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DECOMMISSIONING OF COMMERCIAL

SHALLOW-LAND BURIAL SITES

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INTRODUCTION

This paper describes the results of a study to conceptually decommission commercial low-level waste (LLW) burial grounds.¹ The study was sponsored by the U.S. Nuclear Regulatory Commission to provide information on the available technology, the safety considerations, and the probable costs of decommissioning LLW burial grounds after waste emplacement operations are terminated. This information is intended for use as background data in the development of regulations pertaining to decommissioning activities. It is also intended for use by regulatory agencies and site operators in developing improved waste burial and site maintenance procedures at operating burial grounds.

CHARACTERISTICS OF THE REFERENCE BURIAL GROUNDS

Two generic burial grounds, one located on an arid western site and the other located on a humid eastern site, are used as reference facilities for the study. The characteristics of these postulated facilities are based on real characteristics of the six commercial burial grounds that have operated in the United States. The reference burial grounds are assumed to have the same site capacity for waste, the same radioactive waste inventory, and

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similar trench characteristics and operating procedures. The climate, geology, and hydrology of the two sites are chosen to be typical of real western and eastern sites.

Each site has an area of 70 hectares ($7 \times 10^5 \text{ m}^2$), of which about 50 hectares contain burial trenches. The total site capacity for waste is about $1.5 \times 10^6 \text{ m}^3$ contained in 180 burial trenches. The trenches are 150 m long, 15 m wide at the top sloping to 10 m wide at the bottom, and 7.5 m deep. A space of at least 3 m separates adjacent trenches at the ground surface. Each trench is filled with waste to within 1 m of the ground surface; the top 1 m of trench is reserved for fill soil.

The reference waste inventory in the burial trenches is comprised of 40% (by volume) non-fuel-cycle waste and 60% reactor fuel-cycle waste. An average byproduct specific activity of 9.0 Ci/m^3 is assumed for the waste at the time of burial.

At some commercial sites, high activity beta-gamma waste is buried separately from other waste. To evaluate cost and safety requirements for exhumation of this waste, the reference burial ground is assumed to include 10 slit trenches. Slit trench dimensions are 150 m long by 1.2 m wide by 6 m deep; each trench can accommodate ninety 0.76-m-diameter by 3.6-m-long waste canisters. Typical activities at the time of waste burial range from 1,000 to 5,000 Ci/m^3 .

The western site is semi-arid. Summers are marked by very low precipitation and high temperatures, resulting in soil moisture deficiencies. Occasional periods of high winds are accompanied by blowing sand. Additional characteristics include 1) low annual precipitation, with evaporation greatly exceeding precipitation, 2) great depth to ground water, 3) soil with moderate permeability, 4) relatively great distance to the point of groundwater discharge into surface streams, and 5) no farming in the immediate vicinity of the site.

The eastern site has a continental climate with a wide range of temperature throughout the year. Summers are characterized by intense heat and high humidity, and winters by extreme cold with occasional heavy snowfall and moderate-to-high winds. Additional characteristics include 1) high annual precipitation, 2) shallow depth to ground water, 3) soil with low permeability, 4) relatively short distance to the point of ground water discharge into surface streams, and 5) farming and recreation in the vicinity of the site.

DECOMMISSIONING ALTERNATIVES

Decommissioning may be defined as the measures taken at the end of a facility's operating life to ensure that future risk to public safety is within acceptable bounds. Decommissioning an LLW burial ground normally involves engineered procedures (site/waste stabilization procedures) to ensure the adequate confinement of radioactive wastes left buried at the time of site closure. Burial ground stabilization is followed by a period of long-term care designed to maintain and verify the confinement capability of the site. Long-term care continues until the wastes no longer pose a significant radiological hazard, or until additional actions are taken to reduce the potential consequences of unrestricted site usage.

Relocation of part or all of the waste from the burial trenches may be necessary in some situations. This decommissioning mode is therefore also considered in the study.

Site/Waste Stabilization

Potential site/waste stabilization activities include:

- engineered routing/flow control of ground and surface water
- modification of trench caps to minimize water infiltration into trenches
- stabilization of the land surface and erosion control
- grouting or injection of chemicals into the waste matrix to reduce the mobility of the waste
- control of plants or animals that might disrupt surface stabilization or transport radioactivity from the trenches
- erection of physical barriers to control human activities at the site.

To select an appropriate stabilization plan, radionuclide transport mechanisms capable of initiating a release of radioactivity (i.e., "release agents") are identified, and suitable stabilization techniques for dealing with these release agents are catalogued and evaluated. Plans are then formulated based on the techniques selected. Release agents of importance for a particular

site are identified by critical pathway analysis techniques. For the reference western site of this study, the release agents of concern are human activities (excavation and agriculture) and wind erosion. For the reference eastern site, the release agents of concern are human activities (excavation and agriculture), hydrological releases (percolation and overflow), and water erosion.

In the Reference 1 study, three stabilization plans are described and evaluated for each reference site. The stabilization plans include a minimal plan, a relatively modest one, and a more complex one; they correspond to varying levels of effort that may be required to properly stabilize a site. Brief descriptions of each plan are given in Table 1.

At each reference site, the minimal plan assumes that necessary site stabilization activities have been performed as part of burial ground operating procedures. Therefore, extensive decommissioning measures are not required when burial operations cease. The minimal plan includes site inspections and the performance of any repairs needed to ready a site for long-term care.

The main feature of the modest plan at each site is an increase in the soil thickness over the buried waste (increased capping thickness). In addition, at the eastern site, a system

Table 1. Descriptions of Stabilization Plans for the Reference Sites

Plan	Western Site	Eastern Site
Minimal	Site inspection, Preparation for long-term care.	Site inspection, Preparation for long-term care.
Modest	Increased capping thickness, Revegetation, Vegetation management.	Increased capping thickness, Modification of capping soil, Improved capping drainage, Revegetation, Vegetation management.
Complex	Subsurface rock layer with hard top, Increased capping thickness, Revegetation, Vegetation management.	Peripheral drainage and diversion, Sump pumping with treatment, Subsurface hard layer, Increased capping thickness, Revegetation, Vegetation management.

of drainage ditches is installed to allow precipitation to be directed away from the trenches. Both sites are revegetated with shallow-rooted plants to control vegetation and reduce surface erosion.

The complex plan for each site includes installation of a subsurface layer in addition to an increase in capping thickness. The subsurface layer reduces moisture percolation and plant-root infiltration into the wastes, acts as a deterrent to animal or human penetration, and provides a secondary control against erosion. At the eastern site, a series of drainage/diversion ditches is constructed around the site perimeter to intercept runoff that might encroach on the site. The sites are then revegetated.

Long-Term Care

After site decommissioning is completed and the operating license is terminated, access to a site may need to be controlled for a time until the radioactivity in the buried waste has decayed to levels that permit unrestricted site release. Long-term care procedures are employed during this time to maintain and verify the continued capability of the site to adequately contain the buried radioactivity.

Long-term care includes administrative control, environmental surveillance, and site maintenance. Administrative control includes control of public access/activities at the site, coordination of site surveillance and maintenance programs, and record keeping. Environmental surveillance includes the collection and analysis of environmental samples and the analysis and preservation of environmental data. Site maintenance includes inspection and repair of fences and equipment, erosion control, trench cap repair, water infiltration control, and vegetation management.

Waste Relocation

Waste relocation involves the exhumation of buried waste, repackaging of the waste if necessary, and reburial of the waste at another disposal site or in another trench on the same site. Exhumation of waste originally buried without any intent of later retrieval is an expensive and time-consuming operation, with a potential for significant radiation exposure to decommissioning workers. Therefore, waste relocation would likely be considered only if other decommissioning procedures are inadequate to ensure that future risk from the buried waste is within acceptable bounds.

Relocation of the waste from part or all of a particular trench or trenches may be more likely than waste exhumation from an entire burial ground. Partial waste relocation may be necessary if individual trenches are known to contain very high levels of radioactivity, high concentrations of transuranic or other long-lived wastes, or waste in a form that makes it particularly susceptible to migration (i.e., waste mixed with organic complexing agents). Partial waste relocation cases evaluated in the study include 1) relocation of high beta-gamma activity waste from a slit trench, 2) relocation of a transuranic (TRU) waste package buried in a regular burial trench, and 3) relocation of all the waste from one burial trench. In addition, an estimate is made of the manpower, time, and cost of relocating all the waste from the reference burial ground.

Slit trench excavation and waste retrieval require personnel protection from high radiation dose rates. Most operations are performed remotely. Several equipment options are available for remote excavation of the trench. Canister retrieval is accomplished with a boom crane. Sheet piling is used along the sides of the trench as a safety measure and to limit the width of the trench.

To reduce the possibility of airborne release of TRU contamination, all excavation and waste retrieval operations related to TRU waste exhumation take place inside a metal enclosure equipped for control and filtration of the air leaving the building. If a second level of protection from airborne releases is required, the metal enclosure can be located inside a plastic air-support weather shield.² All personnel operating within the confines of the metal enclosure wear plastic bubble suits for protection from airborne contamination.

After selective exhumation of the high beta-gamma and TRU wastes, removal of the waste remaining in a regular trench can be accomplished by relatively simple earthmoving techniques. Wastes are exhumed by bulk excavation of the trench, using conventional equipment. Because of the difficulty and added cost of sorting soil, it is assumed that all of the soil in the bottom 6.5 m of a trench is exhumed and repackaged with the waste. Two exhumation alternatives are evaluated. One utilizes a backhoe operating from above the trench, permitting most of the operating crew to be relatively remote from the exposed waste. The second involves use of a front-end loader operating from the floor of the trench, with laborers assisting in grappling and excavation of large containers and loose waste. The second alternative requires less time but results in a higher worker exposure to radiation than the first alternative.

DECOMMISSIONING COSTS

Costs for the decommissioning alternatives described previously are calculated assuming efficient performance of the work. Direct costs are estimated, including labor, material, equipment, surveillance, and, where applicable, packaging, transportation, and disposal of wastes. A 25% contingency is added to account for work delays and equipment cost escalations. All costs are in 1978 dollars.

Costs of Site/Waste Stabilization

Estimated costs of site/waste stabilization are summarized in Table 2. Total site stabilization costs for the western site are \$0.4 million for the minimal plan, \$2.5 million for the modest plan, and \$7.7 million for the complex plan, while total costs for the eastern site are \$0.5 million, \$3.8 million, and \$5.3 million for the minimal, modest, and complex plans, respectively. For both the modest and complex plans, site stabilization is performed by a contractor hired by the site operator. Therefore, a contractor's fee is included in the total cost.

Manpower costs include both support staff and decommissioning worker costs. The support staff includes those persons involved in planning and supervising decommissioning operations, in preparing documentation, and in carrying out the accounting, quality control, health physics, and site security functions related to decommissioning.

Table 2. Estimated Costs of Site Stabilization

Cost Category	Cost (\$ millions) ^{a,b}					
	Arid Western Site			Humid Eastern Site		
	Minimal Plan	Modest Plan	Complex Plan	Minimal Plan	Modest Plan	Complex Plan
Manpower	0.395	1.033	1.586	0.424	1.391	1.467
Equipment and Material	0.034	1.262	5.473	0.035	2.107	3.430
Contractor's Fee ^c	--	0.184	0.565	--	0.280	0.391
Miscellaneous Owner Expensed	0.002	0.009	0.010	0.002	0.010	0.010
Environmental Monitoring	0.011	0.027	0.031	0.011	0.034	0.034
Records Maintenance	0.001	0.001	0.001	0.001	0.001	0.001
Total (rounded)	0.4	2.5	7.7	0.5	3.8	5.3

^aNumber of figures shown is for computational accuracy only and does not imply precision to the nearest thousand dollars.

^bCosts include 25% contingency.

^cBased on 8% of the sum of manpower, equipment, and material costs.

^dIncludes utilities, insurance, and taxes.

The complex plan for the western site is calculated to be more costly than that for the eastern site. Both plans include an increase in capping thickness over the trenches. For the western site, the additional soil must be brought from offsite by truck. For the eastern site, a large portion of the required backfill is provided by digging the peripheral drainage/diversion ditches. This also results in somewhat reduced labor and equipment costs for the eastern site.

Costs of Long-Term Care

Long-term care costs for the reference sites are summarized in Table 3. To provide a basis for calculations, long-term care is assumed to continue for 200 years following stabilization of a site.

Annual costs are assumed to be highest during the first few years because of greater site maintenance and environmental surveillance requirements. After an initial site "maturation" period of about 5 years, annual maintenance costs are assumed to decrease significantly. Environmental surveillance is maintained at a significant level for 25 years to evaluate the effectiveness of site stabilization procedures. Environmental surveillance is then reduced to about one-fourth of the original level by reducing the number of sample locations and/or the sampling frequencies. Long-term care requirements and costs following stabilization of

Table 3. Summary of Estimated Long-Term Care Costs

Stabilization Plan That Precedes Long- Term Care	Annual Costs (in millions of 1978 dollars) for Time Period: ^{a,b}			Total Cost for 200 Years (in millions of 1978 dollars) ^a
	0-5 Years After Stabilization	6-25 Years After Stabilization	26-200 Years After Stabilization	
Minimal and Modest Plans for the Arid Western Site	0.181	0.125	0.081	17.6
Complex Plan for the Arid Western Site	0.250	0.120	0.075	16.8
Minimal and Modest Plans for the Humid Eastern Site	0.254	0.196	0.134	28.6
Complex Plan for the Humid Eastern Site	0.382	0.201	0.139	30.2

^aThese costs include contingency costs of 25%.

^bNumber of figures shown is for computational accuracy only.

a site by the minimal or modest plans are postulated to be identical. Maintenance requirements and costs following stabilization by the complex plans are somewhat greater because of the need to maintain and repair subsurface layers and diversion and drainage systems.

Total long-term care costs at the eastern site are almost twice as high as they are at the western site, partly because of higher environmental surveillance costs at the eastern site. However, the cost differential is mainly due to the additional costs of maintenance of stabilization features needed to reduce water infiltration into the trenches at the eastern site.

Costs of Waste Relocation

Costs of partial waste relocation at the western site are summarized in Table 4. Costs are shown separately for exhumation (including core drilling and sampling, sheet piling installation and removal, trench excavation, waste exhumation, and site restoration) and for waste management (including packaging, shipping and disposal). Offsite waste repositories are assumed to be located 2,400 km from the LLW burial ground, with all waste shipments made by truck.

Table 4. Estimated Costs of Partial Waste Relocation at the Western Site

	Cost (\$ millions) ^a				
	Slit	TRU Waste Package		Entire Burial Trench	
	Trench	Single	Double	Excavate	Excavate
	<u>Exhumation</u>	<u>Enclosure</u>	<u>Enclosure</u>	<u>from Above</u>	<u>from Within</u>
Deep Geologic Disposal					
Exhumation	0.411	0.361	0.801	0.590	0.471
Waste Management	<u>2.336</u>	<u>0.024</u>	<u>0.024</u>	<u>43.240</u>	<u>43.240</u>
Total (rounded)	2.8	0.38	0.82	43.8	43.7
Shallow-Land Burial					
Exhumation	0.411			0.590	0.471
Waste Management	<u>1.121</u>			<u>7.190</u>	<u>7.190</u>
Total (rounded)	1.5			7.8	7.7

^aNumber of figures shown is for computational accuracy only.

Some of waste exhumation activities are postulated to require a 20% longer time for completion at the eastern site than at the western site because of the greater potential for adverse weather at the eastern site. Therefore, the costs of waste exhumation are higher at the eastern site than at the western site. However, total waste relocation costs are not significantly changed for the eastern site because waste management costs are the same at both sites.

Waste management controls the cost of relocation of slit trench waste and the waste from an entire burial trench. Based on deep geologic disposal costs in Reference 3, unit costs of \$2,100/m³ for burial of low-level waste (waste that does not require shielding for transport or handling), and \$7,100/m³ for intermediate-level waste (waste that arrives in a shielded container) are assumed for the study. A basic cost of \$168/m³ (\$4.75/ft³) is assumed for disposal at a shallow-land burial ground. Enclosure costs control the cost of TRU waste removal.

Costs of total waste relocation from the reference burial grounds are summarized in Table 5. It is assumed that 10 slit trenches and 10 TRU waste packages must be exhumed in addition to the complete exhumation of the 180 burial trenches. Waste relocation at the reference sites is estimated to require about 20 years (plus 1.5 years for planning and preparation) and to cost about \$1.4 billion. About 94% of this cost is related to waste management (packaging, shipment, and disposal of exhumed waste).

PUBLIC AND OCCUPATIONAL SAFETY

Radiological and nonradiological impacts from normal decommissioning operations and potential accidents are identified and evaluated for the site stabilization and waste relocation options described previously. The safety evaluation includes estimates of radiation dose to the public from normal decommissioning operations and postulated accidents, radiation dose to workers from normal decommissioning operations, and deaths and injuries to decommissioning workers from industrial-type accidents.

The radiation dose to the public is evaluated by determining the 50-year committed dose equivalent to the populace within 80 km of the site from airborne releases. The same population distribution is assumed for both reference sites. This allows a direct comparison of safety effects that are related to the physical characteristics of the two sites. For decommissioning workers,

Table 5. Summary of Costs for Total Relocation of the Waste from the Reference Burial Grounds

Cost Category	Cost (\$ millions) ^a	
	Western Site	Eastern Site
Manpower	46.0	54.2
Equipment and Material	30.5	36.0
Contractor's Fee ^b	6.1	7.2
Work Enclosures	0.5	0.5
Environmental Surveillance	1.1	1.4
Records Maintenance	0.1	0.1
Miscellaneous Owner Expenses	0.4	0.4
Subtotals	84.7	99.8
Waste Management	1 318	1 318
Totals	1 403	1 418

^aNumber of figures is for computational accuracy only.

^bBased on 8% of the sum of labor, material, and equipment costs.

the dose from direct exposure is determined. Workers are presumed to wear respiratory protection devices as needed to provide protection from inhalation of airborne radionuclides.

Safety Evaluation of Site/Waste Stabilization

Table 6 shows radiation dose to decommissioning workers from normal site stabilization activities, based on an assumed external exposure rate of 1 mrem/day. Ingestion and inhalation are not considered important contributors to occupational dose for site stabilization.

Accident data from a U.S. Atomic Energy Commission study⁴ provides a basis for estimating lost-time injuries and fatalities from industrial-type accidents to decommissioning workers. It is estimated that only about one lost-time injury might be expected to occur during site stabilization. The number of fatalities from industrial-type accidents during site stabilization is estimated to be about 1×10^{-3} .

Table 6. Radiation Dose to Decommissioning Workers from Normal Site Stabilization Operations

Stabilization Plan	Radiation Dose (man-rem)	
	Western Site	Eastern Site
Minimal	0.2	0.2
Modest	1.2	2.0
Complex	2.5	2.2

Stabilization of a burial ground involves modification of and addition to surface soils, but no intentional uncovering or exhumation of buried wastes. There is no transportation of radioactive waste. Therefore, routine site/waste stabilization operations are not expected to contribute any significant radiation exposure to the general population.

Most accidents during stabilization are not expected to contribute a significant radiation dose to any member of the public. Trench void-space collapse resulting from the passage of heavy equipment over a trench is calculated to result in a first-year dose of 0.61 mrem and a 50-year committed dose equivalent of 5.2 mrem to the bone of the maximum-exposed individual.

Safety Evaluation of Waste Relocation

Because partial waste relocation is much more probable than relocation of the waste from an entire burial ground, and because complete waste relocation is estimated to take more than 20 years, it is unlikely that one person would be subjected to the radiological effects of an entire burial ground exhumation. Therefore, public and occupational radiological safety effects are described on the basis of partial waste relocation activities. The results are shown in Table 7. The table shows the 50-year committed dose equivalent to the populace within 80 km of the site from airborne releases and the total dose to decommissioning workers from direct exposure. Occupational doses for exhumation of a complete trench are calculated on the basis of excavation from within the trench to maximize the dose numbers. The dose numbers shown in Table 7 indicate that waste exhumation can be very costly in terms of worker exposure.

Table 7. Radiological Safety Evaluation of Normal Waste Relocation Operations

Source of Safety Concern	Radiation Dose (man-rem) ^a		
	Slit Trench Exhumation	TRU Waste Package Exhumation	Exhumation of Entire Burial Trench
Public Safety ^b			
Decommissioning Operations	6×10^{-5}	1×10^{-1}	1×10^2
Transportation	2×10^{-1}	2×10^{-3}	3×10^0
Occupational Safety			
Decommissioning Operations	5.2×10^1	1.1×10^2	2.4×10^2
Transportation	1.8×10^1	2.0×10^{-1}	9.9×10^1

^aRadiation doses from postulated accidents are not included.

^bThe 50-year committed dose equivalent to the population residing within 80 km of the site is reported for routine operations. The organ of reference is the bone. Transportation doses are from external exposure to the population along the transport route.

Table 8 summarizes the results of an analysis of postulated decommissioning accidents during waste relocation operations. A wide spectrum of accidents is considered, with appropriate assumptions leading to calculated airborne releases of radioactivity and resulting radiation doses to the maximum-exposed individual. Results are shown for the seven accidents that result in the highest dose to an organ of the maximum-exposed individual. Table 8 shows that for each of the decommissioning accidents studied, the 50-year committed dose equivalent to the maximum-exposed individual is very small compared to the 50-year dose from natural background radiation.

Table 9 shows estimated occupational lost-time injuries and fatalities from industrial-type accidents and from decommissioning transportation accidents for waste relocation. Except for transportation accidents associated with waste relocation from an entire trench, the number of nonradiological injuries and deaths is estimated to be low.

Table 8. Summary of Radiation Doses to the Maximum-Exposed Individual from Decommissioning Accidents^a

Accident	Airborne Release (Ci)	Estimated Frequency of Occurrence ^b	50-Year Committed Dose Equivalent (mrem)	
			Total Body	Bone
Severe Transportation Accident (TRU)	3.0×10^3	Low	4.2×10^0	9.6×10^1
Exhumation of Undetected TRU Waste	1.6×10^3	High	2.2×10^0	5.1×10^1
Waste Package Handling (TRU)	5.3×10^2	Low	7.5×10^{-1}	1.7×10^1
Undetected TRU Core Drilling	1.6×10^2	High	2.3×10^{-1}	5.2×10^0
Failure of HEPA Filters (TRU)	6.6×10^1	Low	9.4×10^{-2}	2.1×10^0
Spontaneous Combustion of Wastes	1.7×10^1	Medium	1.2×10^{-2}	1.9×10^{-1}
Minor Transportation Accident (TRU)	3.0×10^0	Medium	4.3×10^{-3}	9.6×10^{-2}

^aInhalation doses only.

^bFrequency of occurrence: High $>1.0 \times 10^{-2}$; Medium 1.0×10^{-2} to 1.0×10^{-5} ; Low $<1.0 \times 10^{-5}$ events per year.

Table 9. Estimated Occupational Injuries and Fatalities from Nonradiological Sources for Partial Waste Relocation

Waste Relocation Operation	Waste Exhumation		Transportation	
	Number of Injuries	Number of Fatalities	Number of Injuries	Number of Fatalities
Slit Trench Exhumation	5.2×10^{-2}	1.0×10^{-3}	2.4×10^{-1}	1.4×10^{-2}
TRU Package Exhumation	1.3×10^{-2}	6.7×10^{-5}	2.7×10^{-3}	1.6×10^{-4}
Exhumation of Entire Trench	1.6×10^{-1}	7.3×10^{-4}	2.6×10^0	1.5×10^{-1}

SUMMARY AND CONCLUSIONS

Estimated costs and safety considerations for decommissioning LLW burial grounds have been evaluated. Calculations are based on a generic burial ground assumed to be located at a western and an eastern site. Decommissioning modes include 1) site stabilization followed by long-term care of the site, and 2) waste relocation.

Site stabilization is estimated to cost from \$0.4 million to \$7.5 million, depending on the site and the stabilization option chosen. Long-term care is estimated to cost about \$100,000 annually, with somewhat higher costs during early years because of increased site maintenance and environmental monitoring requirements. Long-term care is required until the site is released for unrestricted public use. Occupational and public safety impacts of site stabilization and long-term care are estimated to be small.

Relocation of all the waste from a reference burial ground is estimated to cost more than \$1.4 billion and to require more than 20 years for completion. Over 90% of the cost is associated with packaging, transportation, and offsite disposal of the exhumed waste. Waste relocation results in significant radiation exposure to decommissioning workers.

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