5667	331	1290	1621	1201	2498	3699	50	297	347
82-122	Granite, Reprocessing Waste, Separate TRU Rooms	5845	293	1441	1734	1000	2776	3776	44	291	335
82-123	Granite, Spent Fuel, Separate TRU Rooms	5849	331	1367	1698	1201	2580	3781	50	320	370

Note: Costs are in millions of '82 dollars.

High and Low Waste Preparation Costs. Cases 82-82 to 82-89 and Cases 82-108 to 82-115 show the effect of waste preparation/receiving cost uncertainties. The costs varied ± 40 percent for capital construction, ± 20 percent for package components, and ± 50 percent for other operations.

These uncertainties consist of a price and a design element. The values for the price uncertainties are based upon the way in which time series surrogates for the real costs of facility construction, facility operation, and package component costs vary around some mean values. That is, the time series of a construction cost index (the Nelson Refinery Construction Cost Index), an operation cost index (the Nelson Refinery Operation Cost Index), and certain metal products cost indexes (steel products and titanium mill shapes) were deflated to constant dollars and then analyzed for variation around their respective means.

The design uncertainties are more subjective. Waste package designs are considered more stable than packaging facility designs so waste packages are assigned a lower design uncertainty than the packaging facility. However, the uncertainties assigned to both the waste package and package facility designs ultimately are judgmental.

Design Variations

The second group of additional cases described are cases which indicate how the reference case costs change when certain design parameters are changed. This second group contains cases showing how the reference case costs change when TRU wastes are not commingled, when optimum CHLW packages are used in salt, and when "simple" waste packages not containing a titanium overpack are used for HLW.

Separate Rooms for TRU. Cases 82-90 to 82-93 and Cases 82-120 to 82-123 show the effect of placing TRU in separate repository drifts. The use of separate drifts for TRU waste results in two changes from the reference cases. First, room mining costs increase because additional volume must be mined for either the HLW or TRU packages, whichever had been included with the other waste type in the commingled reference case. As a result, the total

mining costs increase. Second, the corridor costs are assumed to be proportional to the rooms in the repository. Thus, as the volume of rooms in the noncommingled cases is greater than in the commingled cases, the volume of corridors is also greater, and consequently more costly.

Optimum Packages for Reprocessing Wastes. Cases 82-94 and 82-95 show the effect of using the 9.5 kW, as opposed to the 2.2 kW, packages for CHLW glass. TRU packaging is the same in this case as in the corresponding reference cases.

Use of the large-sized CHLW package affects the waste package material cost, the package assembly facility costs, the receiving facility costs, the room mining costs, the borehole mining costs, and the corridor mining costs. Waste package material costs are less because, even though the cost per package increases, the total number of waste packages required to dispose of 72,000 MTU falls significantly. The waste package assembly facility costs decrease because package throughput is decreased when the optimum-sized package is used; decreased throughput implies smaller capital and operating costs for the packaging and receiving facilities. Room mining costs increase over the reference case cost because, even though there are fewer packages, they are emplaced at a greater pitch resulting in a greater volume of material mined. Total hole costs, however, decrease even though the cost per hole increases. Corridor costs decrease in proportion to room costs.

It should be noted that there is only one package design, the reference design, for spent fuel.

Simple Packages. Cases 82-96 to 82-99 and 82-116 to 82-119 show the impact of using "thin" steel waste packages for HLW instead of using "thick" steel waste packages clad with TiCode-12 as in the reference package design.

The simple packages result in a reduction in package materials costs, packaging facility costs, and hole costs. Package materials and packaging facility costs decrease because the titanium overpack is eliminated and less steel is used per package. Hole costs decrease because simple waste packages have a smaller diameter than the titanium-clad packages. All other costs remain the same.

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