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Technology, Safety and Costs of Decommissioning a Reference Low-Level Waste Burial Ground

Main Report

Prepared by E.S. Murphy, G.M. Holter

Battelle-Pacific Northwest Laboratory

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Main Report

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FOREWORD
BY
NUCLEAR REGULATORY COMMISSION STAFF

The NRC staff is in the process of reappraising its regulatory position relative to the decommissioning of nuclear facilities.(1) As a part of this activity NRC has initiated two series of studies through technical assistance contracts. These contracts are being undertaken to develop information to support the preparation of new standards covering decommissioning.

The basic series of studies will cover the technology, safety and costs of decommissioning reference nuclear facilities. Light water reactors, fuel cycle facilities and non-fuel cycle nuclear facilities are included. Facilities of current design on typical sites are selected for the studies. Separate reports will be prepared as the studies of the various facilities are completed.

The first report in this series was published in FY 1977 and covered a fuel reprocessing plant.(2) The second report was published in FY 1978 and covered a pressurized water reactor.(3) The third report was published in FY 1979 and covered a small mixed oxide fuel fabrication plant.(4) The following report is the fourth of the series and covers a low-level waste burial ground. Additional topics will be reported on the tentative schedule as follows:

FY 1980
- Boiling Water Reactor
- Uranium Fabrication Plant

FY 1981
- Non-Fuel Cycle Nuclear Facilities
- Multiple Reactor Facilities

A second series of studies covers supporting information on decommissioning of nuclear facilities. Three reports are included in this series. The first, published in FY 1978, consists of an annotated bibliography on the decommissioning of nuclear facilities.(5) The second, published in FY 1979, is a review and analysis of current regulations.(6) The third report in the series covers the facilitation of decommissioning of light water reactors.(7)

Subsequent to the initiation of the program described above, the NRC staff initiated a rulemaking program concerning the issuances of licenses for the disposal of low-level waste. An Advance Notice of Rulemaking (8) was issued in the Federal Register on October 25, 1978. The present schedule for development of the regulation is based on issuing the proposed regulation early in 1981 and the final regulation in 1982. The low-level waste disposal rule as currently planned will contain provisions regarding decommissioning of these facilities. The NRC staff is in the process of preparing, with the aid of an outside technical contractor, an Environmental Impact Statement to support NRC decisionmaking in the rulemaking. The contractor and the Environmental Impact Statement will address, in this independent effort, the technology, safety and costs of decommissioning low-level waste disposal facilities.

The information provided in this report, including any comments, will be included in the report for consideration by the Commission in establishing criteria and new standards for decommissioning of low-level waste disposal facilities. Persons wishing to comment on this report should mail their comments to:

Chief
Fuel Process Systems Standards
Division of Engineering Standards
Office of Standards Development
Washington DC 20555

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(1) Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities. NUREG-0436, Revision 1, Office of Standards Development, U.S. Nuclear Regulatory Commission, December 1978.

(2) Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant. NUREG-0278, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, October 1977.

(3) Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station. NUREG/CR-0130, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, June 1978.

(4) Technology, Safety and Costs of Decommissioning a Reference Small Mixed Oxide Fuel Fabrication Plant. NUREG/CR-0129, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, February 1979.

(5) Decommissioning of Nuclear Facilities - An Annotated Bibliography. NUREG/CR-0131, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, September 1978.

(6) Decommissioning Commercial Nuclear Facilities: A Review and Analysis of Current Regulations. NUREG/CR-0671, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, August 1979.

(7) Facilitation of Decommissioning of Light Water Reactors, NUREG/CR-0569, Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, December 1979.

(8) Disposal of Low-Level Radioactive Waste, Advance Notice of Proposed Rulemaking, Federal Register, 43:43911, October 25, 1978.

ABSTRACT

Safety and cost information are developed for the conceptual decommissioning of commercial low-level waste (LLW) 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 two burial grounds are assumed to have the same site capacity for waste, the same radioactive waste inventory, and 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 reference burial ground occupies about 70 hectares and includes 180 trenches filled with a total of 1.5 x 10^6 m^3 of radioactive waste. The waste consists of 60% (by volume) nuclear fuel-cycle waste with an average activity of about 15 Ci/m^3 and 40% non-fuel-cycle waste with an average activity of about 0.1 Ci/m^3. In addition, there are 10 slit trenches containing about 1.5 x 10^3 m^3 of high beta-gamma activity waste.

A methodology is developed for the analysis of release conditions for a decommissioned LLW burial ground. The methodology is based on the concept of an allowable annual dose to a maximum-exposed individual. For a burial ground where a subsurface radioactive inventory remains, release of the site on a conditional use basis may be necessary. Conditional use requirements include site and/or waste stabilization procedures, property use restrictions, and administrative control of the site by a government agency for an extended period of time.

The basic decommissioning options considered in the study are site/waste stabilization followed by long-term care of the site, and waste relocation.

Site/waste stabilization involves the use of engineered procedures to reduce the rate and extent of radionuclide release from buried wastes left in place after site closure. Three stabilization plans are evaluated for each reference site. The plans correspond to varying levels of effort that may be required to properly stabilize a site. The minimal plan assumes that stabilization has been an integral part of normal site procedures during burial

ground operation and, therefore, only minor effort is required to prepare the site for long-term care. The modest and complex plans correspond to increasingly greater needs for site/waste stabilization before the site is turned over to a government agency for long-term care.

For the plans evaluated in this study, site stabilization is estimated to require from 10 to 36 weeks to complete, with calculated expenditures of from 7.7 to 39.8 man-years of effort and total decommissioning costs of from $0.5 million to $7.7 million in 1978 dollars. Manpower and cost estimates include support staff and decommissioning worker labor requirements and costs for both the planning and preparation and the actual site stabilization phases of decommissioning.

The total accumulated occupational radiation dose for normal site stabilization activities is estimated to be between 0.1 and 2 man-rem, depending on the location of the burial ground and on the stabilization plan chosen. Because site stabilization does not involve direct contact with buried waste, the public safety impact of normal stabilization activities is estimated to be negligible.

If the buried waste is left in place in a decommissioned burial ground, long-term care is required to maintain and verify the continued capability of the site to confine the radioactivity to the immediate vicinity of the burial trenches. Long-term care activities include inspection and maintenance, environmental monitoring, and site administration. For the reference burial grounds of this study, estimated long-term care costs vary from about $70,000/year to $360,000/year, depending on site characteristics, on the kind of stabilization activities that precede long-term care, and on the elapsed time since site closure. The annual occupational radiation dose for normal long-term care activities is estimated to be less than 0.3 man-rem.

Waste relocation involves the exhumation of buried waste, repackaging of the waste if necessary, and reburial of the waste at another burial site, at a federal repository, or in another trench on the same site. Because waste relocation is very costly both in terms of dollars and of radiation exposure to decommissioning workers, it would likely only be considered in situations where other decommissioning procedures are not adequate to assure that future risk from the facility is within acceptable bounds.

Three waste relocation cases are considered in the study. These are:

- relocation of the waste from a slit trench
- relocation of transuranic-contaminated (TRU) waste from a section of burial trench
- relocation of all the waste from a single burial trench.

Relocation of the waste from a slit trench is estimated to require from 19 to 56 weeks and to cost from $1.4 million to $3.2 million, depending on site location and on the exhumation and waste disposal options chosen. The cost of waste management (repackaging, shipment, and disposal of exhumed waste) is the major cost item for relocation of the waste from a slit trench. The accumulated occupational radiation dose is estimated to be about 35 man-rem.

Relocation of a package of TRU waste buried in an ordinary trench is estimated to require from 13 to 22 weeks and to cost from $440,000 to $910,000, depending on site location and on the work enclosure and exhumation option chosen. The major cost item for this activity is the cost of the work enclosure. The accumulated occupational radiation dose is estimated to be about 120 man-rem.

Relocation of all the waste in a single burial trench is estimated to require from 25 to 34 weeks and to cost from $0.7 million to $44 million, depending on the site location and on the exhumation and waste disposal options chosen. The cost of waste management is the major cost item for this activity. The total accumulated occupational exposure is estimated to be about 260 man-rem.

An estimate is made of the cost of relocating the waste from an entire burial ground. For the generic burial grounds of the study, waste relocation is estimated to require approximately 21 years at the western site and 25 years at the eastern site and to cost about $1.4 billion.

The safety impact of normal waste relocation operations on the general public is found to be small compared to the impact on decommissioning workers. The principal impact on the public is the radiation dose resulting from transportation of the exhumed waste to a new disposal site.

An analysis is made of the radiological consequences of postulated decommissioning accidents during site stabilization and 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. Calculations indicate that the 50-year committed dose equivalent to the maximum-exposed individual resulting from postulated decommissioning accidents is very small compared to the 50-year dose due to natural background radiation.

Three options to providing funds for decommissioning and long-term care of LLW burial grounds are identified and evaluated. The options include payment of costs before site operations begin, payment during the operating lifetime of the burial ground by contributions to a sinking fund, and payment when decommissioning costs are incurred. The sinking fund approach is currently used by all of the states that license and regulate burial sites, to provide funds for long-term care.

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1.0 INTRODUCTION

This report presents the results of a study sponsored by the U.S. Nuclear Regulatory Commission to conceptually decommission commercial low-level waste (LLW) burial grounds. The primary purpose of this study is to provide information on the available technology, the safety considerations, and the probable costs of decommissioning LLW burial grounds after burial 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 during the operating lifetime of an LLW burial ground.

Decommissioning is defined as the measures taken at the end of a facility's operating life to ensure that future risk to public safety from the facility is within acceptable bounds. For an LLW burial ground, the basic decommissioning modes considered are site/waste stabilization and waste relocation. Long-term care activities that follow site closure are also considered.

Site and/or waste stabilization involves the use of engineered procedures to reduce the rate and extent of radionuclide release from buried wastes left in place in a decommissioned LLW burial ground. A number of different approaches, or plans, can be employed to stabilize a burial ground. To select an appropriate plan, radionuclide transport mechanisms capable of initiating a release of radioactivity from a particular site (i.e., "release mechanisms") are identified, and suitable stabilization techniques for dealing with these release mechanisms are cataloged and evaluated. Plans are then formulated based on the techniques selected.

Potential site/waste stabilization activities include:

- engineered routing/flow control of ground and surface water
- modification of trench caps to minimize water infiltration into the trenches
- stabilization of the land surface and erosion control

- grouting and/or use of chemical additives to reduce the mobility of the waste
- control of plants and animals that might disrupt surface stabilization measures or transport radioactivity from the trenches
- erection of physical barriers to control human activities at the site.

Shallow-land burial of radioactive waste is intended to provide for permanent disposal under conditions that ensure that future risk from the waste is kept within acceptable limits. Waste relocation involves exhumation of the buried waste, repackaging it if necessary, and reburial at another waste disposal site or in another trench on the same site. These operations are expensive and time-consuming, with a potential for significant radiation exposure to decommissioning workers. Therefore, waste relocation would likely be considered only in situations where site/waste stabilization and long-term care procedures are not sufficient to ensure the continued capability of the site to provide adequate containment of the buried waste.

In this study, partial waste relocation from an LLW burial ground is investigated for the following cases:

- relocation of high beta-gamma activity waste from a slit trench
- relocation of transuranic-contaminated (TRU) waste from a section of a burial trench
- relocation of all the waste from a single burial trench.

In addition, an estimate of the cost of relocating the waste from an entire burial ground is made by extrapolation of the estimates of manpower, time, and waste disposal requirements made for the three cases listed above.

Long-term care is required to maintain and verify the continued waste containment capability of a site after burial operations cease. Long-term care may be initiated immediately upon site closure, or it may be preceded by the site/waste stabilization activities described above. Long-term care activities include:

- site surveillance and inspection
- maintenance and repair of trench caps and engineered surface features

- environmental monitoring, data evaluation, and records maintenance
- administrative procedures for control of the site.

Long-term care continues until it is determined that the radioactivity at the site has decayed to the point where the wastes no longer pose a significant radiological hazard, or until additional actions are taken to reach this point.

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 this study. The characteristics of these postulated facilities are based on actual 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 similar trench characteristics and operating procedures. The climate, geology, and hydrology of the two sites are chosen to be typical of actual western and eastern sites. Each site description provides a basis for evaluating decommissioning methods and costs, and for estimating possible environmental impacts.

A methodology is developed for the analysis of release conditions for a decommissioned LLW burial ground. For a burial site where a subsurface radioactive inventory remains, release conditions may include site and/or waste stabilization requirements, land use restrictions, and requirements for institutional control. The analysis methodology is based on a comparison of calculated maximum annual doses to a maximum-exposed individual to an assumed annual dose limit. If, for a particular site use scenario, the calculated maximum annual dose does not exceed the assumed annual dose limit, the scenario may be used to define conditions for conditional or unrestricted release of the site.

Work plans are developed for both site/waste stabilization and waste relocation. For both of these decommissioning modes, alternative sets of activities are described and evaluated. The principles guiding the choice of work plans include:

- assurance of the safety of the public and of decommissioning workers in a cost-effective manner
- utilization of demonstrated methods for activities associated with decommissioning the sites.

From these work plans, estimates are made of manpower requirements, work schedules, material and equipment needs, waste management requirements (for waste relocation activities), costs, and radiation exposure to decommissioning workers and to the public. Estimates are also made of manpower, material requirements, and costs for long-term care, and of environmental surveillance requirements during decommissioning operations and long-term care activities.

The choices of plans and techniques made in this study are believed to be realistic and representative of the operations that would be required to decommission an LLW burial ground and provide an appropriate level of safety at a reasonable cost. The decommissioning procedures, safety impacts, and costs developed in this study are sensitive to the radionuclide inventory in the buried waste and to the physical characteristics and postulated operating histories of the reference burial grounds. Significant improvements in burial ground operating procedures have occurred since commercial operations started in the early 1960s. Operating procedures will likely continue to improve, and criteria for the acceptability of wastes for burial will change. The assumptions made with regard to the reference facilities of this study should be examined carefully before attempting to apply the study results to a burial ground with different characteristics.

The study results are presented in two volumes. Volume 1 (Main Report) contains background information and study results in summary form. A glossary is presented at the end of Volume 1. Volume 2 (Appendices) contains the detailed analyses and data needed to support the results given in Volume 1. The supporting data are presented in a manner that facilitates their use for examining decommissioning actions other than those included in this study.

2.0 SUMMARY

The results of this study to conceptually decommission commercial low-level waste (LLW) burial grounds are summarized in this section. The purpose of this study is 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.

2.1 DECOMMISSIONING ALTERNATIVES

Decommissioning is defined as the measures taken at the end of a facility's operating life to ensure that future risk to public safety from the facility is within acceptable bounds. For an LLW burial ground, the basic decommissioning modes considered are site/waste stabilization and waste relocation. Long-term care activities that follow site closure are also considered.

Site and/or waste stabilization involves the use of engineered procedures to reduce the rate and extent of radionuclide migration from buried wastes left in place in a decommissioned LLW burial ground. A number of different approaches, or plans, can be employed to stabilize a burial ground. To select an appropriate plan, radionuclide transport mechanisms capable of initiating a release of radioactivity from a particular site (i.e., "release mechanisms") are identified, and suitable stabilization techniques for dealing with these release mechanisms are cataloged and evaluated. Plans are then formulated based on the techniques selected. The dominant radionuclide release mechanisms postulated for the reference burial grounds and the site/waste stabilization plans chosen for evaluation in the study are summarized in Section 2.8.1.

Long-term care includes activities required to maintain and verify the continued capability of a site to adequately contain the radioactivity in the buried waste. The activities are, in general, a continuation of maintenance and surveillance activities and procedures established during the site operating and stabilization periods. Long-term care may be initiated immediately upon site closure, or may be preceded by preventive or remedial site/waste stabilization activities or by partial waste relocation. Long-term care activities continue until measurements and calculations indicate that the radioactivity in the burial trenches has decayed to levels permitting unrestricted release of the site or until additional actions are taken to reduce the potential consequences of unrestricted site usage.

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 that has a potential for significant radiation exposure to decommissioning workers. Therefore, waste relocation would likely be considered only in situations where other decommissioning procedures are inadequate to ensure that future risk from the facility is within acceptable bounds.

Some of the key bases for this study are:

1. The study is to evaluate, to the extent possible, real and contemporary facilities. For comparative purposes, two sites are evaluated: an arid western site and a humid eastern site. While specific burial facilities are not evaluated, the parameters chosen for the two reference sites are representative of parameters at existing western and eastern sites.
2. Decommissioning modes analyzed include several techniques for site/waste stabilization and for waste relocation.
3. The methods used to accomplish decommissioning utilize presently available technology. Where developmental techniques are applied, they are in an advanced state of development and are believed to be ready for application.
4. Decommissioning methods and procedures are selected on the basis of providing adequate public and occupational safety in a cost-effective manner.

5. Decommissioning options are evaluated assuming efficient performance of the work. A 25% contingency is added to cost totals to account for such things as work delays and unanticipated equipment costs.

6. Site decommissioning is the responsibility of the burial ground operator. Following site decommissioning, institutional control of the site is maintained for a period of time until the site is released for unrestricted use. The period of time for which it is possible to maintain institutional control cannot be specified with certainty because of the many factors involved. For purposes of calculating allowable limits of radioactivity and of estimating long-term care costs, it is assumed that institutional control is maintained for about 200 years after final closure of a site.

2.2 REVIEW OF BURIAL GROUND EXPERIENCE

Six commercial LLW burial grounds and five major Department of Energy burial grounds have operated in the United States. No LLW burial ground has been decommissioned to date. However, site/waste stabilization activities have been implemented at several sites to reduce contact of the buried waste by water and to minimize the migration of radioactivity away from the site. In addition, experimental programs have been conducted at the Idaho National Engineering Laboratory and at the Savannah River Laboratory to establish procedures and to identify costs of exhumation of buried wastes. These activities and programs contain elements that are directly applicable to the requirements for decommissioning LLW burial grounds.

2.3 STATUS OF REGULATORY GUIDANCE FOR DECOMMISSIONING

Federal regulations require commercial LLW disposal sites to be on land owned by either the federal or a state government. At five of the six commercial sites, the states own the land and lease it to the burial ground operators. At the Richland site, the federal government leases the land to the state of Washington and the state then leases it to the burial ground operator.

Five of the six commercial sites are located in agreement states and are licensed by the respective states. The exception is the Nuclear Engineering Company site near Sheffield, Illinois, which is licensed by the NRC because Illinois is not an agreement state. At Barnwell, South Carolina, and Richland, Washington, the NRC regulates the handling of special nuclear material, since large quantities are authorized to be handled at these facilities. The states regulate the handling of byproduct and source material at these sites.

When burial operations at a commercial site are completed and the license is terminated, the state government assumes responsibility for long-term care of the site. All of the states require the site operator to contribute to a fund to cover the cost of long-term care. The fund is based on a charge per unit volume of waste buried, and varies from site to site. In general, it is believed that long-term care funds provide sufficient money for routine maintenance and surveillance of a retired site, but are not adequate for extensive corrective actions should the need arise.

Many parallels exist between the technical and institutional considerations for decommissioning and long-term care of LLW burial grounds and uranium mill tailings piles. At both types of facilities, major areas of concern include minimizing the migration of radionuclides from the waste, stabilizing the ground surface, environmental monitoring, and the control of human activities at a decommissioned site. Legislation and information pertaining to post-operational activities at tailings piles are contained in the Uranium Mill Tailings Control Act of 1978(1) and the Generic Environmental Impact Statement (GEIS) on Uranium Milling,(2) respectively. These documents may also be considered for guidance in establishing regulations for the decommissioning and long-term care of LLW burial grounds.

Performance objectives for burial ground site closure and stabilization have been developed in a recent Branch Position(3) by the NRC. The Branch Position is intended to provide guidance for a site operator in developing site closure and stabilization plans to prepare a site for transfer to a custodial government agency. Major provisions of the Branch Position deal with 1) measures to stabilize the site to place it in a condition such that the need for active ongoing maintenance is eliminated and only passive surveillance and monitoring are required during the long-term care period that follows license termination, and 2) assurance of the availability of funds to complete the site closure and stabilization plan.

The NRC is presently considering developing a more explicit policy for nuclear facility decommissioning, as well as amending its regulations in 10 CFR Parts 30, 40, 50, and 70 to include more-specific guidance on decommissioning criteria for production and utilization facility licensees and byproduct, source, and SNM licensees.(4) One type of nuclear facility for which specific decommissioning criteria are being considered is an LLW burial ground. An Advance Notice of Proposed Rulemaking, setting forth the NRC's plans for development of regulations for low-level waste burial grounds, including decommissioning requirements, and providing notice of a preliminary draft regulation, 10 CFR Part 61, has been published in the Federal Register.(5)

2.4 APPROACHES TO FINANCING DECOMMISSIONING

In each state where a commercial LLW burial ground has operated, a long-term care fund (i.e., a sinking fund) has been established. The money is paid to the state by the site operator and is based on per-unit-volume burial charges. Payments at some sites have been increased periodically to account for cost escalations. The purpose of these existing funds is to ensure the availability of monies for administrative control of a site, and for routine maintenance and surveillance when the operating license is terminated and care of the site becomes the responsibility of a government agency.

The importance of financial assurance for decommissioning was recognized by the Congress of the United States in the Uranium Mill Tailings Control Act of 1978.(1) A new section, 161x, was added to the Atomic Energy Act of 1954, providing explicit authority for the NRC to require that an adequate bond, surety or other financial arrangement be made by mill licensees to ensure cleanup and reclamation prior to termination of the license. If determined necessary, financial arrangements for long-term maintenance and monitoring may also be made a requirement of license termination. The act stipulates that the need for long-term maintenance and monitoring of tailings sites should be minimized and, to the maximum extent practical, eliminated. Since the requirements for decommissioning LLW burial grounds and mill tailings piles are similar in many respects, this act may provide some guidance in resolving the problem of providing adequate funds to decommission LLW burial grounds.

In this study, three general approaches to financing decommissioning and long-term care are identified:

1. creation of a decommissioning and long-term care fund during the operating lifetime of a burial ground by periodic payments into a reserve fund (i.e., creation of a sinking fund)
2. payment of anticipated decommissioning and long-term care costs into an account prior to the start of burial ground operations
3. payment of decommissioning and long-term care costs when incurred (i.e., after site closure).

Various combinations of these alternatives are also possible.

The prepayment option provides the greatest assurance that the site operator will be financially responsible for decommissioning and long-term care. However, this option may be disadvantageous to the site operator because it deprives him of funds that might be used for capital investment. The pay-when-incurred option provides the least degree of assurance of operator fiscal responsibility. However, a performance bond might be used to ensure operator responsibility if this option were chosen.

If the sinking fund option is chosen, several alternatives are available to reduce the risk of unavailability of funds in the event of premature burial ground closure. These include one or more of the following:

1. an initial cash payment to the sinking fund prior to the start of burial ground operations
2. higher per-unit sinking fund charges (in real, i.e., constant dollars) during early years of operation
3. a performance bond posted by the facility operator
4. a decommissioning assurance insurance pool.

The first two options can be considered as combinations of the sinking fund and prepayment options. Performance bonds may be difficult to obtain and are only as good as the surety company. However, the performance bond approach is used by several states to ensure the reclamation of strip-mined land, and by the states of Wyoming and Utah to ensure the reclamation of uranium mining and milling sites when operations are terminated. The fourth option, while feasible, requires additional study and might have to be implemented by the federal government.

2.5 CHARACTERIZATION OF REFERENCE LLW BURIAL FACILITIES

Generic LLW burial facilities are used as the 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 approach taken is to treat the burial ground and the surrounding environment as two separate systems. The burial ground, with its inventory of buried radioactive waste, is described generically. This generic burial ground is then assumed to be located on two real reference sites, an arid western site and a humid eastern site, for which representative parameters are chosen.

2.5.1 Burial Ground Description

The generic burial ground is assumed to be located on an upland area of generally flat or gently rolling terrain. The total site area is 70 hectares (7×10^5 m^2), of which about 50 hectares contain burial trenches. The remaining land area is used for buildings, access roads, and a 50-m-wide exclusion area around the site perimeter between the trench area and the site fence.

The total site capacity for waste is about 1.5×10^6 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. 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. When a trench is completely filled, it is covered with a trench cap of soil mounded to 1 m above grade. The effective waste volume per trench is about 8,300 m^3. It is assumed that six trenches are filled during each of 30 years of operation of the burial ground.

At some commercial sites, high activity beta-gamma waste is buried separately from other radioactive waste in specially designed dry wells, pits, or slit trenches. To evaluate requirements for exhumation of this waste, should exhumation be required as part of decommissioning operations, the reference burial ground is assumed to include 10 slit trenches for burial of highly activated non-fuel-bearing wastes from LWR core internals. These wastes are packaged in canisters and transported in massive lead-and-steel casks. Special handling and burial procedures are required. A typical slit trench is 150 m long, 1.2 m wide, and 6 m deep, and contains 150 m^3 of waste packaged in 90 canisters.

2.5.2 Reference Waste Inventory

The reference waste inventory in the burial trenches is assumed to be comprised of 40% (by volume) non-fuel-cycle waste and 60% reactor fuel-cycle waste. Volumes and specific activities for the different categories of waste assumed to be present in a reference burial trench are given in Table 2.5-1.

TABLE 2.5-1. Characterization of Waste in Reference Trench

Contaminated Material	Waste (m^3)	Volume (%)	Specific Activity (Ci/m^3)
Fuel-Cycle Waste			
Solidified Liquids(a)	3 320	40.0	2.0
Demineralizer Resin(a)	370	4.5	160.0
Filter/Demineralizer Sludge(a)	580	7.0	10.0
Cartridge Filters	40	0.5	20.0
Trash	670	8.0	0.1
Subtotal	4 980	60.0	
Non-Fuel-Cycle Waste			
Trash	3 320	40.0	0.1
Total	8 300	100.0	

(a) Solidified in concrete, urea formaldehyde, or some other solidification agent.

The non-fuel-cycle waste includes paper trash, packing material, protective clothing, broken glassware, plastic sheeting and tubing, expended scintillation cocktail (usually in the form of solidified or absorbed liquids), animal carcasses, obsolete equipment, and building rubble. The waste comes mainly from hospitals, medical schools, and universities and colleges, and is estimated to have an average specific activity of less than 0.1 Ci/m^3. The principal isotopes in the waste are ^{3}H and ^{14}C.

Fuel-cycle waste includes many of the waste categories listed in the previous paragraph, as well as higher activity waste such as spent ion-exchange resins, filters, filter sludges, solidified evaporator bottoms, shielding, piping, instrumentation, control rods, and neutron-activated materials. Most of this waste (approximately 98%) comes from nuclear reactor operations. The principal isotopes in the waste include ^{55}Fe, ^{60}Co, ^{63}Ni (from LWR decommissioning), ^{134}Cs, and ^{137}Cs. Approximately 80% of the annual solid radioactive waste volume from nuclear reactor operation results from the processing of liquid streams to reduce the radioactivity level in effluents.

Published reports of isotopic mixtures in low-level waste at existing burial grounds, or in reactor radioactive waste, do not provide the consistent and comprehensive set of data needed to project radioactivities for the reference burial ground inventory. The radionuclide inventory for this study is therefore based on an unpublished generic burial ground inventory prepared by NRC staff members. The inventory is normalized by assuming a byproduct specific activity of 9.0 Ci/m^3 at the time of waste burial. To obtain the total burial ground inventory at the time of site closure, the inventory in individual trenches is decayed, using the assumption that six trenches are filled during each of the 30 years of burial ground operation. Allowance is made for the ingrowth of radioactive daughters not present in the original inventory.

Waste in the slit trenches consists mainly of non-fuel-bearing components from LWR core internals packaged in 0.76-m-diameter by 3.6-m-long steel canisters. Typical activities at the time of waste burial are in the range of 1,000 to 5,000 Ci/m^3, consisting mainly of ^{55}Fe and ^{60}Co.

2.5.3 Reference Site Characteristics

The generic burial ground is postulated to be located on two reference sites, an arid western site and a humid eastern site. The climate, geology, and hydrology of the western and eastern sites are chosen to be representative of the Richland, Washington, and Sheffield, Illinois, sites, respectively. Some averaging of site parameters is made to simplify the analysis.

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:

- low annual precipitation, with evaporation greatly exceeding precipitation
- great depth to ground water
- soil with moderate-to-high permeability
- relatively great distance from the burial ground to the point of groundwater discharge into surface streams.

The eastern site has a continental climate with a wide range of temperature through 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:

- high annual precipitation
- shallow depth to ground water
- soil with low permeability
- relatively short distance from the burial ground to the point of groundwater discharge into surface streams.

2.6 ANALYSIS OF RELEASE CONDITIONS FOR DECOMMISSIONED BURIAL GROUNDS

A methodology is described for predicting conditions for the conditional or unrestricted release of an LLW burial ground after burial operations cease.

For a burial ground where subsurface radioactive inventories remain, release conditions may include waste relocation requirements, site and/or waste stabilization procedures, institutional controls, and property-use restrictions for the general public. The methodology described in this study is based on the concept that no member of the public will be allowed to receive a maximum annual dose in excess of a limit yet to be established by U.S. regulatory agencies.

Uses that may be considered for a decommissioned LLW burial ground fall under the general categories of restricted use, conditional use, and unrestricted use. The restricted-use category permits reuse of facilities and land for nuclear activities only. The conditional-use category is an interim category that permits limited public use of the burial ground without disturbing the waste, assuming that controls to ensure public safety can be adequately enforced. The interim period for enforcement of the restrictions lasts until the important radionuclides in the waste decay to insignificant levels or until additional decommissioning procedures reduce the radiation dose to levels that permit unrestricted use. Unrestricted use means that the potential exposure to members of the public from any radioactive wastes remaining buried on the site will not exceed the annual dose limit that may be established by U.S. regulatory agencies. One objective of decommissioning is to achieve the eventual unrestricted release of land areas that the public had been denied use of during the normal operational life of the burial ground.

The methodology for analysis of release conditions for a decommissioned burial site consists of comparing the calculated maximum annual dose to the maximum-exposed individual with an established annual dose limit. The maximum-exposed individual is postulated to remain on the site 24 hours per day. This individual is assumed to: 1) live in a house built on the site, 2) consume all of his food from crops and animal products grown on the site, 3) drink water from a well on the site, and 4) work at onsite construction (excavation) for 2000 hours per year. The dose to the maximum-exposed individual is calculated for all important potential exposure pathways. In the absence of specific guidance on the acceptable annual dose to individuals living on or near a decommissioned site, for demonstration purposes in this study, the annual dose limit to the maximum-exposed individual is assumed to be 50 mrem.

Results and conclusions derived from this pathway methodology approach depend on the site characteristics, on the assumed burial ground radionuclide inventory, and on the mathematical models used to evaluate potential exposure pathways and to estimate doses to the maximum-exposed individual. Many uncertainties exist in the radionuclide transport models and in parameters (e.g., hydraulic conductivity, distribution coefficients, leach times, etc.) used with the models. Because of these uncertainties, a generally conservative approach is attempted in this study that may result in conservative (high) estimates of doses to the maximum-exposed individual. Conversely, some non-conservatism may have resulted from the neglect of effects of chelating agents and of the corrosion of waste because of an inadequate data base. It must be emphasized that the results reported here apply specifically to the reference sites and to the assumed radionuclide inventory. The methodology presented in this study must be reapplied and the doses recalculated for each burial ground that has a different inventory and different site characteristics. This must be done using site-specific parameters to draw any conclusions about possible acceptable public uses of those decommissioned sites.

Two property-release scenarios are evaluated to determine release conditions for the reference burial grounds of this study. The first scenario assumes conditional release of the reference site 200 years after closure and stabilization of the site. Long-term care of the burial ground is assumed during the interim period that precedes site release, and the trench overburden is maintained during this period.

Potential doses to a maximum-exposed individual who lives and works on either the western or eastern site are shown in Table 2.6-1. For the western site, the water pathway is determined to be negligible. Therefore, the exposure pathways considered are inhalation, direct external exposure, and ingestion of foods grown on the released decommissioned burial ground. Additional exposure pathways of importance for the eastern site are ingestion of aquatic foods from a nearby river and ingestion of water from a well drilled into a contaminated aquifer beneath the site.

The first two columns of data in Table 2.6-1 show estimated maximum annual doses at the western and eastern sites during the first 50 years after site release assuming that individuals living on a site do not engage in excavation activities or drink water from onsite wells (eastern site). With the exception

TABLE 2.6-1. Maximum Annual Doses for Conditional Release of the Reference Burial Grounds with Different Use Restrictions(a)

Organ of Reference	Maximum Annual Dose During First 50 Years After Site Release--No Excavation and No Drinking of Water from Contaminated Wells (mrem)		Maximum Annual Dose at Western Site During First 50 Years After Site Release--Excavation Permitted (mrem)	Maximum Annual Dose at Western Site Assuming Total Erosion of Trench Overburden(b) (mrem)	Maximum Annual Dose at Eastern Site Assuming Use of Water from Well Drilled into Contaminated Aquifer Beneath Site (mrem)
	Western Site	Eastern Site			
Total Body	3.8	23	380	1 300	120 000
Bone	81	174	460	33 000	520 000
Lungs	0.008	0.008	380	50	220
Thyroid	0.053	1.8	380	380	80
GI-LLI	0.012	0.012	380	5	11

(a)Conditional release assumed to occur 200 years after site closure.
(b)Calculated at 450 years after site release (650 years after site closure).

of the maximum bone dose, all potential organ doses are within the assumed 50 mrem/year dose limit. For comparison purposes, the third column of data shows estimated maximum annual doses at the western site assuming that excavation is permitted. The fourth column of data shows estimated maximum annual doses at the western site assuming total erosion of trench overburden. (This is assumed to occur approximately 450 years after site release, based on the estimated erosion rate at the western site.) The last column of data shows estimated maximum annual doses at the eastern site assuming that the site resident obtains all of his drinking water from a well drilled into the contaminated aquifer beneath the site. Most of the organ doses in data columns 3 through 5 are clearly in excess of the assumed dose limit, and demonstrate the importance of imposing use limitations for conditional release of the decommissioned reference sites.

A conditional use of the decommissioned western site would be possible provided the following actions are enforced:

- stabilize the ground surface to minimize surface erosion
- control the type of farming or other land use to prevent the growth of deep-rooted plants
- restrict activities that result in excavation of the site.

A conditional use of the decommissioned eastern site would include enforcement of those restrictions described for the western site, plus the following additional restrictions:

- prohibit the use of water from shallow wells drilled on or near the site
- maintain site drainage features to control surface water runoff and prevent inundation of burial trenches with water
- stabilize the waste to minimize leaching to the aquifer, or control the use of aquatic organisms and water from nearby streams.

The second property-release scenario for the reference burial grounds assumes unrestricted release of a site after 200 years. Since most of the radionuclides that contribute to the large doses shown in columns 3 through 5 of Table 2.6-1 have long radioactive half lives, the potential maximum annual dose to the maximum-exposed individual from unrestricted release of the site will remain above 50 mrem/year for thousands of years. To permit unrestricted release of the sites described in this study, the inventory of buried radioactive waste would need to be modified by limiting it to short-lived radionuclides and by restricting the quantities of ^{90}Sr and ^{137}Cs buried at the sites. A modified radionuclide inventory that would permit unrestricted release of the reference sites 200 years after burial ground closure is shown in Table 8.4-2 of Section 8.

2.7 ENVIRONMENTAL SURVEILLANCE AND RECORDS MAINTENANCE

The primary intent of environmental surveillance during decommissioning is to ensure that the decommissioning activities do not cause significant transport of radioactivity from the site, resulting in an unacceptable health hazard to the public. During long-term care, environmental surveillance serves to verify the radionuclide-confinement capability of the burial ground and to identify problem situations requiring remedial action.

Post-operational environmental monitoring programs should normally be extensions of the program carried out during burial ground operations, with appropriate additions to or deletions from the base program to account for differences between operational and post-operational (decommissioning and long-term care) activities at the site. This assumes that the monitoring program during burial ground operations has been properly designed to monitor the critical pathways for movement of radioactivity from the site and to sample for those radionuclides identified as significant contributors to dose.

Stabilization of a burial ground site involves movement of surface soils, but no intentional uncovering or exhumation of buried wastes. Therefore, the environmental monitoring program during stabilization is postulated to be the same as that during burial operations, except as follows:

- The frequency of onsite soil sampling is increased to detect any changes in soil radioactivity resulting from soil disruption during stabilization activities. Samples are taken weekly at locations of greatest soil disruption.
- If stabilization activities involve soil movement that results in an increased dust loading in the air, additional air samples may be required.
- Sampling of onsite vegetation is continued during stabilization at the same frequency as for normal burial operations. However, because site vegetation is disrupted during stabilization, the samples are obtained at special locations designated during the planning and preparation phase.

The environmental monitoring program during waste relocation is also postulated to be similar to that during normal burial operations. Special samples or analyses may be required by the regulatory agency responsible for the site or by the health and safety supervisor. Changes to the normal monitoring program during waste relocation include:

- The number of onsite soil samples is increased. The additional samples are taken in areas of greatest soil disruption, according to specifications prepared during planning and preparation. Samples are taken weekly.
- Additional air samples are required. Two additional samplers are located offsite, in the prevailing downwind direction. A continuously recording exposure-rate instrument is installed near the work area to detect sudden changes in airborne radioactivity.

- Sampling of vegetation is continued at the same frequency as for normal burial operations. However, because disruption of onsite vegetation is inevitable during waste relocation, special sample points may be required.

If site stabilization activities are effective, it should be possible to reduce the level of environmental monitoring activity required during long-term care from that required during site operation. However, it may be necessary to maintain environmental sampling and analysis efforts at the same level for a few years to evaluate the effectiveness of site stabilization and other decommissioning procedures. In this study, it is assumed that environmental monitoring requirements during the first 25 years of long-term care are similar to requirements during burial operations. After 25 years, the environmental monitoring program for long-term care is reduced to about one-fourth of the original level, by reducing the number of sample locations and/or the sampling frequency.

During the decommissioning and subsequent long-term care of an LLW burial ground, all activities should be documented and accurate records of the project maintained. In addition, environmental monitoring data should be maintained in the records repository. Records would need to be preserved for the period of long-term care, until a site is released for unrestricted use. Because administrative control of a burial site may be required for many years, it is important that burial ground records by accessible for this time period and that they be preserved in a usable form. For long-term preservation of records, microfilms could be made; this would also reduce the need for filing space. To facilitate data evaluation, data requiring repeated, rapid retrieval could be stored in a computer bank as well as in the files.

2.8 DECOMMISSIONING METHODS

The basic decommissioning options considered in this study are site/waste stabilization followed by long-term care of the site, and waste relocation.

2.8.1 Site/Waste Stabilization

Site/waste stabilization consists of combinations of stabilization techniques devised to deal with release mechanisms of concern for a particular burial site. To select a stabilization plan for a site, the dominant radionuclide release mechanisms, together with suitable stabilization techniques for dealing with these release mechanisms, are identified. Combinations of techniques are then formulated and evaluated for their effectiveness in reducing the mobility of the buried radionuclides and in preventing contact of the waste by potential transport mechanisms.

Release mechanisms of importance for a particular site are identified, using the methodology for identifying critical radionuclide release pathways summarized in Section 2.6. In order of decreasing importance, the dominant release mechanisms for the reference western site are:

- human activities (excavation and agriculture)
- wind erosion.

For the reference eastern site, the dominant release mechanisms (in order of decreasing importance) are:

- human activities (excavation and agriculture)
- hydrological releases (percolation and overflow)
- water erosion.

Factors used to evaluate stabilization plans and techniques include:

- effectiveness against the dominant release mechanism
- initial cost
- annual maintenance cost
- anticipated useful life
- ease of application.

The most important evaluation factor is effectiveness in controlling the dominant release mechanisms. Cost considerations and anticipated useful life are of secondary importance. Ease of application is the least important.

For this study, three site/waste stabilization plans are described and evaluated for each reference site. The stabilization plans, listed in Table 2.8-1, include a minimal plan, a relatively modest one, and a more complex one. These plans correspond to varying levels of effort that may be

TABLE 2.8-1. Site/Waste Stabilization Plans for the Reference Sites

Plan Designation	Description	Time Required (weeks)[a]
Arid Western Site		
Minimal Plan	Site inspection, Stabilization of final trenches and of damaged areas, Vegetation management.	10
Modest Plan	Increased capping thickness, Revegetation, Vegetation management	29
Complex Plan	Subsurface rock layer with hard top, Increased capping thickness, Revegetation, Vegetation management.	35
Humid Eastern Site		
Minimal Plan	Site inspection, Stabilization of final trenches and of damaged areas, Vegetation management	11
Modest Plan	Increased capping thickness, Capping soil properties modification, Improved capping drainage, Revegetation, Vegetation management.	34
Complex Plan	Peripheral drainage and diversion, Sump pumping with treatment, Subsurface hard layer, Increased capping thickness, Revegetation, Vegetation management.	36

(a)Does not include planning and preparation time.

required to properly stabilize a site. The minimal plan assumes that stabilization has been an integral part of normal site procedures during burial ground operation and, therefore, only a minor effort is required to prepare the site for long-term care. The modest and complex plans assume that burial trenches were not stabilized as they were filled. Therefore, stabilization of the entire site is necessary before the site is turned over to a government agency for long-term care. Ordinarily, the choice of a plan for a given site is not influenced by the choice for another site. However, in this study the minimal and the modest plans for the two sites are essentially the same, differing only because of site-specific differences. This allows a comparison of similar plans applied to different sites. The complex plans for the two sites are intentionally different, to allow for detailed analysis of a wider range of stabilization alternatives.

The stabilization plans evaluated in this study are intentionally chosen to demonstrate the methodology and costs of a range of decommissioning alternatives and to enable comparisons to be made between alternatives. The actual level of effort required to properly stabilize a specific site must be determined at the time of site closure; this requires a detailed analysis of site-specific data.

2.8.2 Long-Term Care

Long-term care of an LLW burial site includes all procedures required to maintain and verify site capability to confine the radionuclides to the immediate vicinity of the burial trenches. These procedures are, in general, a continuation of maintenance and surveillance procedures established during site operation and stabilization. Long-term care of a site continues until it is determined that the buried waste materials no longer pose a potential radiological hazard.

Long-term care includes administrative control, environmental surveillance, and site maintenance.

Administrative control includes:

- control of site access
- coordination of surveillance and maintenance activities
- control of land-use and property-development activities
- performance of necessary records maintenance.

Environmental surveillance includes:

- collection of environmental samples
- analysis of environmental samples
- records maintenance.

Site maintenance includes:

- maintenance and repair of fences, gates, monitoring systems, etc.
- erosion control
- trench cap repair
- water infiltration control
- vegetation management.

2.8.3 Waste Relocation

Waste relocation involves exhumation of the buried waste, repackaging the waste if necessary, and reburial of the waste at a deep geologic disposal site, a federal or other commercial shallow-land burial ground, or in another trench on the same site. Because of the potential for significant radiation exposure to decommissioning workers and the high dollar costs, waste relocation would likely be considered only in situations where site/waste stabilization and long-term care are not sufficient to ensure the continued capability of the site to provide adequate containment of the buried waste. Waste relocation is investigated in detail for the following cases:

- relocation of high beta-gamma radioactivity waste from a slit trench
- relocation of TRU waste from a conventional burial trench
- relocation of all the waste from a conventional burial trench.

In addition, an estimate is made of the manpower, time, and cost of relocating the waste from the entire reference burial ground.

Relocation of high beta-gamma radioactivity waste from a slit trench includes several distinct operations. These are:

- core drilling and sampling
- overburden removal
- sheet piling installation
- trench excavation and waste exhumation
- packaging and shipping of retrieved waste canisters
- sheet piling removal
- trench backfilling and site restoration.

Slit trench excavation and waste retrieval requires personnel protection from radioactive contamination and high radiation dose rates. Most operations are performed remotely, and entrance to the pit is generally prohibited because of the high dose rate. Several equipment options are evaluated for remote excavation after overburden removal and sheet piling installation. These options are summarized in Table 2.8-2. All of the excavation options assume the use of sheet piling along two sides of the trench, as a safety measure and to limit the width of excavation. To assess the impact of sheet piling on decommissioning costs and schedules, a non-piled exhumation is examined for the polar crane excavation option.

TABLE 2.8-2. Options for Remote Excavation of a Slit Trench

Option	Description	Excavation Rate (m^3/hr)
Hydraulic Excavation	Uses high-velocity stream of water to sluice out soil from burial trench	5
Pneumatic Excavation	Combines mechanical digging of trench soil with pneumatic transport of soil out of trenches.	10
Polar Crane with Sheet Piling	Uses remotely operated clamshell-type digger suspended from polar crane	20
Polar Crane Without Sheet Piling	Polar crane option but without sheet piling. Requires removal of greater volume of soil.	30
Mobile Gantry Crane	Uses remotely operated clamshell-type digger suspended from gantry crane.	16
Structure Enclosed Mobile Gantry Crane	Gantry crane option, but enclosed in lightweight sheet-metal building for weather protection	8.5

Relocation of TRU waste from a conventional burial trench includes the following operations:

- core drilling and sampling
- overburden removal
- sheet piling installation
- installation of work enclosure
- TRU package exhumation
- repackaging and shipment of the waste
- removal of sheet piling and work enclosure
- backfilling and site restoration.

To reduce the possibility of airborne release of TRU contamination, all excavation and waste retrieval operations take place within an enclosure equipped for control and filtration of the air leaving the building. Four enclosure/excavation options are considered in this study and are summarized in Table 2.8-3. Two of the options involve men working in the pit area. All personnel operating within the confines of the metal building erected over the excavation wear plastic bubble suits for protection against airborne contamination.

TABLE 2.8-3. Options for Exhumation of TRU Waste from a Conventional Burial Trench

Option	Enclosure	Excavation Non-TRU Waste	TRU Package Disinterment
Single enclosure with manual excavation	Lightweight metal building	Backhoe	Backhoe and men with shovels
Single enclosure with remote excavation	Lightweight metal building	Gantry crane with clamshell	Gantry crane and mobile remotely controlled manipulator
Double enclosure with manual excavation	Lightweight metal building inside air support weather shield	Backhoe	Backhoe and men with shovels
Double enclosure with remote excavation	Lightweight metal building inside air support weather shield	Gantry crane with clamshell	Gantry crane and mobile remotely controlled manipulator

Relocation of all the waste from a conventional trench can be accomplished by relatively simple earthmoving techniques, after selective exhumation of the more hazardous wastes. It is assumed that high beta-gamma activity waste and TRU waste is selectively removed using the techniques summarized previously. Relocation of the waste remaining in a trench involves the following steps:

- core drilling and sampling
- overburden removal
- waste exhumation
- repackaging and shipment of the waste
- trench backfilling and site restoration.

Wastes are exhumed by bulk excavation of the trench, using conventional, commercially available 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 cases are considered. 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 case involves the use of a front-end loader operating from the floor of the trench, with laborers assisting in the grappling and excavation of the randomly mixed drums and boxes and the loose waste.

2.9 DECOMMISSIONING COSTS

Costs are calculated for the decommissioning options described in Section 2.8. All costs are given in 1978 dollars, and a 25% contingency is included in the values presented.

2.9.1 Costs of Site/Waste Stabilization

Estimated costs of site/waste stabilization are summarized in Table 2.9-1. Total site stabilization costs for the western site are $0.5 million for the minimal plan, $2.6 million for the modest plan, and $7.7 million for the complex plan, while total costs for the eastern site are $0.5 million, $3.9 million, and $5.5 million for the minimal, modest, and complex plans, respectively. The cost analysis is based on the assumption that for both the modest and complex plans, site stabilization is performed by a contractor hired by the site

TABLE 2.9-1. Estimated Costs of Site Stabilization

Cost Category	Cost ($ millions)[(a,b)] Arid Western Site Minimal Plan	Modest Plan	Complex Plan	Humid Eastern Site Minimal Plan	Modest Plan	Complex Plan
Manpower						
Support Staff	0.298	0.704	0.770	0.309	0.758	0.781
Decommissioning Workers	0.066	0.360	0.859	0.070	0.636	0.761
Contractor's Equipment	0.035	0.374	0.870	0.041	0.568	0.703
Material and Expendable Equipment	0.071	0.905	4.558	0.076	1.563	2.758
Contractor's Fee(c)	--	0.188	0.565	--	0.283	0.400
Miscellaneous Owner Expense(d)	0.008	0.018	0.020	0.008	0.019	0.020
Environmental Monitoring	0.008	0.023	0.028	0.012	0.035	0.038
Records Maintenance	0.001	0.006	0.006	0.001	0.026	0.006
Total (rounded)	0.5	2.6	7.7	0.5	3.9	5.5

(a)Number of figures shown is for computational accuracy only and does not imply precision to the nearest thousand dollars.
(b)Costs include 25% contingency.
(c)Based on 8% of the sum of manpower, equipment, and material costs.
(d)Includes utilities, insurance, and taxes.

operator. Therefore, a contractor's fee is included in the total cost. This fee is subtracted from the total cost if the work is done by the site operator. Support staff manpower costs include planning and preparation costs. The complex plan for the western site has the greatest material requirements and costs and the greatest costs to move these materials into place. Material requirements and associated costs for the complex plan for the eastern site are reduced somewhat, because a large portion of the backfill required to increase the capping thickness is provided by digging the peripheral drainage/diversion ditches. This also results in somewhat reduced equipment requirements and costs.

2.9.2 Costs of Long-Term Care

Total estimated costs of long-term care following site stabilization are summarized in Table 2.9-2. A long-term care period of 200 years is assumed. The annual costs of long-term care are anticipated to be greatest during the first two or three decades immediately following site stabilization. During this early period, trench subsidence is expected to be greatest, and the costs of trench maintenance and repair will therefore be at their highest. In addition, environmental monitoring costs are assumed to be highest during the first years of long-term care. After this initial site "maturation" period, the annual costs are estimated to be significantly reduced.

TABLE 2.9-2. Summary of Estimated Long-Term Care Costs

	Costs (in millions of 1978 dollars) for Time Period[a,b]						
	0-5 Years After Stabilization		6-25 Years After Stabilization		26-200 Years After Stabilization		
Stabilization Plan that Precedes Long-Term Care	Annual	Period Total	Annual	Period Total	Annual	Period Total	Total Costs for 200 Years (in millions of 1978 dollars)[a]
Minimal and Modest Plans for the Western Site	0.162	0.808	0.106	2.122	0.078	13.580	16.5
Complex Plan for the Western Site	0.230	1.150	0.100	2.000	0.072	12.512	15.7
Minimal and Modest Plans for the Eastern Site	0.235	1.175	0.177	3.542	0.131	22.855	27.6
Complex Plan for the Eastern Site	0.363	1.815	0.182	3.642	0.136	23.730	29.2

(a)Costs include contingency of 25%.
(b)Number of figures shown is for computational accuracy only.

Long-term care costs are significantly higher at the eastern site than they are at the western site. In part, this is due to higher environmental monitoring costs at the eastern site. However, the cost differential is mainly due to the additional costs of maintenance of stabilization features (e.g., subsurface layers and drainage ditches) needed to reduce infiltration of water into the trenches at the eastern site.

2.9.3 Costs of Waste Relocation

Waste relocation activities are postulated to require a 20% longer time period 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 relocation are higher at the eastern site than at the western site.

Estimated costs of relocation of high beta-gamma activity waste from a slit trench are summarized in Table 2.9-3. Costs are shown for the six exhumation alternatives considered in this study and for the waste management options

TABLE 2.9-3. Estimated Costs of Relocation of High Beta-Gamma Activity Waste from a Slit Trench

	Cost ($ millions)[a,b]					
	Hydraulic Excavation	Pneumatic Excavation	Polar Crane w/Sheet Piling	Polar Crane w/o Sheet Piling	Gantry Crane	Gantry Crane Enclosed
Western Site						
Deep Geologic Disposal						
Exhumation	0.639	0.500	0.361	0.178	0.406	0.640
Waste Management	2.421	2.421	2.421	2.421	2.421	2.421
Total (rounded)	3.1	2.9	2.8	2.6	2.8	3.1
Shallow-Land Burial						
Exhumation	0.639	0.500	0.361	0.178	0.406	0.640
Waste Management	1.206	1.206	1.206	1.206	1.206	1.206
Total (rounded)	1.8	1.7	1.6	1.4	1.6	1.8
Eastern Site						
Deep Geologic Disposal						
Exhumation	0.745	0.572	0.414	0.209	0.462	0.720
Waste Management	2.421	2.421	2.421	2.421	2.421	2.421
Total (rounded)	3.2	3.0	2.8	2.6	2.9	3.1
Shallow-Land Burial						
Exhumation	0.745	0.572	0.414	0.209	0.462	0.720
Waste Management	1.206	1.206	1.206	1.206	1.206	1.206
Total (rounded)	2.0	1.8	1.6	1.4	1.7	1.9

(a) Number of figures shown is for computational accuracy only and does not imply precision to the nearest thousand dollars.

(b) Costs include 25% contingency.

of shipment to deep geologic disposal or to another shallow-land burial site. Exhumation costs vary by about a factor of 4, depending on the option chosen. While the use of sheet piling adds significantly to the cost of exhumation (about $125,000 for exhumation from a slit trench), it is recommended for safety reasons. Waste management costs (including the costs of packaging, shipping, and disposal of the exhumed waste) are estimated to be about $2.4 million for deep geologic disposal and about $1.2 million for shallow-land burial. Thus, waste management is the cost-controlling factor for relocation of slit trench waste.

Estimated costs of relocation of TRU waste from a conventional burial trench are summarized in Table 2.9-4. Costs are shown for the four exhumation alternatives considered. The exhumed waste is assumed to be shipped to deep geologic disposal. The cost-controlling item for this operation is the choice of enclosure. The cost of the single enclosure is estimated to be $200,000, while the cost of the double enclosure is estimated to be $525,000.

TABLE 2.9-4. Estimated Costs of Relocation of TRU Waste from a Conventional Burial Trench

	Cost ($ millions)[a,b]			
	Single Enclosure w/Manual Excavation	Single Enclosure w/Remote Excavation	Double Enclosure w/Manual Excavation	Double Enclosure w/Remote Excavation
Western Site				
Exhumation	0.434	0.414	0.871	0.854
Waste Management	0.024	0.024	0.024	0.024
Total (rounded)	0.46	0.44	0.90	0.88
Eastern Site				
Exhumation	0.441	0.421	0.888	0.866
Waste Management	0.024	0.024	0.024	0.024
Total (rounded)	0.46	0.44	0.91	0.89

(a)Number of figures shown is for computational accuracy only and does not imply precision to the nearest thousand dollars.
(b)Costs include 25% contingency.

Estimated costs of relocation of all the waste from a conventional burial trench (i.e., the waste remaining in the trench after packages of high beta-gamma activity or TRU waste are selectively removed) are summarized in Table 2.9-5. Costs are shown for the two exhumation options considered in this study and for the waste management options of deep geologic disposal, disposal at another shallow-land burial site, or reburial in another onsite trench. Waste management controls the cost of waste relocation from a conventional trench, as it does the cost of waste relocation from a slit trench. The cost of excavation from within a trench is estimated to be only about 80% of the cost of excavation from above a trench. However, excavation from within a trench has a greater potential for radiation dose to workers than does excavation from above a trench.

TABLE 2.9-5. Estimated Costs of Relocation of all the Waste from a Conventional Burial Trench

	Cost ($ millions)[a,b]			
	Western Site		Eastern Site	
	Excavation from Above the Trench	Excavation from Within the Trench	Excavation from Above the Trench	Excavation from Within the Trench
Deep Geologic Disposal				
Exhumation	0.582	0.465	0.710	0.555
Waste Management	43.280	43.280	43.280	43.280
Total (rounded)	43.9	43.7	44.0	43.8
Shallow-Land Burial				
Exhumation	0.582	0.465	0.710	0.555
Waste Management	7.220	7.220	7.220	7.220
Total (rounded)	7.8	7.7	7.9	7.8
Reburial Onsite				
Exhumation	0.582	0.465	0.710	0.555
Waste Management	0.165	0.165	0.165	0.165
Total (rounded)	0.75	0.63	0.88	0.72

---

[a] Number of figures shown is for computational accuracy only and does not imply precision to the nearest thousand dollars.

[b] Costs include 25% contingency.

2.9.4 Cost Comparisons

The total costs of stabilization and long-term care (for 200 years) of a burial ground are compared, in Table 2.9-6, with the cost of waste relocation for the entire burial ground. For waste relocation, it is assumed that 10 slit trenches and 10 TRU waste packages must be exhumed, in addition to relocating the waste from the 180 burial trenches. The TRU waste is assumed to be shipped to deep geologic disposal. The remainder of the waste is shipped to a federal or other commercial shallow-land burial site. Approximately 93% of the total waste relocation cost is associated with waste management activities. All costs are in constant 1978 dollars and include a 25% contingency.

TABLE 2.9-6. Total Estimated Costs for Possible Decommissioning Choices

	Decommissioning Costs ($ millions)(a,b)			
	Stabilization	Long-Term Care(c)	Waste Relocation	Total
Western Site				
Minimal Stabilization Plus Long-Term Care	0.5	16.5	---	17.0
Modest Stabilization Plus Long-Term Care	2.6	16.5	---	19.1
Complex Stabilization Plus Long-Term Care	7.7	15.7	---	23.4
Waste Relocation	---	---	1 410	1 410
Eastern Site				
Minimal Stabilization Plus Long-Term Care	0.5	27.6	---	28.1
Modest Stabilization Plus Long-Term Care	3.9	27.6	---	31.5
Complex Stabilization Plus Long-Term Care	5.5	29.2	---	34.7
Waste Relocation	---	---	1 429	1 429

(a)Values include a 25% contingency.
(b)Values are in constant 1978 dollars.
(c)Long-term care continues for 200 years after stabilization of the site.

2.10 OCCUPATIONAL AND PUBLIC SAFETY

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

The results of the safety evaluation of normal decommissioning operations are summarized in Table 2.10-1. 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. It also shows the number of fatalities and serious injuries expected as a result of nonradiological accidents to decommissioning workers. The same population distribution is assumed for both the western and the eastern sites, even though the actual population distributions around the two sites are different. This allows a direct comparison of safety effects that are related to the physical characteristics of the two sites.

No airborne releases result from routine site/waste stabilization operations, because no operations involving direct waste contact are postulated; therefore, no public doses are calculated. The occupational dose for site/waste stabilization depends on the specific stabilization plan considered. Occupational doses from external exposure for site/waste stabilization are calculated to range from 0.1 to 2.0 man-rem.

For waste relocation, the reference technologies evaluated include slit trench exhumation using a remotely operated clamshell-type digger suspended from a gantry crane, exhumation of a package of TRU waste from a conventional trench using manual excavation techniques within a single enclosure, and relocation of all the waste from a single burial trench by excavation from within the trench. Since operations at the western site are found to give larger airborne releases because of higher wind conditions, the calculated doses for the western site are larger than those for the eastern site. For waste exhumation

TABLE 2.10-1. Summary of Safety Analysis for Decommissioning the Reference LLW Burial Grounds

Type of Safety Concern	Source of Safety Concern	Units	Western Site: Site/Waste Stabilization	Western Site: Slit Trench Exhumation	Western Site: TRU Waste Package Removal	Western Site: Exhumation of Entire Burial Trench	Eastern Site: Site/Waste Stabilization	Eastern Site: Slit Trench Exhumation	Eastern Site: TRU Waste Package Removal	Eastern Site: Exhumation of Entire Burial Trench
Public Safety(a)										
Radiation Exposure	Decommissioning Operations	man-rem	---(b)	6×10^{-5}	1×10^{-3}	7×10^{1}	---(b)	6×10^{-5}	3×10^{-3}	7×10^{1}
	Transportation	man-rem	---(b)	2×10^{-1}	2×10^{-3}	3×10^{0}	---(b)	5×10^{-1}	6×10^{-3}	1×10^{1}
	Long-Term Care	man-rem	---(b)	---	---	---	---(b)	---	---	---
Occupational Safety										
Serious Lost-Time Injuries	Decommissioning Operations	number	3.8×10^{-1}(c)	3.8×10^{-2}	1.7×10^{-2}	7.5×10^{-2}	6.4×10^{-1}(c)	3.8×10^{-2}	1.7×10^{-2}	7.5×10^{-2}
	Transportation	number(d)	---	2.4×10^{-1}	2.7×10^{-3}	2.6×10^{0}	---	2.4×10^{1}	2.7×10^{-3}	2.6×10^{0}
	Long-Term Care	number/year	1.8×10^{-1}(c)	---	---	---	3.4×10^{-2}(c)	---	---	---
Fatalities	Decommissioning Operations	number	4.1×10^{-3}(c)	2.1×10^{-4}	9.7×10^{-5}	3.9×10^{-4}	3.2×10^{-3}(c)	2.1×10^{-4}	9.7×10^{-5}	3.9×10^{-4}
	Transportation	number(d)	---	1.4×10^{-2}	1.6×10^{-4}	1.5×10^{-1}	---	1.4×10^{-2}	1.6×10^{-4}	1.5×10^{-1}
	Long-Term Care	number/year	2.1×10^{-4}(c)	---	---	---	1.7×10^{-4}(c)	---	---	---
Radiation Exposure	Decommissioning Operations	man-rem	2.0×10^{0}(c)	3.5×10^{1}	1.2×10^{2}	2.6×10^{2}	2.0×10^{0}(c)	3.5×10^{1}	1.2×10^{2}	2.6×10^{2}
	Transportation	man-rem(d)	---	1.8×10^{1}	2.0×10^{-1}	9.9×10^{1}	---	1.8×10^{1}	2.0×10^{-1}	9.9×10^{1}
	Long-Term Care	man-rem/year	2.7×10^{-1}(c)	---	---	---	2.7×10^{-1}(c)	---	---	---

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(a) Radiation doses from postulated accidents are not included. The 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 bone. Transportation doses are from external exposure to the population along the transport route.
(b) No airborne radioactivity results from routine site/waste stabilization operations.
(c) Worst case of several options.
(d) These values result from offsite shipments.

operations, the 50-year committed dose equivalents to the bone of the maximum-exposed individual at the western site are: 1.0×10^{-4} mrem for 1-year-old slit trench waste exhumation, 0.01 mrem for TRU waste exhumation, and 80 mrem for complete trench exhumation. The total calculated occupational doses from external exposure for waste relocation operations are: 35 man-rem for slit trench waste exhumation, 120 man-rem for partial trench (TRU) waste exhumation, and 260 man-rem for complete trench waste exhumation. These dose numbers indicate that waste relocation operations are very costly in terms of worker exposure.

An analysis is made of postulated decommissioning accidents during waste relocation and site/waste stabilization. A wide spectrum of accidents (24 different accidents) is considered, with appropriate assumptions leading to calculated airborne releases of radioactivity and calculated radiation doses to the maximum-exposed individual. Estimates of accident frequency are made in terms of high (greater than 10^{-2} events per year), medium (10^{-2} to 10^{-5} events per year), or low (less than 10^{-5} events per year). Table 2.10-2 summarizes the results of this analysis for the ten accidents that result in the highest doses to an organ of the maximum-exposed individual.

TABLE 2.10-2. Summary of Radiation Doses to the Maximum-Exposed Individual from Decommissioning Accidents[a]

Operation/Incident	Airborne Release (μCi)	Estimated Frequency of Occurrence[b]	First-Year Dose (mrem) Total Body	First-Year Dose (mrem) Bone	Fifty-Year Committed Dose Equivalent (mrem) Total Body	Fifty-Year Committed Dose Equivalent (mrem) Bone
Waste Relocation						
Severe Transportation Accident (TRU)	3.1×10^{3}	Low	6.1×10^{0}	1.4×10^{2}	2.0×10^{2}	4.6×10^{3}
Exhumation of Undetected TRU Waste	1.1×10^{3}	High	4.8×10^{-2}	1.6×10^{0}	1.6×10^{0}	3.6×10^{1}
Waste Package Handling (TRU)	5.6×10^{2}	Low	2.4×10^{-2}	5.5×10^{-1}	7.8×10^{-1}	1.7×10^{1}
Onsite Transportation Accident	1.0×10^{4}	Medium	8.9×10^{-2}	6.3×10^{-1}	3.5×10^{-1}	5.3×10^{0}
Severe Transportation Accident (non-TRU)	1.5×10^{2}	Medium	1.3×10^{-2}	9.1×10^{-2}	5.1×10^{0}	7.7×10^{-1}
Minor Transportation Accident (TRU)	3.1×10^{0}	Low	6.1×10^{-3}	1.4×10^{-1}	2.0×10^{-1}	4.6×10^{0}
Failure of HEPA Filters	7.2×10^{1}	Low	3.1×10^{-3}	7.2×10^{-2}	1.0×10^{-1}	2.3×10^{0}
Spontaneous Combustion of Wastes	1.7×10^{3}	Medium	3.1×10^{-3}	2.2×10^{-2}	1.2×10^{-2}	1.9×10^{-1}
Trench Void-Space Collapse	4.7×10^{2}	Medium	8.6×10^{-4}	6.1×10^{-3}	3.4×10^{-3}	5.2×10^{-2}
Site Stabilization						
Trench Void-Space Collapse	4.7×10^{3}	Medium	8.6×10^{-3}	6.1×10^{-2}	3.4×10^{-2}	5.2×10^{-1}

(a) Inhalation doses only.
(b) Frequency of occurrence: High >1 × 10^{-2}; Medium 1 × 10^{-2} to 1 × 10^{-5}; Low <1 × 10^{-5} events per year.

2.11 FACILITATION OF DECOMMISSIONING

Factors that would facilitate the decommissioning of LLW burial grounds can be grouped into three categories: 1) design considerations, 2) operating practices, and 3) research needs.

Design considerations to facilitate decommissioning include criteria for site selection and for the design and construction of burial trenches. Site selection refers to measures to ensure that a burial site meets prescribed geologic, hydrologic, and demographic criteria. Careful site selection allows reliable estimates to be made of decommissioning needs and makes it easier to evaluate the effectiveness of decommissioning activities. Care in the design and construction of burial trenches may improve their waste containment capability, thereby substantially reducing the need for costly trench repairs and stabilization procedures when a site is closed.

Operating practices to facilitate decommissioning include waste form and packaging considerations, waste burial practices, and records maintenance procedures. Improvements in the form and packaging of wastes could have several desirable consequences such as a reduction in trench subsidence, the simplification of waste migration analysis, and a possible reduction in radionuclide migration rates. Segregation of long-lived or hazardous wastes may reduce the magnitude and cost of decommissioning by making it possible to limit certain decommissioning procedures to those areas of the burial ground where such wastes are buried. Engineered storage of long-lived or hazardous wastes would facilitate the future relocation of these wastes should this be necessary. Improvements in the accuracy and completeness of burial ground records and development of data processing methods to analyze the records would aid in the planning and performance of decommissioning.

Research is needed in several technical areas to ensure that LLW burial sites are properly decommissioned. Many site/waste stabilization techniques are still in the development stage. Research is needed to assess the effectiveness of candidate techniques, to determine their useful lifetimes, and to evaluate the costs of implementation and maintenance. Many uncertainties exist in the radionuclide transport models used to predict radionuclide migration from

LLW burial grounds. Research is needed to develop more realistic transport models and to verify these models by comparison of predicted migration rates with experimental results for real sites. Research is also needed to obtain more accurate values of the parameters used with the models.

Existing commercial burial grounds, some of which may require decommissioning in the near future, provide an excellent arena for research to improve the technical information base regarding decommissioning. The development of confidence in engineering techniques for burial ground stabilization and the validation of pathway analysis models could lead to the possible future release of these sites on a conditional or unrestricted use basis.

2.12 STUDY CONCLUSIONS

Major conclusions of this study are:

- Decommissioning of an LLW burial ground can be accomplished using currently available technology. However, research is needed in several technical areas to ensure that sites are properly decommissioned.
- Decommissioning costs are significantly higher for waste relocation than they are for site stabilization plus long-term care. Waste management costs (costs of packaging, shipping and disposal of the exhumed waste) are the major cost items for waste relocation.
- Site stabilization and long-term care of an LLW burial ground can be accomplished with no significant impact on the safety of the general public. The impact of waste relocation operations on the safety of the general public is estimated to be small. Site stabilization and long-term care operations result in modest radiation exposure of decommissioning workers. However, waste relocation operations result in significant radiation exposure of decommissioning workers.
- Several improvements could be made in the design and operation of LLW burial grounds to facilitate decommissioning these facilities.
- Because of high dollar costs and large occupational doses associated with waste relocation, the preferred mode for decommissioning an LLW burial

ground is site stabilization. At existing burial grounds where subsurface radioactive inventories remain, site stabilization would be followed by a period of long-term care during which administrative control of the site would be maintained, site surveillance and maintenance activities would continue, and public use of the site on a conditional basis might be permitted. To allow unrestricted release following the decommissioning of future burial grounds, it may be necessary to limit the type, quantity, and chemical and physical form of the radionuclides buried at these sites.

REFERENCES

1. U.S. Congress, 95th Congress, Public Law 95-6D4, "The Uranium Mill Tailings Radiation Control Act of 1978."

2. Generic Environmental Impact Statement on Uranium Milling, NUREG-D511, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, DC, April 1979.*

3. "Branch Position--Low-Level Waste Burial Ground Site Closure and Stabilization," Revision 1, Low-Level Waste Branch, U.S. Nuclear Regulatory Commission, Washington, DC, May 17, 1979.

4. Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facities, NUREG-0436, Revision 1, U.S. Nuclear Regulatory Commission, Washington, DC, December 1978.*

5. "Disposal of Low Level Radioactive Wastes: Availability of Preliminary Draft Regulation," Federal Register, Vol. 45, No. 41, pp. 13104-13106, February 1980.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, and the National Technical Information Service, Springfield, Virginia 22161.

3.0 REVIEW OF BURIAL GROUND EXPERIENCE

Disposal of low-level radioactive wastes generated by the private commercial sector and by government-sponsored programs is currently accomplished by shallow-land burial. This section briefly describes commercial and Department of Energy (DOE) low-level waste (LLW) burial grounds (Section 3.1) and summarizes the operating experience at the various sites (Section 3.2).

No LLW burial ground has been decommissioned to date. However, remedial activities have been implemented at several sites to reduce contact of the buried waste by water and to minimize the migration of radioactivity away from the site. In addition, experimental programs have been conducted at the Idaho National Engineering Laboratory (INEL) and the Savannah River Laboratory (SRL) to establish procedures and identify costs of exhumation of buried wastes. These activities and programs contain elements that are directly applicable to the requirements for decommissioning shallow-land burial grounds.

3.1 BURIAL GROUND DESCRIPTIONS

Physical and operational descriptions of the six commercial burial sites and five major DOE sites are given in this section. This information provides the bases for characteristics of the reference burial grounds described in Section 7.

3.1.1 Commercial Burial Grounds

Radioactive waste generated by private industry was initially disposed of at burial grounds operated by the Atomic Energy Commission (AEC). During the 1950s the volume of radioactive waste generated in the private sector dramatically increased. AEC-operated burial grounds at Oak Ridge National Laboratory (ORNL) in Tennessee and at the Idaho National Engineering Laboratory (INEL) in Idaho received a portion of this waste. However, much of the radioactive waste generated by private industry was managed by sea disposal services offered by several private companies.

As public pressures against sea disposal increased, the AEC took steps to phase out this disposal method and to establish regulations permitting commercial operation of LLW burial grounds on federal- or state-owned land.

In 1962, the first commercial burial facility was opened near Beatty, Nevada. This facility provided an alternative to both sea disposal and the AEC burial ground sites. A second commercial site was opened shortly thereafter near Morehead, Kentucky, and in May 1963 the AEC discontinued the practice of accepting radioactive waste materials from private industry. Additional commercial waste burial sites were opened in subsequent years, and by 1971 six commercial burial grounds were licensed for the handling and disposal of radioactive waste from private industry sources.

The six commercial waste burial grounds that have operated in the United States are listed in Table 3.1-1. Their approximate geographic locations are shown in Figure 3.1-1. Commercial LLW burial grounds receive a variety of low-level radioactive wastes originating from nuclear reactor operations, nuclear fuel-cycle activities, university and industrial research centers, pharmaceutical manufacturers, medical diagnostic and treatment facilities, and waste disposal and decontamination companies. Details of low-level wastes received for burial at commercial sites are given in Section 7.3 and Appendix B. Brief descriptions of the sites and summaries of their operating experience are given here.

TABLE 3.1-1. Commercial Waste Burial Grounds

Site Location	Operator	Initial Date of Operation	Current Status
Beatty, Nevada	Nuclear Engineering Co.	1962	Open
Morehead, Kentucky	Nuclear Engineering Co.	1963	Temporarily Closed by State
West Valley, New York	Nuclear Fuel Services, Inc.	1963	Closed by Site Operator in 1975
Richland, Washington	Nuclear Engineering Co.	1965	Open
Sheffield, Illinois	Nuclear Engineering Co.	1967	Filled to Licensed Capacity
Barnwell, South Carolina	Chem-Nuclear Systems	1971	Open

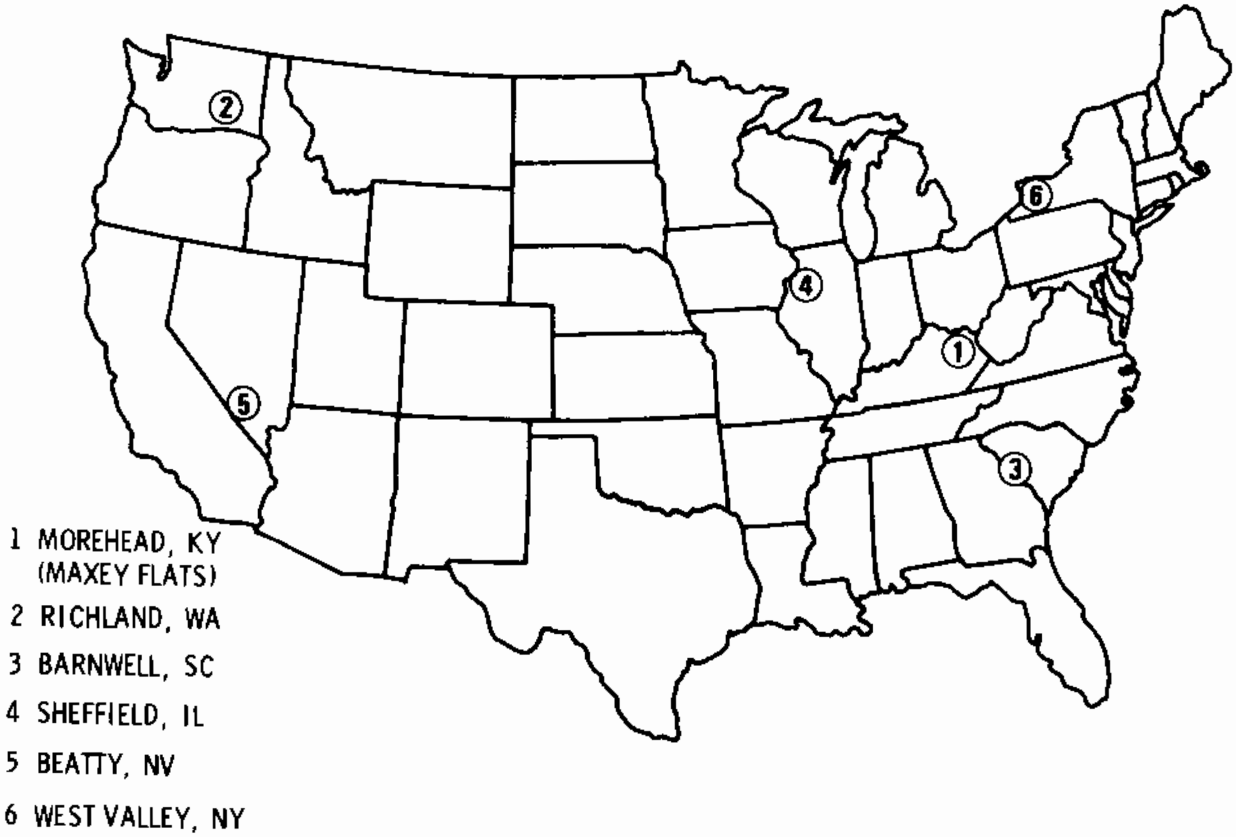

FIGURE 3.1-1. Commercial Waste Burial Sites

3.1.1.1 Characteristics of Commercial Burial Grounds

Commercial burial grounds have generally been located on the basis of regional requirements for radioactive waste disposal. Although site selection involves a large number of considerations, final siting decisions have been based largely on hydrogeologic and economic factors. The existing commercial burial grounds are located in different physiographic areas and have varying hydrogeological characteristics. Important physical characteristics of the sites are presented in Table 3.1-2. As evidenced from the information in the table, soil characteristics and soil thickness vary greatly from site to site, as does the nature of the underlying bedrock. Annual precipitation at humid sites averages about 1000 mm (± 200 mm). At arid sites, rainfall averages about 100 to 200 mm per year.

TABLE 3.1-2. Commercial Burial Site Characteristics[a]

	Barnwell, South Carolina	Beatty, Nevada	Morehead, Kentucky	Richland, Washington	Sheffield, Illinois	West Valley, New York
Area Licensed for Burial(ha)	110	32	102	40	9	9
Burial Capacity (m^3)	2.4 x 10[illegible]	7.4 x 10[illegible]	2.2 x 10[illegible]	9.1 x 10[illegible]	2.0 x 10	2.0 x 10
Climate	Humid	Arid	Humid	Semi-Arid	Humid	Humid
Mean Annual Precipitation (mm)	1100	100	1200	200	900	1000
Geomorphology	Coastal Plain	Basin & Range Desert	Ridge & Valley Appalachian	Columbia Plateau Semi-Desert	Glacial	Glacial
Surficial Material:						
Type	Sand & Clay	Alluvial Sand & Gravel	Weathered Shale, Clay & Sand	Clay, Sand & Gravel	Glacial Drift; Sand, Silt & Gravel	Glacial Drift; Clay, Silt & Sand
Thickness (m)	10	>200	3-5	>150	20-30	20-30
Bedrock:						
Classification	Clay, Sand & Sandstone	Metamorphic & Sedimentary	Shale	Volcanic Basalt	Shale, Sandstone & Coal	Shale
Structure	Flat-lying	Folded	Flat-lying	Massive/Flat-lying	Flat-lying	Flat-lying
Groundwater Depth to Shallowest Saturated Zone (m)	10-20	90-90	1-2	100	5-20	Variable, 1-20
Depth to Continuous Groundwater Zone (m)	10-20	80-90	50-70	100	5-20	20
Depth to Regional Aquifer (m)	200	80-90	None Present	100	100	None Present
Nearest Surface Water:						
Location	Lower Three Run Creek, 2 km	Amargosa River, 3 km	500 m	Columbia River, 10 km	At Site Boundaries; Lake to North	Onsite
Flow Characteristics	Small Perennial	Ephemeral, Following Storms	Small, Perennial	Large, Perennial	Small Perennial to South	Small, Perennial
Water Flow Paths From Burial Areas	Pore Spaces in Sand	Unsaturated Flow in Sand & Gravel Pores	Shale Fractures	Unsaturated Flow in Sand & Gravel Pores	Pore Spaces in Fill	Shale Fractures
Interstitial Permeability to Water (cm/day)	0.02	0.02-0.1	0.02	Variable	0.04-40	0.05
Sorptive or Ion Exchange Capacity of Burial Ground Soil	Moderate	Moderate	High	Moderate	Low	High
Observed Radionuclide Migration	Not Observed	Not Observed	On and Offsite Ground and Surface Water	Not Observed	Tritium	Onsite Ground Water; Offsite Surface Water

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(a) Taken, in part, from Table 24.4, ERDA 76-43, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," May 1976.

An important factor that has been observed to affect the containment capability of a burial ground is the degree to which ground and surface water can contact the waste and subsequently cause migration of the radionuclides away from the burial location. As a result, a hydrologic assessment is prepared during the licensing procedure for each site. This assessment provides an estimate, prior to use of the burial ground, of the degree to which ground and surface water will contact the waste following burial, the pathway of the water away from the site, the ion-exchange or adsorptive capacity of the materials along that path, and the extent to which the radionuclide content of offsite ground and surface waters will be affected by burial ground operation.

The numerical values of hydrogeological properties given in Table 3.1-2 are either estimates of a range of values, or approximate mid-range values. Some values vary from point to point and on a seasonal and annual basis at each burial site. Permeabilities are based on a limited number of analyses, usually on disturbed material obtained from test drill holes. The depth to ground water is very difficult to precisely determine in nonhomogeneous materials of low permeability. Trenches or shafts used for waste burial are approximately 10 m or less in depth at most burial sites. In regions where saturated zones are routinely encountered at depths of 15 m or less, some of the buried waste materials will be saturated with water at least some of the time. In locations where saturated zones are at depths in excess of 50 m, saturated conditions will rarely, if ever, occur within the waste materials. Several factors affect adsorptive capacities of soil materials for migrating radionuclides. These factors include the radionuclides that are migrating, the characteristics of the waste form, the soil chemistry during migration, the vertical position of the radionuclides within the subsurface material and the flow path through the material. Adsorptive capacities shown in Table 3.1-2 are qualitative estimates, based on the soil type in the zone of interest.

Burial operations at all of the sites except Sheffield are licensed by the state in which the burial ground is located, under a federal agreement giving the state licensing authority. An "agreement state" is a state that has entered into an agreement with the U.S. Nuclear Regulatory Commission (NRC), allowing the state to control the receipt, possession, use, and transfer of by-product and source material and of quantities of special nuclear material not sufficient to form a critical mass. The scope of the agreement allows the state to license disposal sites for the burial of radioactive wastes, except those wastes resulting from irradiated fuel separation. Since Illinois is not an agreement state, the Sheffield burial ground is licensed by the NRC, but it also possesses a state permit to bury waste. Two of the sites (Richland and Barnwell) have NRC licenses to bury special nuclear material in quantities exceeding state licensable quantities. When waste burial operations cease and the operating license is terminated, the responsibility for long-term care of a site reverts to the state in which the burial ground is located. During burial operations, the state collects a fee from the site operator, based on the volume of waste buried. This fee is intended to provide funds for the eventual long-term care of the site.

3.1.1.2 Operating Experience at Commercial Burial Grounds

Brief summaries of operating practices at the six commercial sites are given in Table 3.1-3. Radioactive waste disposal operations are similar to conventional sanitary landfill operations, with the additional precautions requisite to handling radioactive materials. Burial in open, unlined trenches is the common practice, with each trench containing a mixture of radionuclides and waste forms. Water is the principal mechanism that has been observed to cause radionuclide migration away from burial trenches at existing sites. These occurrences and the related health implications are discussed in Section 3.2.1.

Comprehensive environmental monitoring programs are established at all sites, in compliance with licensing requirements. Environmental samples of water, soil, and vegetation are routinely taken both onsite and offsite at all of the sites. Air samples are taken at the eastern sites. Details of environmental monitoring activities at the various sites are given in Section 9.1.

TABLE 3.1-3. Operating Practices at Commercial Burial Grounds[(a)]

	Barnwell, South Carolina	Beatty, Nevada	Morehead, Kentucky	Richland, Washington	Sheffield, Illinois	West Valley, New York
Burial Trench Size (m)	140 x 15 x 5-7 deep	260 x 12-15 x 8 deep	60-150 x 24 x 6-8 deep	90 x 8 x 6 deep	150 x 15-18 x 6-8 deep	180-210 x 10 x 6 deep
Provisions for Water Collection and Containment	Trenches Sloped 1°, 0.6-1.0 m of Sand in Bottom of Trench. Sump & Standpipe	None	Trenches Sloped 1°, Pit & Standpipe at Low Corner. Clay Berm around Trench	None	Trench Bottom Slopes to Centerline & one end. Ditch filled with broken brick. Sump & Standpipe	Trenches Sloped 2° Sump with Riser Pipe at Low End
Waste Disposal Procedure	Trench Filled to 1 m of Surface	Trench Filled to 1 m of Surface	Trench Filled to 0.6 m of Surface	Trench Filled to 0.6 m of Surface	Trench Filled to 0.6 m of Surface	Trench Filled to Original Grade Level
Waste Covering Frequency	Daily	As Trench is Filled	Daily	As Trench is Filled	Daily	Daily
Cover:						
Type	0.6 m of Clay Plus Additional Mounded Cover	Excavated Earth Fill, No Compacting	1 m Compacted Clay, Mounded & Reseeded	Excavated Earth Fill, No Compacting	Compacted Clay Cover; Surface Reseeded	Excavated Earth Fill; Compacted; Topsoil Added
Depth	3 m Cover at Centerline, 1.5 m Cover at Trench Edge	Minimum 2 m total; Mounded to 0.6 m Above Grade	Minimum 1 m Cover; Mounded to 0.6 m Above Grade	Minimum 2 m total; Mounded to 1 m Above Grade	Minimum 1 m Final Cover; Mounded	Minimum 3 m Cover; Mounded to 1.5 m Minimum Above Grade
Licensee Monitoring Programs:						
- Water	Onsite Wells-Semiannually	Onsite Well-Monthly	Onsite Wells-Monthly	Onsite Wells-Quarterly	Onsite Wells-Quarterly	Onsite Streams-Quarterly
	Offsite Water Supplies - Annually	Offsite Ground Water - Semiannually	Offsite Water-Quarterly	Offsite Surface Water - Semiannually	Offsite Surface Water - Quarterly	Offsite Surface Water - Weekly
- Soil	Offsite - Quarterly	Offsite - Semiannually	Onsite & Offsite-Quarterly	Offsite - Quarterly	Offsite - Quarterly	Offsite - Quarterly
- Vegetation	Offsite - Annually	Offsite - Semiannually	Onsite & Offsite-Quarterly	Offsite - Quarterly	Offsite - Quarterly	Offsite - Annually
- Air	Offsite - Continuous	None	Onsite - Continuous	None	Onsite - Continuous	Offsite - Continuous

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(a) Taken, in part, from Table 24.1, ERDA 76-43, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," May 1976.

There is considerable similarity in the overall operations of the six commercial waste burial sites. However, some differences are found in the types and forms of wastes accepted, trench capping procedures, surface water control measures, and other site-specific operating procedures. Trench dimensions range from 60 to 260 m long, 8 to 20 m wide at ground surface, and 5 to 8 m deep. A major requirement at most sites is that the bottom of a trench shall be above the maximum groundwater elevation.

Following are short reviews of general operational experiences at the humid eastern sites and at the arid western sites. More specific information for each site is presented in Table 3.1-3.

Humid Eastern Sites. The four humid eastern sites include Sheffield, West Valley, Morehead, and Barnwell. These sites can be generally described as locations with moderately high precipitation and soils of relatively low permeability. These factors combine to make the control and management of surface and ground water major operational considerations at the sites.

At the eastern sites, waste materials and packages are generally buried randomly, as received, and are usually covered daily to limit contact of water with the waste. The covering is accomplished with earth backfill or by providing temporary covering, such as tarps or other rain-shielding devices, depending on the extent to which the trench is filled.

Covering and sealing of the waste in the burial trenches is also used as a water control measure at the eastern sites. Although the techniques vary with local climate, soil, and groundwater conditions, generally 1 to 3 m of soil is mounded and graded over the top of the waste, with the mound 1 to 2 m high over the centerline of the trench. Trench capping efforts also involve the application of more impermeable soils, such as clay, in constructing the trench cover, followed by seeding the mound with grass and constructing drainage fields around the mounded trenches.

The trench bottoms at the eastern sites are sloped 1 to 2 degrees, and sumps with stand pipes are provided at the low end to monitor and/or remove water that may infiltrate and accumulate in completed trenches. Water infiltration into completed trenches has been observed at both Morehead and West Valley. Section 3.2.1 discusses these occurrences and the related corrective measures that have been taken. No comparable water management problems have been observed at the Sheffield or Barnwell sites; however, migration of tritium has been observed at Sheffield. Effective management of surface water, through the application of improved trench capping techniques and surface water diversion measures, is a major factor in determining the success of site operators in preventing water infiltration of burial trenches and in confining the radionuclide inventory.

Arid Western Sites. The Beatty and Richland sites are both located in arid western regions. Because of the low amount of precipitation and relatively high soil permeability at the sites, water management problems common to the eastern sites do not exist at the western sites. Consequently, operational procedures at Beatty and Richland are less involved than at the eastern sites.

The waste materials and packages are generally placed randomly in the trenches, as received. The trenches are backfilled with excavated earth when the trench space is filled to capacity with waste materials, or sooner if required for shielding or security. The earth backfill is not compacted. Built-up trench caps are provided at Beatty but not at Richland.

No migration of radionuclides from the arid sites, due to natural phenomena, has been documented. Some minor release of radioactivity from the Beatty site did occur through unauthorized removal of contaminated articles from the burial ground. Many of the contaminated articles were subsequently recovered from the Beatty community and returned to the site for disposal. Improved site access controls and security measures have since been established by the site operator to preclude similar occurrences in the future.

3.1.2 DOE Burial Grounds

Shallow-earth burial has been used for disposal of radioactive wastes at DOE sites since the inception of nuclear weapons research and production programs in the early 1940s. Waste materials currently received at these burial grounds originate from weapons production and research and development programs, National Laboratory operations, and various DOE contractor facilities. The DOE burial grounds receive a wide variety of waste materials, ranging from low-activity radiopharmaceuticals to high-activity fission products. No wastes are currently received from the commercial sector.

3.1.2.1 Descriptions of DOE Burial Grounds

Major burial grounds for radioactive waste are presently operated at five DOE sites:

- Savannah River Laboratory (SRL), South Carolina
- Idaho National Engineering Laboratory (INEL), Idaho
- Oak Ridge National Laboratory (ORNL), Tennessee
- Hanford, Washington
- Los Alamos Scientific Laboratory (LASL), New Mexico.

The approximate geographic locations of these major DOE burial sites are shown on Figure 3.1-2. Other smaller DOE burial sites are located at or near Portsmouth, Ohio; Las Vegas, Nevada (Nevada Test Site); Fernald, Ohio; Paducah, Kentucky; Amarillo, Texas; and Albuquerque, New Mexico (Sandia Laboratory).

Burial grounds at DOE sites are generally located within their laboratory or reservation boundaries. The original site selections for the laboratory or production reservations were based largely on remoteness from population centers. Burial grounds are typically located in the more remote portions of a site, thus providing for considerable isolation. Initially, burial ground areas were not located on the basis of detailed geologic or hydrologic assessments. Rather, locations were selected that appeared to offer an acceptable containment capability. In later years, cooperative agreements were negotiated with the U.S. Geological Survey to provide detailed site investigations. At present, most DOE sites with burial grounds maintain staffs of qualified geologists and hydrologists to provide in-depth site investigations as needed. A summary of general site characteristics for the five major DOE burial grounds is presented in Table 3.1-4.

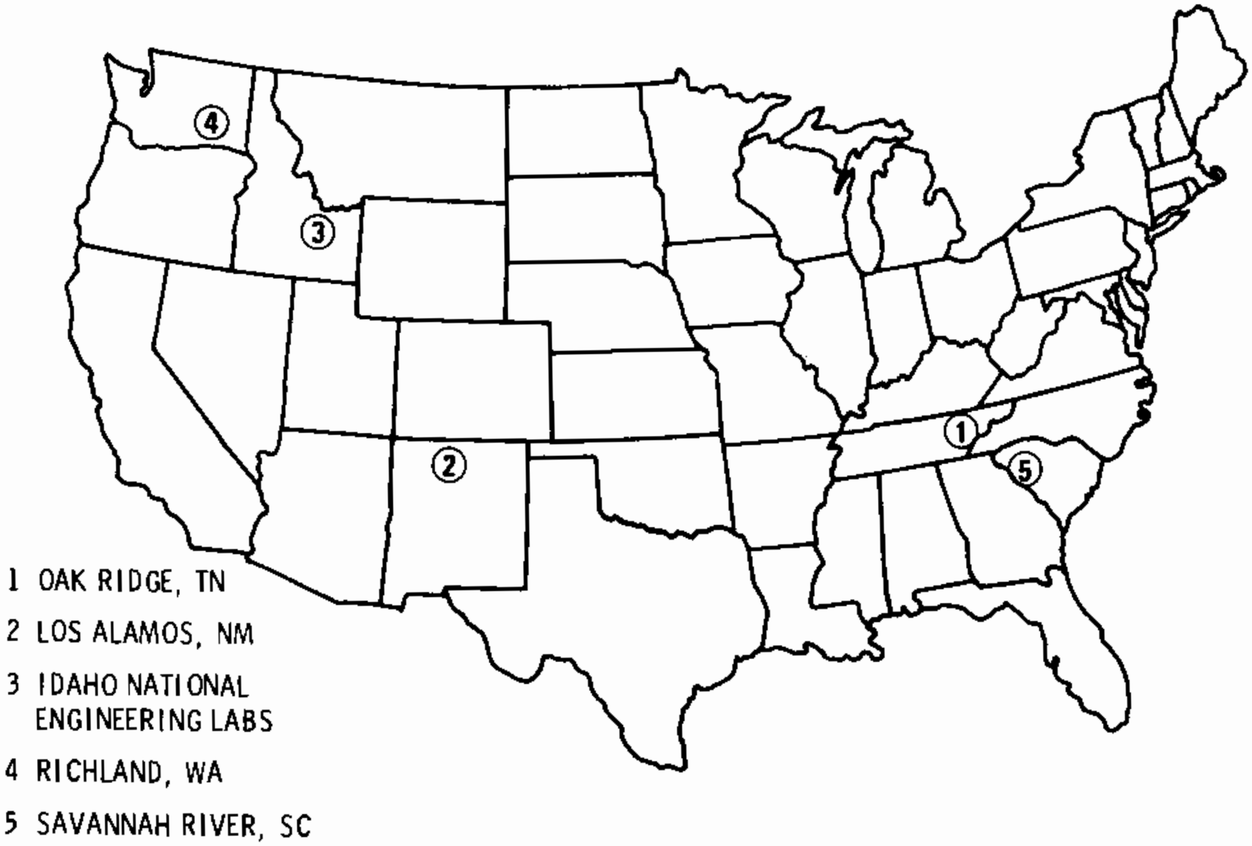

FIGURE 3.1-2. Major DOE Waste Burial Sites

3.1.2.2 Operating Experience at DOE Burial Grounds

DOE sites handle and dispose of all radioactive wastes generated onsite. These wastes are generally similar to those delivered to commercial burial sites. However, the relative proportions and degree of contamination of some DOE-generated wastes differ significantly from commercial wastes and may also include considerable quantities of very large and bulky obsolete or failed equipment and building debris. In general, attempts at effecting significant size reduction are neither specifically required nor attempted because of the close proximity of the onsite burial ground.

As at commercial sites, solid wastes buried at DOE sites are packaged for containment of the radioactivity during handling, transport, and any temporary storage prior to burial. Only wastes received from offsite sources

TABLE 3.1-4. DOE Burial Site Characteristics[a]

	Savannah River	Oak Ridge	Los Alamos	Idaho	Hanford
Mean Annual Precipitation (mm)	1100	1300	400	200	200
Surface Material Type	Sand and Claysand	Weathered Shale and Fill	Weathered Tuff	Alluvial Sand and Gravel	Clay, Sand and Gravel
Thickness (m)	0-10	0-10	0-2	1-10	Over 150
Interstitial Permeability to Water	Very Low	Very Low	Moderate	Moderate	Variable
Bedrock Material Type	Clay, Sand and Sandstone	Shale	Volcanic Tuff	Basalt	Volcanics
Structure	Flat-lying	Folded	Flat-lying	Flat-lying	Flat-lying
Groundwater Depth to Shallowest Saturated Zone (m)	10-20	0-5	200-400	60-300	100
Depth of Continuous Groundwater Zone (m)	10-20	2-5	200-400	60-300	100
Depth to Regional Aquifer (m)	200	None Present	200-400	60-300	100
Surface Water Proximity	Onsite	Onsite	1 km	3 km	10 km
Flow Characteristics	Small, Perennial	Small, Perennial	Small, Ephemeral	Small, Ephemeral	Large, Perennial (Columbia River)
Adsorptive or Ion Exchange Capacity of Material Surrounding Burial	Moderate	High	High	Moderate	Moderate
Principal Flow Paths Away From Burial	Pore Spaces in Sand	Shale Fractures and Pores in Fill	Fractures and Pores in Sand	Pores in Sand	Pores in Sand
Radionuclide Migration Pathways	Onsite Ground Water	Offsite Ground Water Offsite Surface Water	Onsite Vadose Water Zone	Onsite Ground Water	Update by Deep-rooted Plants

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(a) Taken from Table 24.7, ERDA 76-43, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," May 1976.

must be packaged to meet specific Department of Transportation packaging criteria. Much of the laboratory waste that is generated onsite (i.e., paper, plastic, rubber, glass, small metal items, etc.) is packaged in plastic bags and cardboard boxes. Waste packaging at DOE sites is not intended to provide containment following burial, except for tritium, TRU waste, and some high activity beta-gamma wastes. The use of asphaltic compounds to either line or completely encase tritium waste packages is employed at several locations. Complete asphalt encasement of a smaller container within a larger container (e.g., a 115-ℓ drum inside of a 208-ℓ drum) has been quite successful for containing tritium in wastes.(1)

Highly active beta-gamma wastes at several DOE sites are packaged for burial inside concrete containers, such as sealed culverts or large boxes. This is done both for radiation protection during handling and for added containment of radionuclides following burial. At other sites, high-activity beta-gamma wastes are buried in vertical shafts that vary in size from 0.2 to 2.4 m in diameter and from 6 to 20 m in depth. The disposal shafts are usually capped with earth fill and/or concrete to a depth of about 1 to 2 m.

Final covering of pits and trenches is accomplished by filling to grade and, at several locations, mounding to more than a meter above grade. At some sites a vegetative cover is established over completed burial trenches to control surface erosion. A summary of general operating practices at DOE burial grounds is presented in Table 3.1-5.

3.2 EXPERIENCE RELATED TO DECOMMISSIONING

Corrective measures have been taken at commercial and DOE sites where environmental monitoring programs have indicated some migration of radioactivity from waste materials buried in the trenches. Corrective measures at Morehead, West Valley, and Oak Ridge have been largely site/waste stabilization activities.

At the Savannah River Laboratory and the Idaho National Engineering Laboratory, experimental waste exhumation programs have been conducted.

TABLE 3.1-5. Operating Practices at DOE Burial Grounds[(a)]

	Savannah River	Oak Ridge	Los Alamos	Idaho	Hanford
Burial Trench/Pit Size (m)	6 wide x 6 deep x variable length	3 wide x 15 long x 3-4.5 deep	8-30 wide x 120-180 long x 8 deep	Trench: 2-3 wide x 275 long x 4 deep	1.5-5 wide (bottom width) x 4-8 deep x variable length
Provisions for Water Collection and Containment	None; Trenches have Monitoring Wells	Trenches Sloped to One End; 15 cm Metal Casing as Monitoring Well	None	None	None
Waste Disposal Procedures	Random Placement in Trenches	Trench Filled to 1 m of Surface	Pits Filled in Layered Fashion; Final Waste Layer 1 m Below Surface	Pits/Trenches Filled to 1 m of Surface	Trench Filled From One End
Waste Covering Frequency	Covered After Disposal for Fire, Contamination, Radiation Control	When Trench is Filled	Combustibles Covered Day of Delivery; Others as Required for Contamination Control and Layering	As Trench/Pit is Filled	Daily after Deliveries
Type of Final Cover	Excavated Fill to Ground Surface; Mounded as Necessary	Excavated Material to Ground Surface; Few Experimentally Sealed; -0.5 m Below Surface; Reseeded	Excavated Tuff Fill with Compaction by Heavy Earth-moving Equipment	Excavated Soil Fill; Reseeded	Excavated Fill to Surface; Mounding as Necessary
Depth of Final Cover	Minimum 1.2 m Cover, or that Needed to Reduce Dose to <6 mR/hr at Surface	Minimum 1 m to Ground Surface	Minimum 1.5 m Total Excavated Tuff Cover with Mounding to 0.5-1 m Above Grade	Minimum 1 m to Ground Surface	Minimum 2.5 m Total, or that Needed to Reduce Dose to <1 mR/hr at Surface
Other		Minimum 1.5 m Between Trenches	Minimum 4.5 m Between Pits at Surface; Minimum 15 cm Crushed, Compacted Tuff in Pit Bottom Prior to Waste Fill	Minimum 0.6 m Soil in Pit/Trench Bottom to Underlie Wastes	

(a) Taken from Table 24.5, ERDA 76-43, "Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle," May 1976.

3.2.1 Site/Waste Stabilization

Trenches at Morehead, West Valley, and Oak Ridge are excavated in soil material of low permeability. The buried waste has a high porosity (low bulk density), and the trench cover, which consists largely of soil material excavated from the trenches, is more permeable than the original parent formation. The three sites are located in regions of relatively high rainfall. These combined factors have resulted in the accumulation of water in some completed trenches, because rain water that infiltrates the permeable material over the trenches is impounded in the trenches by the less permeable surrounding material. Impounded trench water can escape from a trench either by subsurface migration, due to the hydrostatic head of the perched water, or by overflow seepage from the trench cap.(2) At Oak Ridge, the trench water problem is compounded by a shallow groundwater system and poor surface drainage.

Subsurface movement of radionuclides leached by impounded water, along fissured or more permeable zones, is documented at Oak Ridge and is believed to have occurred at Morehead.(3,4) The same type of movement may have occurred at West Valley, although studies have not yet shown this.(5) At the New York site, some trenches eventually filled with water and overflowed.

Actions being taken at these sites to control and prevent releases include surface water control, surface sealing of burial trenches, and pumping of water from the trenches. Groundwater diversion dams have been constructed at Oak Ridge. At all sites, extensive geologic and hydrologic studies are being conducted to provide additional information on the nature and extent of the problem.

More detailed discussions of the radionuclide migration problems and of remedial measures taken at the three sites are given in the sections that follow.

3.2.1.1 Morehead, Kentucky

The commercial burial ground near Morehead, Kentucky, is licensed and regulated by the State of Kentucky. Burial operations began in 1963. In the late 1960s and early 1970s, measurements indicated that rain water was infiltrating the trenches and accumulating in completed trenches.

Kentucky required the site operator to initiate a program to control onsite water and to remove the water that was accumulating in the trenches. To meet this requirement, water is pumped from the burial trenches and stored in large above-ground holding tanks. The water is evaporated to reduce the volume, and the residue from the evaporator is held in a large storage tank. When approval is obtained from the Kentucky Department for Human Resources (KDHR), this residue will be solidified and buried onsite. The trenches are routinely examined for water accumulation and are pumped as often as additional water is observed.(6)

In 1972, monitoring data from Kentucky's environmental surveillance program indicated that the site might be contributing radioactivity to the local environment. In November 1973, the state instituted a special six-month environmental monitoring study to identify the source and scope of the increased levels of environmental radioactivity in the site environs. The study report(7) concluded that the burial ground was contributing radioactivity to the local environment; that the activity detected did not create a public health hazard; and that further studies were necessary to determine to what extent migration was occurring and to assess the long-range public health and safety significance of the findings. Isotopes identified in monitoring samples included tritium, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu and ^{239}Pu. Levels of radioactivity ranged from slightly above background to orders of magnitude above background for certain individual samples.

The report identified four possible mechanisms for the release of radioactivity from the site:

1. surface water runoff
2. lateral movement from trenches through the soil zone
3. movement from the trenches through fractures in surrounding rocks
4. atmospheric fallout from the onsite evaporator.

The study did not, however, attempt to quantify the relative significance of the suggested release mechanisms.

The site operator has conducted a program to reduce the movement of radioactivity from the burial site. Since it was assumed that trench water resulted from infiltration of precipitation rather than from ground water, the permeability of the trench caps was reduced by providing additional soil cover, with further compacting and reshaping of the caps to facilitate runoff.(8) The surface of the burial site has been regraded and contoured to improve area drainage; all onsite, nonengineered ponds have been eliminated; and a vegetation cover has been planted to retard surface erosion. Pumping of water that accumulates in completed trenches has continued. These efforts, plus the removal of several areas of surface contamination, have apparently been effective in reducing the release of radioactivity from the site, since radioactivity levels detectable offsite are decreasing.(9)

The Morehead site was closed in December 1977,(10) by order of the Kentucky Department of Human Resources, until agreement is reached on the administration of the site water-management program and on other provisions for the long-term care of the site. For the next two years, the state will maintain the site while further studies are conducted. The site currently remains closed.

3.2.1.2 West Valley, New York

The West Valley site was opened in 1963. During the early 1970s, environmental monitoring samples indicated that some radioactivity was migrating from the site. In 1973, the site operator and the State of New York initiated a joint study program(11) to further characterize the site and define the extent of the apparent radionuclide migration away from the site. The study results indicated that a small level of tritium migration was occurring; however, movement of other radionuclides was not detected. The report concluded that the slight releases of tritium from the trenches of the old north burial area would not produce a statistically significant health effect.(12)

In March 1975, seepage of water from trenches in the old north burial area (Figure 3.2-1) was observed, and the site operator began pumping water

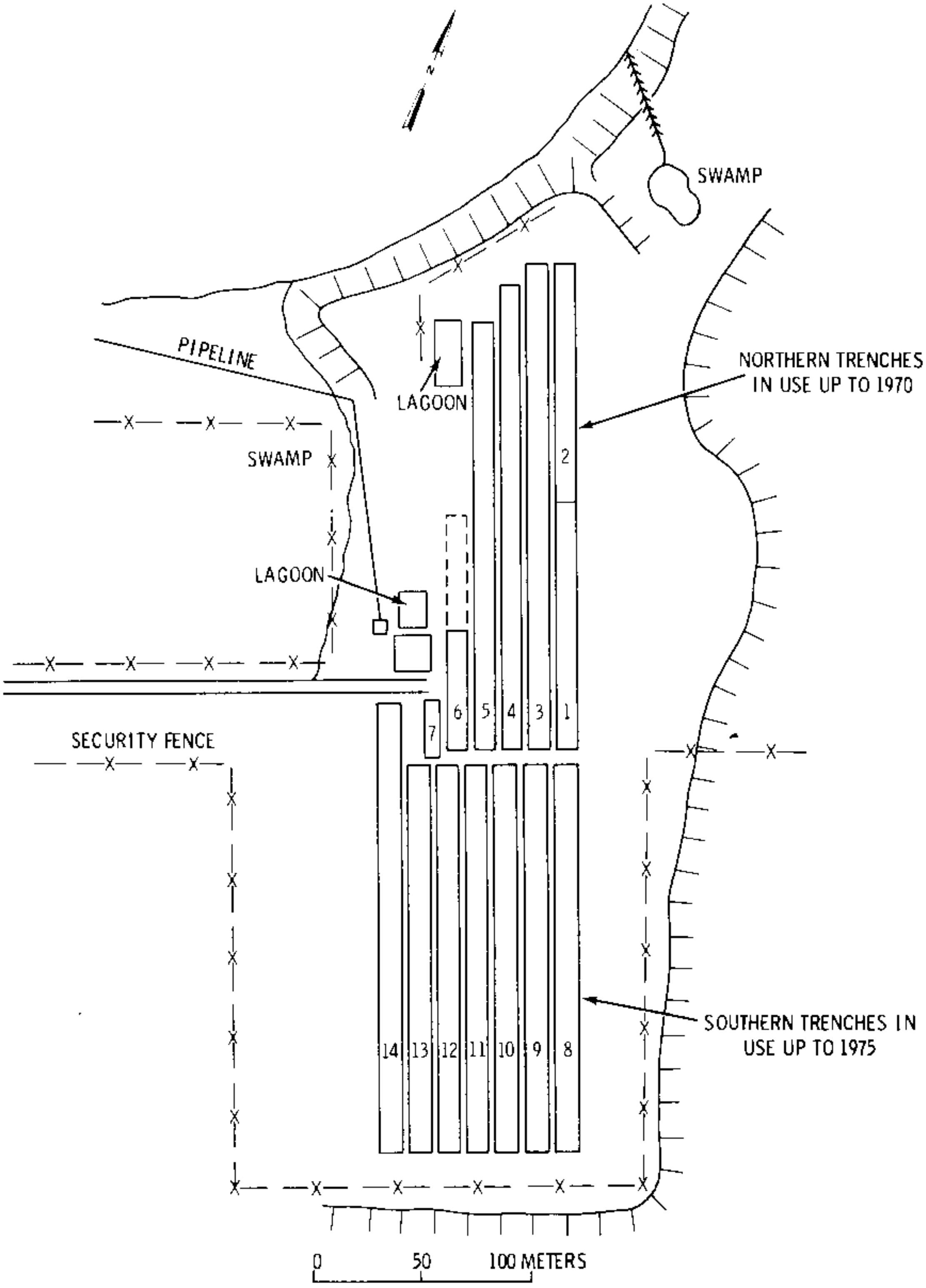


FIGURE 3.2-1. Burial Grounds at West Valley, New York - Plan View

from the trenches to a holding lagoon to reduce the potential for radionuclide migration from buried waste materials. Although trench water seepage was quite evident during this period, no significant increase in radioactivity in local streams that drain the site was detected.

Continued pumping of water from the north area trenches and subsequent processing of the trench water in a low-level waste treatment system onsite have apparently reduced the level of offsite releases. No releases have been observed from the new south burial area where improved capping and cap compaction techniques are used to retard water infiltration into the trenches. Studies by the USGS, EPA, New York State, and the U.S. Nuclear Regulatory Commission have continued at the site to characterize the migration mechanism from the trenches in the north area and to define further remedial measures. It is currently believed that migration of radioactivity through the soil layer is slight and that rainwater infiltration through the trench cover, settlement of the trench cover material, and decomposition and collapse of waste packages are the most probable causes of the water accumulation in the north burial area.

During the summer of 1978, the cover of the north area trenches was improved by the site operator, with the approval of the State of New York. The original trench covers were removed and replaced with several layers of silty till, which were compacted by a 50-ton roller. A layer of topsoil was added to the compacted till and planted with a state-approved native grass. An impervious plastic sheet was provided to cover the steeper slopes of the trench cover; a layer of crushed stone was then applied to the plastic sheet to anchor and protect it from sunlight. The trenches were individually mounded and drainage ditches were provided between the trenches to facilitate drainage of standing water from the burial area.

The effectiveness of these remedial measures at West Valley is currently under evaluation by the New York State Geological Service (NYSGS),(13) which daily monitors surface erosion and trench water levels in the burial area. The NYSGS will continue to study the area to verify that these remedial actions together with any proposed solutions to the water infiltration problem are geologically sound and do not lead to increased erosion.

The site operator voluntarily suspended operation of the site in 1975 during the onset of trench seepage. The site currently remains closed.

3.2.1.3 Oak Ridge, Tennessee

Environmental monitoring programs at ORNL have detected the movement of ^{3}H, ^{137}Cs, ^{90}Sr, ^{238}Pu, ^{244}Cm and some other radionuclides from burial grounds 4 and 5.(3) A study of radionuclide migration for the years 1963 through 1975 indicated a strong relationship between the total radionuclide release and the amount of precipitation. The study also suggested that surface water control measures could reduce the release rate by providing barriers to infiltrating precipitation, thereby reducing the amount of water passing through the buried waste materials.

Data from Oak Ridge indicate that additional problems resulted from the presence of organic chelating agents in the buried wastes. (Such agents are common in decontaminating solutions and can be expected as a component of wastes delivered to commercial sites as well.) Upon contact with water, these agents become mobile and readily carry otherwise immobile radionuclides. The effectiveness of soil adsorptive and ion exchange properties is also lessened for complexed radionuclides, Thus, the natural containment capabilities of the site are reduced.

In July 1974, corrective measures were proposed to reduce or eliminate the downward movement of water into the burial ground trenches. For burial ground 4, a surface water diversion system was installed to collect surface runoff from the upper portion of the basin and transmit it across the burial ground (Figure 3.2-2). Prior to the installation of this system, surface runoff originating from an upper basin flowed onto the burial ground and infiltrated into the buried waste. At burial ground 5, where surface seepage had been observed during the wet winter months, construction efforts were initiated in May 1975 to install surface sealing measures and groundwater diversion dams at specific locations in the trenches. The surface sealing technique included the use of 10-mil thick polyvinyl chloride (PVC) sheeting, with a 0.6 m topsoil covering with surface vegetation. The trench dams were

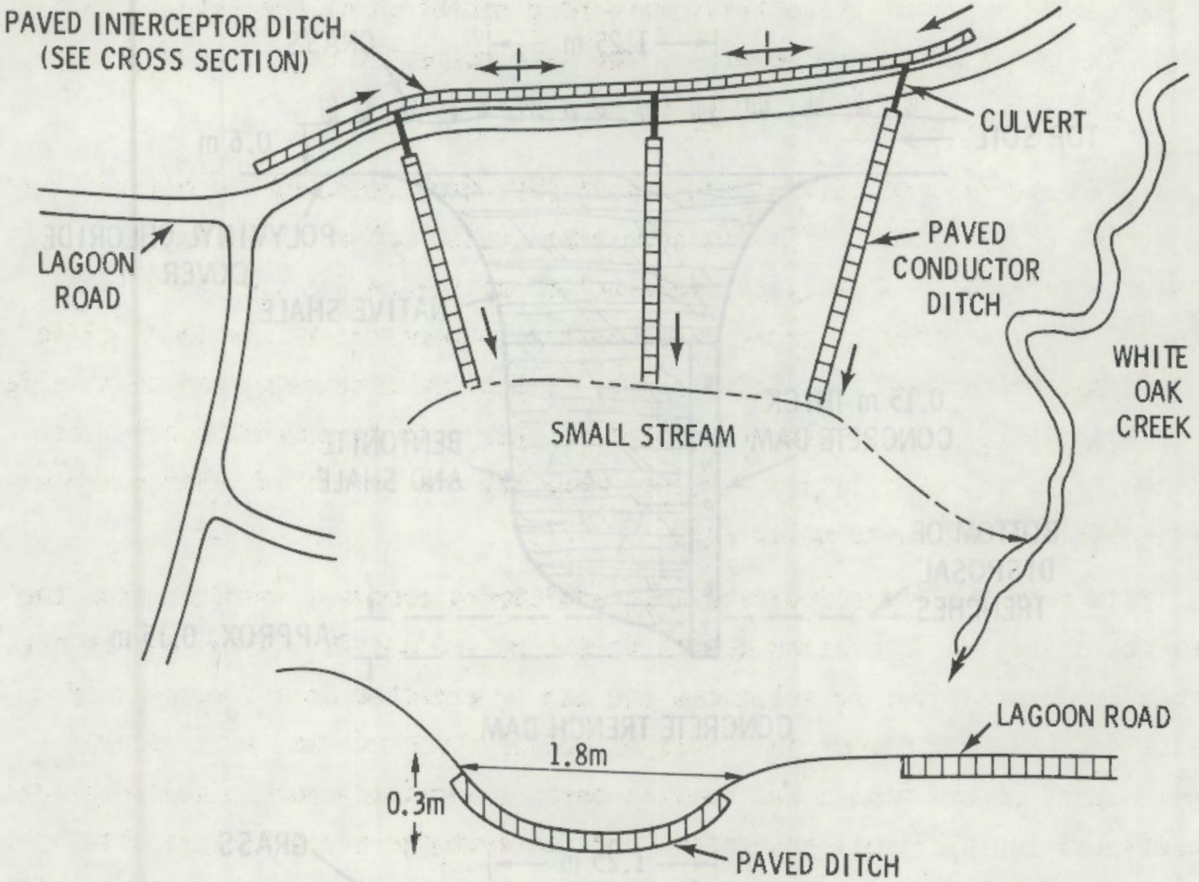
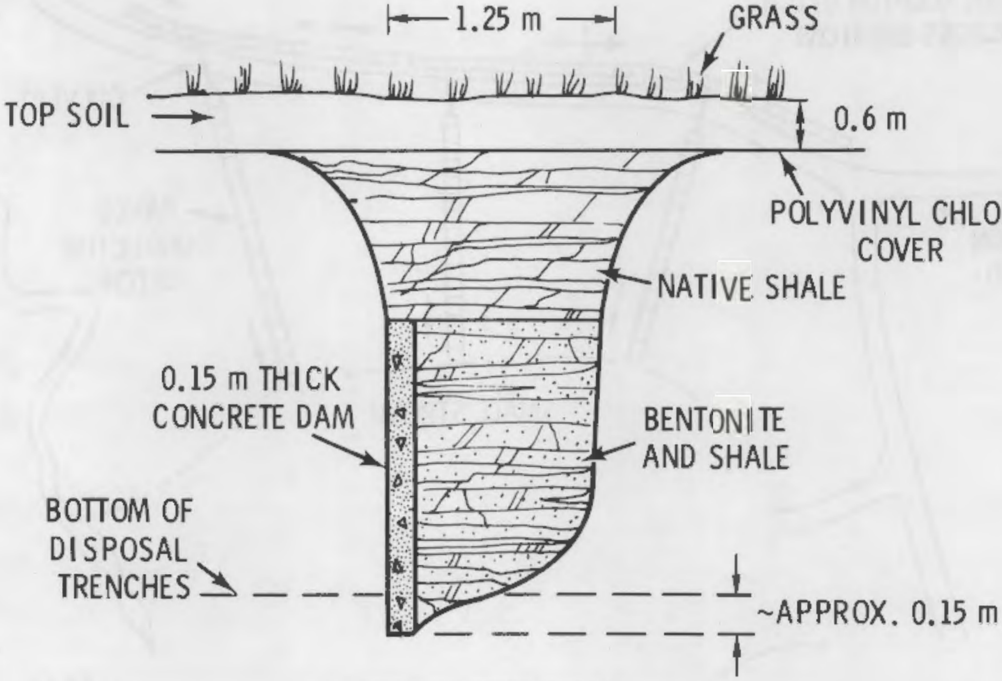


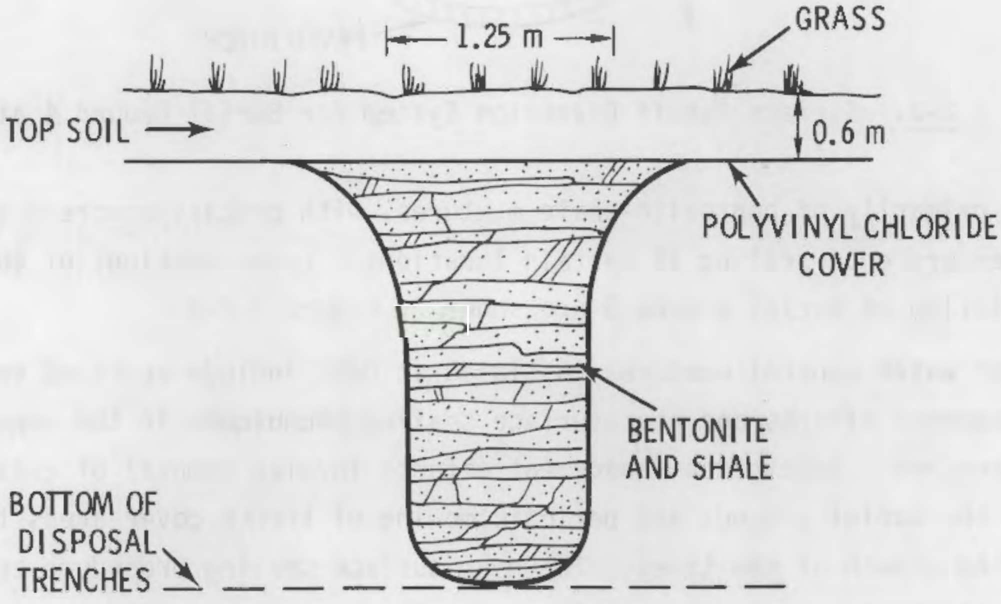
FIGURE 3.2-2. Surface Runoff Diversion System for Burial Ground 4 at ORNL

composed primarily of bentonite-shale mixtures, with precast concrete slabs used to ensure good sealing at certain locations. Cross sections of the trench dams installed at burial ground 5 are shown in Figure 3.2-3.

Other water control measures initiated at ORNL include upgraded vegetation management efforts and near-surface sealing techniques in the newer burial trenches. Vegetation management efforts involve removal of existing trees on the burial grounds and periodic mowing of trench cover areas to control the growth of new trees. The near-surface sealing procedure consists of application of a 7- to 10-cm-thick bentonite-shale layer (15% bentonite) at a depth of 0.6 m below the finished grade elevation. The bentonite is applied to the ground surface and disced into the top 7 cm of the surface. After addition of an appropriate amount of water, the surface is compacted with conventional rolling equipment. The sealed area is then backfilled with topsoil, graded to desired contours, and seeded with grass.



CONCRETE TRENCH DAM



BENTONITE SHALE TRENCH DAM

FIGURE 3.2-3. Cross Sections of the Concrete and Bentonite-Shale Dams Across Trenches in ORNL Burial Ground 5

The effectiveness of corrective measures at ORNL is currently under detailed evaluation. Although final evaluation of the corrective measures is not complete, it has been observed that radionuclide releases from burial ground 4 are continuing to decrease. In addition, no surface seepage was detected at burial ground 5 during the winter months after completion of the surface sealing and trench dam installations.

3.2.2 Waste Exhumation at DOE Sites

Programs have been conducted at DOE waste burial sites to assess the feasibility of exhuming, repackaging, and relocating buried radioactive material. The general objectives of these programs are to develop methods and procedures for the safe retrieval and relocation of buried low-level radioactive wastes and to define the associated costs and schedules for such operations. The following sections provide brief summaries of waste exhumation activities at the Savannah River Laboratory (SRL) and the Idaho National Engineering Laboratory (INEL).

3.2.2.1 Savannah River Laboratory

In 1972, a test excavation was made in a burial trench that had been filled in 1958.(14) The overburden was removed from a 7.5-m by 9-m section of trench. This was accomplished with a conventional mechanical shovel by removing thin layers (2- to 5-cm layers) of soil down to a depth of 2 m where the first pieces of buried waste were encountered. The waste material excavation was then continued with a hydraulic clamshell to a depth of about 6 m below the grade surface (0.6 to 1.0 m below the bottom of the original trench excavation).

The excavated waste materials were found to be randomly distributed in the soil and included wooden burial boxes, steel bars and pipes, electrical wires, ropes, tarpaulins, a variety of plastic and cotton protective clothing articles, rubber shoe covers, cardboard boxes, and miscellaneous paper materials. The waste articles were in exceptionally well-preserved condition. Exhumed waste was damp but not saturated. After examination, exhumed waste materials were placed in plywood burial containers and replaced in the trench excavation. The soil overburden was then restored over the plywood containers.

The test excavation at SRL was completed in about three weeks and involved 10 workers. Radioactivity levels encountered at the excavation were essentially at normal area background. Because of the low radiation level and dampness of the soil and waste materials, no containment structures were required to limit the spread of contamination. All work was performed under standard radiation protection procedures: protective clothing consisted of coveralls, shoe covers, and gloves. Respiratory protective equipment was not needed.

The published report of the waste exhumation does not include cost data.

3.2.2.2 Idaho National Engineering Laboratory

Waste retrieval programs were initiated at INEL in 1974 to develop methods and technology and to define cost requirements for the exhumation, repackaging and onsite relocation of buried transuranic waste materials. Two programs, the Initial Drum Retrieval (IDR) project(15) and the Early Waste Retrieval (EWR) project(16,17) have demonstrated the feasibility of waste exhumation operations and have advanced the state of related technology for the associated tasks.

The Initial Drum Retrieval (IDR) program objective was to demonstrate the retrieval, repackaging, and interim storage of drums containing transuranic contaminated (TRU) wastes that were buried during the period of 1968 to 1970. Burial site excavations were performed in a portable Air Support Weather Shield (ASWS), an air-supported, reinforced fabric structure, measuring 36.0 m by 52.4 m and 12.2 m in height. Most of the trench overburden was removed with modified industrial implements including a front-end loader and back hoe; final excavation was performed by hand by workmen entering the excavation area. The 208-ℓ waste drums, buried 5 to 6 years, were found stacked in an orderly fashion in the trench and exhibited surface rust but were largely intact. Less than 2% of the drums were breached or were without lids. The retrieved drums, some containing liquids, were placed in triple-layered plastic bags and then into larger over-pack drums containing a dessicant or absorbent material. Some of the drums that had been breached or exhibited surface contamination were placed in fiberglass boxes or metal bins after overpacking was completed. The repackaged material was then transferred to interim onsite storage locations.

The excavation and repackaging tasks of the IDR program were performed by workmen within the ASWS containment. The workmen wore coveralls, gloves, and shoe covers and carried respirators, although the respirators were not worn during routine operations.

From the period of September 1974 through September 1976, a total of 4539 drums were retrieved, packaged, and relocated under the IDR program.(15) Program costs from July 1974 through September 1976, exclusive of the procurement and installation of the ASWS containment structure, have reportedly totaled about $983,000. Detailed breakdowns of the IDR program costs through September 1976 may be found in the reference document.(15)

A second waste retrieval program at INEL, the Early Waste Retrieval (EWR) project(16,17) was initiated in FY 1976 to investigate the problems associated with retrieval and repackaging of drummed and boxed TRU waste material that was buried between 1960 and 1963. Retrieval of the waste began during May 1976.

The EWR burial ground excavations were conducted within a double containment structure consisting of an ASWS similar to the one used in the IOR program and a smaller portable metal-panel building called the Operating Area Confinement (OAC) building, located directly over the excavation area and within the ASWS. The OAC building, a 12.2 m by 18.3 m by 6.1 m structure, equipped with a controlled ventilation system with high-efficiency filtration, was moved from place to place within the ASWS as excavation operations proceeded.

The major portion of the trench overburden was removed with conventional earth-moving equipment within the ASWS. After most of the overburden was removed, the OAC building was installed over the excavation and a backhoe was then used to remove the remaining trench overburden. Final soil removal around the waste containers was accomplished manually with shovels. The final excavation and repackaging operations were performed by workmen in protective apparel called "bubble suits"; the plastic bubble suits were provided with a fresh air supply and two-way radio communication.

The waste materials and drums were found to be randomly distributed in the trenches. Virtually all the waste drums were severely rusted and otherwise badly deteriorated. Several of the drums contained liquids. In some cases, the liquids leaked from the drums during excavation. In all cases, the spread of contamination was confined within the OAC building. The drums and waste materials were repackaged in multiple-layered plastic bags. The plastic bags were placed in overpacks consisting of multilayered cardboard boxes or asphalt-lined metal bins to which sorbent materials had been added. All contaminated soil found in the trenches was removed and similarly packaged. The repackaged waste was then relocated onsite at interim storage areas.

Program funding levels for the EWR program(16) were reported at $400,000 in FY 1976, $500,000 in FY 1977, and $600,000 in FY 1978. The waste retrieval programs at INEL provided significant advances in safe waste retrieval methods, equipment designs, and repackaging techniques for buried transuranic waste.

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4.0 DECOMMISSIONING ALTERNATIVES AND STUDY APPROACH

When waste burial operations at a low-level waste (LLW) burial ground are completed, the facility must be decommissioned (i.e., placed in such a condition that future risk to public safety from the facility is within acceptable bounds). The intent of decommissioning is to provide for eventual unrestricted release of the site. Site release might occur soon after decommissioning is completed, or it might be preceded by a period of limited institutional control lasting for many years.

This section outlines possible decommissioning alternatives that could satisfy public safety requirements and that are considered in detail in this study. These alternatives range from simple site closure accompanied by an ongoing program of environmental surveillance and administrative control of the site, to exhumation and relocation of the buried waste resulting in immediate unrestricted release of the site. The decommissioning alternative chosen for implementation in a particular situation will depend on a number of factors, including:

1) site parameters (geology, hydrology, climate, etc.)
2) the inventory of radioactive wastes buried at the site (including waste characteristics)
3) the operating history, including any evidence of migration of radionuclides
4) decisions about anticipated future use of the site or of the land or other resources in the immediate vicinity
5) financial resources available for decommissioning and/or long-term care.

Section 4.1 describes the alternatives for decommissioning an LLW burial site that are considered in this study. The technical approach used in the study is outlined in Section 4.2. Some important ground rules that provide the bases for the study are listed in Section 4.3.

4.1 DECOMMISSIONING ALTERNATIVES

This study of the decommissioning of an LLW burial ground is one in a series of studies that investigate the technology, safety and costs of decommissioning light-water power reactors and nuclear fuel-cycle facilities.(1) For these studies, three basic decommissioning modes have been established: dismantlement, entombment, and safe storage. Published reports(2,3) define these modes and describe their application to the decommissioning of a pressurized water reactor and a mixed-oxide fuel fabrication plant.

Shallow-land burial sites serve as repositories for the low-level radioactive wastes produced during the operation of other nuclear facilities. In addition, radioactive wastes from the decommissioning of other nuclear facilities are currently disposed of by shallow land burial. Burial is intended to provide a mechanism for insuring that future risk from these wastes is kept within acceptable limits. The wastes are normally buried with no intent or provision for ready retrievability at a later date. To the extent that an existing burial ground fails to perform its function of adequately containing the waste from man's environment, remedial measures must be taken. Preventive measures may also be taken during burial operations or when burial operations cease to insure the confinement of the waste for a specified time period and to reduce vulnerability of the waste to potential transport mechanisms.

For the LLW burial ground study, a decommissioning terminology is adopted that describes operations that might be employed to insure adequate confinement of the buried radioactive waste from man's environment. The basic decommissioning operations considered include site/waste stabilization, waste relocation, and long-term care. These operations are briefly defined in Table 4.1-1, and compared with the decommissioning modes used in the other studies. The rationale for these modes and more detailed descriptions are found in the sections that follow.

4.1.1 Definition of and Rationale for Site/Waste Stabilization

Site/waste stabilization is defined as those preventive or remedial measures taken to insure that the radioactivity in the buried wastes is retained within the confines of the burial ground. It involves the use of engineered

TABLE 4.1-1. Decommissioning Mode Characteristics

Mode	Definition	Facility Status	Use Category
Burial Grounds			
Waste Relocation (Dismantlement)	Buried waste is exhumed, repackaged as necessary, and reburied at another location.	Environmental surveillance not necessary except to verify that site can be released. Site maintenance not required. Administrative control of site not required.	Unrestricted public access and use of site.
Site/Waste Stabilization (Entombment)	Engineered procedures are employed to protect the waste from contact with potential transport mechanisms and/or to restrict waste migration to acceptable levels. Followed by a period of long-term care.	Environmental surveillance required. Inspection and maintenance of ground surface and of engineered stabilization features required. Administrative control of site required.	Public access limited and public activities restricted to surface or near-surface or use of land
Long-Term Care (Safe Storage)	Site is maintained in essentially the condition that exists at the termination of burial operations or at the conclusion of site/waste stabilization activities. This is a temporary condition until the waste has decayed to levels that permit unrestricted release of the site.	Environmental surveillance required. Inspection and maintenance required. Administrative control of site required.	Public access limited and public activities restricted. Site may be released for unrestricted use when long-term care period ends.
Other Nuclear Facilities			
Dismantlement	Removal from the facility/site of all materials with residual radioactivity levels greater than those permitted for unrestricted use of the property.	Environmental monitoring not required. Maintenance or surveillance not required. No administrative control of facility/site	Facility/site released for unrestricted public use.
Entombment	Comprehensive cleanup and decontamination is coupled with confinement of the remaining contaminated components within a monolithic structure designed to provide containment integrity for a time period sufficiently long to permit decay of the contained radioactivity to unrestricted release levels.	Infrequent environmental surveillance. Minimal maintenance requirements. Security provided by hardened barriers and fences.	Facility/site released for conditional use.
Safe Storage	Facility is maintained in a condition in which the risk to public safety is within acceptable bounds. Some cleanup and decontamination is coupled with construction of barriers to confine the radioactivity and restrict public access. A temporary condition for a specified time period.	Environmental monitoring required. Maintenance and surveillance required. Administrative control of site required.	Conditional use of facility/site may be permitted consistent with the level of decontamination and the extent and type of confinement barriers.

procedures to reduce the mobility of the buried waste and protect it from the effects of various potential transport mechanisms. The principal objectives of stabilization activities are: 1) to restrict the rate of release of radionuclides from the site to acceptable levels until the radioactivity in the waste has decayed to innocuous levels, 2) to render the site suitable for a variety of surface or near-surface public activities that would not disturb the waste, and 3) to reduce the requirements for long-term maintenance and surveillance.

Potential site/waste stabilization activities include:

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

Stabilization procedures would normally be included as part of burial ground operations. For sites where adequate site/waste stabilization has not been performed during the operating phase, these activities would be performed at the conclusion of burial operations prior to termination of the operating license. Site/waste stabilization implies that a portion or all of the waste is left in place, and permitted public activities are restricted to land uses that do not compromise stabilization procedures or waste confinement. Termination of the operating license is therefore followed by a period of long-term care of the site. Long-term care activities are summarized in the next section.

4.1.2 Definition of and Rationale for Long-Term Care

Current waste burial operations at commercial sites are based on a concept of long-term care following the completion of these operations. At each site, the operator makes payments into a state-controlled fund to provide monies for long-term care activities. Long-term care is required to maintain and verify the capability of a site to adequately confine the radioactivity in the buried waste. The activities are, in general, a continuation of maintenance and surveillance activities and procedures established during the site operating and stabilization periods.

These activities include:

- environmental monitoring and records maintenance
- inspection and repair of trench caps and fences
- drainage control to prevent the accumulation of surface water
- erosion control
- vegetation control
- removal and processing of trench water at sites where measurements indicate a need for trench water removal
- administrative control of the site to insure that public uses of the land are restricted to those activities appropriate to site conditions.

Long-term care activities continue until measurements and calculations indicate that the radioactivity in the burial trenches has decayed to levels permitting unrestricted release of the site or until additional actions are taken to reduce the potential consequences of unrestricted site usage.

4.1.3 Definition of and Rationale for Waste Relocation

Waste relocation involves the exhumation of buried waste, repackaging of the waste if necessary, and reburial of the waste at a repository, another burial ground or LLW 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. Furthermore, waste exhumed at one site requires reburial someplace else. Therefore, waste relocation would likely be considered only in situations where other decommissioning procedures are not adequate to insure that future risk from the facility is within acceptable bounds.

Two conditions might exist that would make exhumation and relocation of the buried waste appropriate:

1) The burial ground does not provide the required confinement of the waste from man's environment, and site/waste stabilization activities do not provide acceptable remedial alternatives; or
2) A use of the site is contemplated that makes it necessary to relocate the waste.

The inability of a burial ground to provide the required confinement of the waste from man's environment may be related to:

- the isotopic characteristics of the waste (e.g., transuranic waste concentrations in excess of permissible levels)
- the physical or chemical form of the waste (e.g., complexing agents [organics] contained in the waste that increase the mobility of some radionuclides, thereby increasing their rate of discharge into ground or surface water)
- problems with the site (e.g., water or erosion problems that cannot be adequately corrected by site/waste stabilization procedures).

In some instances, exhumation may be necessary because site/waste stabilization procedures do not provide an appropriate solution to a waste migration problem. In other situations, initial stabilization costs coupled with long-term care and maintenance costs may approximate or exceed the cost of exhumation.

In some situations requiring waste exhumation (e.g., unacceptable levels of buried transuranic waste), it may be necessary to ship the waste to a site for deep geologic disposal. In other cases (e.g., localized water or surface erosion problems), it may be possible to relocate the waste in other trenches on the same burial site.

The presence of buried waste necessarily restricts the kinds of activities that can be carried out at or in the vicinity of an LLW burial site. Changing political, social, or economic conditions may make it desirable to have a site available for unrestricted public use before the buried waste has decayed to levels considered acceptable for release of the site. Waste relocation may be necessary in order to insure that unrestricted release of a site will not result in a potential dose rate to users of the property exceeding appropriate limits as may be defined by federal regulatory agencies.

4.1.4 Combinations of Decommissioning Modes

At a particular site, combinations of decommissioning activities may be necessary to place the site in a condition such that future risk from the burial ground is within acceptable bounds.

Combinations of decommissioning modes may be necessary when individual trenches are known to contain high concentrations of transuranic waste or waste mixed with organic complexing agents. In these instances, partial waste relocation (i.e., relocation of the waste from part or all of a particular trench or trenches) may be a requirement in conjunction with stabilization of the rest of the site.

Partial waste relocation may also be required if burial trenches have been located in an area with geologic or hydrologic characteristics that make stabilization a costly or technically unfeasible alternative. In this case, the waste that is exhumed might be reburied in other onsite trenches or it might be transported to another disposal site.

The characteristics of a site may be such that different stabilization techniques are required for trenches in different areas. For example, at the DOE site at Oak Ridge, Tennessee, a series of interceptor ditches was constructed to control surface runoff in the vicinity of one series of trenches and a concrete/bentonite trench dam was used to divert ground water around another series of trenches (see Section 3.2).

The application of decommissioning techniques must be based on a careful analysis of the site to establish and document the characteristics of the buried wastes, the operating history of the site, and geologic, hydrologic and climatologic features that may influence rates of radionuclide migration from the burial trenches. The basic approach to decommissioning outlined in this study is intended to provide guidance for individual site application. However, because each site has different characteristics, the application of decommissioning techniques and procedures used in this study to actual sites may not be straightforward. Decommissioning of LLW burial sites must be considered on an individual basis.

4.2 TECHNICAL APPROACH

This section describes the technical approach used in conducting this decommissioning study. The technical approach is shown in simplified form in Figure 4.2-1.

The first step in conducting the study is to select the reference LLW burial facilities and to characterize them in sufficient depth to perform an engineering and safety analysis of their decommissioning. Two reference sites are chosen: an arid western site and a humid eastern site. The approach taken is to treat the burial ground and the surrounding environment as separate systems. The burial ground, with its inventory of buried radioactive waste, is described generically. This generic burial ground is then assumed to be located on two sites, for which the climate, geology, and hydrology are chosen to be representative of actual western and eastern LLW burial grounds.

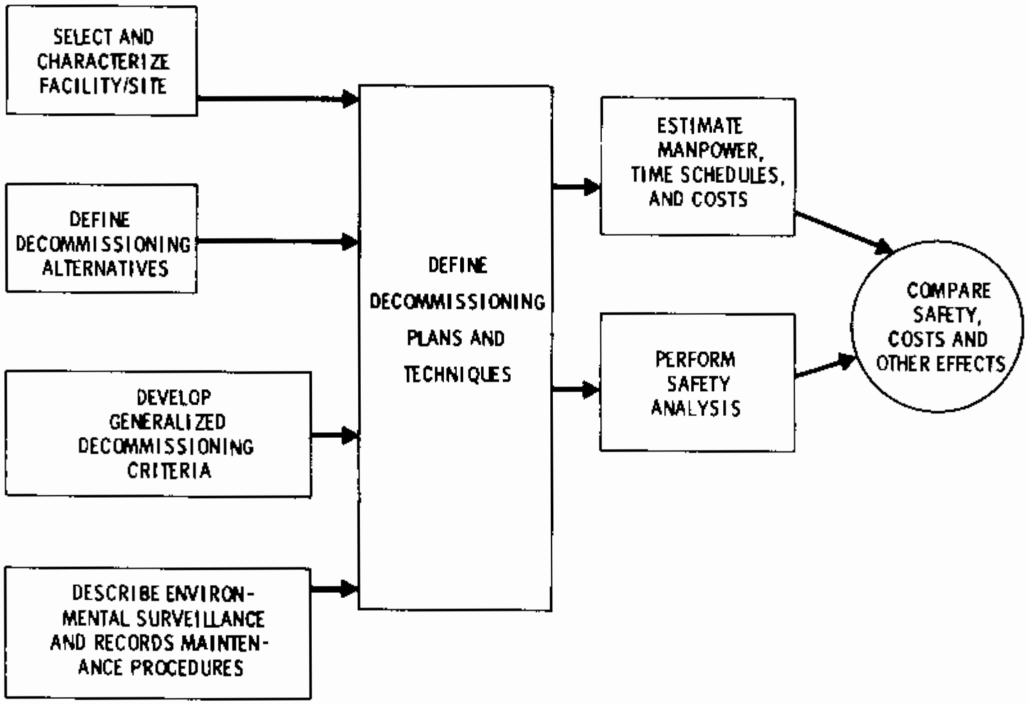

FIGURE 4.2-1. Technical Approach for Decommissioning Study

Detailed descriptions of the facilities are completed, including such information as the waste capacity of the sites, the inventory of buried radioactive waste, burial ground operating procedures, and the relevant geologic, hydrologic, and meteorologic data for the sites.

Several decommissioning modes (i.e., waste relocation and various site/waste stabilization options) are selected for evaluation. The decommissioning modes are related to site use limitations for a decommissioned facility (i.e., unrestricted use and conditional use involving surface or near-surface use of the land). Relevant regulatory guidance is reviewed, summarized, and used as an aid and basis in the study.

A methodology is developed for the analysis of release conditions for a decommissioned LLW burial ground. For a burial site where a subsurface radioactive inventory remains, release conditions may include site and/or waste stabilization requirements, land use restrictions, and requirements for institutional control. The methodology for determining conditions for the release of a decommissioned site is based on a calculation of radiation doses to the maximum-exposed member of the public from the important potential pathways through which radionuclides buried at the site may reach man.

Regulatory requirements and current practice for environmental surveillance and records maintenance at commercial LLW burial grounds are reviewed. Guidance for development of environmental surveillance programs at LLW burial grounds, based on critical pathway analysis, is outlined. Special requirements and procedures for environmental surveillance and records maintenance during decommissioning and long-term care are described.

Techniques for site/waste stabilization and for waste relocation are reviewed. The application of site/waste stabilization procedures to the control of specific potential transport mechanisms is defined, and the effectiveness and costs of the different stabilization procedures are evaluated. Work and time schedules are developed to conceptually decommission the reference sites by both site/waste stabilization and waste relocation. Techniques utilized are selected on the basis of engineering judgment to maintain a balance between safety and cost.

Direct costs of decommissioning are estimated, including labor, materials, equipment, surveillance, and, where applicable, packaging, transportation, and disposal of wastes. Costs are projected into the future to provide a reference base for estimating future financial requirements. Alternatives for financing decommissioning are examined and compared using example costs from this study. Cost ranges are defined to estimate the sensitivity of the total cost to variations in selected key cost elements.

Safety analyses are performed for each of the decommissioning modes studied. These analyses include radiological and nonradiological hazards to the public and to workers from normal decommissioning operations and from postulated accidents. The safety analyses utilize established data and methodology to estimate the various factors required, such as release mechanisms, dispersion pathways, and exposure modes of the released materials.

4.3 KEY STUDY BASES

From the outset, a number of important ground rules are established to guide the emphasis of this study. These bases are derived from the primary objective of the study -- to provide an analysis of the technology, safety, costs, and other factors involved in decommissioning an LLW burial ground. The study is intended to provide background information useful to regulators, designers, and operators of LLW burial facilities. From these objectives, the key bases are established for all aspects of the study to insure that the overall study objectives (see Section 1) are achieved. These key bases have a major impact on the estimates of safety, cost, and time for decommissioning. Many aspects of decommissioning are dependent on site location, radionuclide inventory, burial ground operating practices, and specific facility shutdown conditions. The bases and assumptions used in this study must therefore be carefully examined before the results can be applied to any other burial ground.

The key bases are:

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

2) The study is to evaluate, to the extent possible, real and contemporary LLW burial facilities. This basis is an obvious necessity to meet the study objectives and the primary basis above. Two sites are evaluated: an arid western site and a humid eastern site. Site parameters for the western site are chosen to be representative of the Richland, Washington, burial ground, and site parameters for the eastern site are chosen to be representative of the Sheffield, Illinois, burial ground. The same waste inventory is assumed at both sites. The inventory is generic, but quantities and isotopic concentrations are believed to be typical of radioactive wastes currently being buried. The design of burial trenches and the procedures for filling and capping the trenches are chosen to be different at the eastern and western sites and are based on current practice.

3) Decommissioning modes analyzed in the study include several techniques for site/waste stabilization and for waste relocation.

4) Current technology and techniques are used in descriptions of decommissioning procedures. Where developmental techniques are applied in the study, they are in an advanced state of development and believed to be ready for application.

5) Decommissioning methods and procedures are selected on the basis of providing good public and occupational safety in a cost-effective manner.

6) Decommissioning and radiation protection philosophies and techniques applied in the study conform to the principle of keeping public and occupational radiation doses as low as is reasonably achievable (ALARA).

7) Decommissioning is assumed to be relatively trouble-free, and decommissioning options are evaluated assuming efficient performance of the work. A 25% contingency is added to cost totals to account for such things as work delays and unanticipated equipment costs.

8) Operating procedures are assumed to have been such that the ground surface is free of significant radioactive contamination at the time that decommissioning operations begin. No wastes are left unburied when burial operations cease, and all burial trenches are capped.

9) The study is limited to the decommissioning of a radioactive waste burial site and any site facilities that are contaminated as a result of radioactive waste burial operations. Nonradioactive facilities at a site are not decommissioned.

10) The chemical or pyrophoric hazards of wastes buried at LLW burial grounds are not specifically considered in this report. Wastes buried at some commercial sites may include non-radioactive toxic material that is more hazardous than some of the radioactive waste. However, no serious problems have occurred to date with regard to chemical or pyrophoric materials buried at commercial LLW sites.

11) Site decommissioning is the responsibility of the burial ground operator. Following site decommissioning, institutional control of the site is maintained for a period of time until the site is released for unrestricted use. The period of time for which it is possible to maintain institutional control cannot be specified with certainty because of the many factors involved. For purposes of calculating allowable limits of radioactivity and of estimating long-term care costs, it is assumed that institutional control is maintained for about 200 years after final closure of a site.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, and the National Technical Information Service, Springfield, Virginia 22161.

5.0 REGULATORY CONSIDERATIONS FOR DECOMMISSIONING

This section contains a brief review of the current regulatory status of low-level waste (LLW) burial grounds and presents some regulatory considerations related to decommissioning these facilities.

The authority to regulate commercial nuclear facilities and materials is reserved to the federal government by the Atomic Energy Act of 1954 and its subsequent amendments. Regulatory authority is delegated to the Nuclear Regulatory Commission (NRC), and the NRC has in turn promulgated regulations in Title 10 of the Code of Federal Regulations to carry out the provisions of the Act. The NRC has also published Regulatory Guides to assist licensees in meeting the requirements of the regulations.

Decommissioning activities have not been a principal focus of government regulatory activity. Consequently, although many governmental requirements apply to decommissioning of nuclear facilities, they do so only indirectly. There are currently no formal criteria for decommissioning of LLW burial grounds. The NRC is presently considering development of a more explicit policy for nuclear facility decommissioning(1) and amending its regulations in the Code of Federal Regulations to include specific guidance on decommissioning criteria for a variety of nuclear facilities, including LLW burial grounds.

Section 5.1 contains a brief review of the regulatory status of LLW burial grounds. Section 5.2 contains a discussion of regulations, guides, and standards in the general areas of radiation exposure limits, transportation of nuclear materials, and financial requirements for decommissioning. These provide a basis for formal decommissioning criteria. Section 5.3 describes the NRC program for development of regulations relating to decommissioning LLW burial grounds.

5.1 REGULATORY STATUS OF LLW BURIAL GROUNDS

Federal guidance indicates that commercial LLW disposal sites should be on land owned by either the federal government or a state government.(2,3) At five of the six commercial sites, the states own the land and lease it to the burial ground operators. At the Richland site, the federal government leases the land to the state of Washington, and the state then leases it to the burial ground operator.

Five of the six commercial sites are located in agreement states[a] and are licensed by the respective states. The exception is the Nuclear Engineering Company site near Sheffield, Illinois, that is licensed by the NRC because Illinois is not an agreement state. At Barnwell, South Carolina, and Richland, Washington, the NRC regulates the handling of special nuclear material (SNM), since large quantities are authorized to be handled at these facilities. The states regulate the handling of byproduct and source material at these sites.

When burial operations at a commercial site are completed and the license is terminated, a government agency assumes responsibility for long-term care of the site. All of the states require the site operator to contribute to a fund to cover the cost of long-term care. The fund is based on a charge per unit volume of waste buried and varies from site to site. In general, it is believed that long-term care funds provide sufficient money for routine maintenance and surveillance of a retired site, but are not adequate for extensive corrective actions should the need arise.(4)

Although agreement states can presumably adopt regulations applicable to decommissioning of LLW burial grounds, none appear to have done so. Nor is decommissioning explicitly treated in current license agreements.(5) License agreements do specify certain required operational practices, such as trench depth, size, and location; backfill depth; surface runoff control; and radiation monitoring procedures. In addition, some operating licenses contain provisions that specify the general condition of a site prior to burial ground closure, or that direct the licensee, prior to termination of the license, to submit plans to the appropriate state regulatory agency describing steps to be taken to properly close and restore the site.

(a)An agreement state is one that has entered into an agreement with the NRC that transfers to the state regulatory responsibility for source material, byproduct material, and quantities of special nuclear material insufficient to form a critical mass.

The Decommissioning Procedures Plan that is one condition of the burial license and lease agreement between Chem-Nuclear Systems, Inc., and the State of South Carolina for operation of the Barnwell site(6) contains the following provisions specifying the condition in which the licensee must leave the site at the conclusion of burial operations:

- The entire burial ground must be enclosed in a chain-link fence and properly posted.
- Surface contamination on the site must not exceed a specified level.
- Trenches must be covered with sufficient soil so that radiation levels at any site location do not exceed a specified level.
- Trench areas must be properly landscaped, including mounding, seeding, and sloping to ensure proper surface water runoff.

In addition, the license for the Barnwell site precludes exhumation of previously buried waste.

The Task Force on Radioactive Waste Management, in its report to the 1974 Conference of Radiation Control Program Directors,(7) made the following recommendations relating to decommissioning requirements for new burial ground licenses:

- Information should be provided on the proposed funding of long-term care programs to be administered by the appropriate state agency.
- Plans for site decommissioning, including cost estimates, should be provided by the applicant prior to the licensing of a new site.

Many parallels exist between the technical and institutional considerations for decommissioning and long-term care of 1) LLW burial grounds and 2) uranium mill tailings piles. At both types of facilities, major areas of concern include minimizing the migration of radionuclides from the waste, stabilizing the ground surface, environmental monitoring, and the control of human activities at a decommissioned site. Legislation and information pertaining to post-operational activities at tailings piles are contained in the Uranium Mill Tailings Control Act of 1978(8) and the Generic Environmental Impact

Statement (GEIS) on Uranium Milling,(9) respectively. These documents may also be considered for guidance in establishing regulations for the decommissioning and long-term care of LLW burial grounds.

Major provisions of the Uranium Mill Tailings Control Act call for 1) government ownership of tailings and tailings disposal sites, 2) financial surety that the mill operator will be responsible for the costs of site decommissioning and long-term care, 3) elimination to the extent practicable of long-term maintenance, and 4) reclamation and management of tailings to national standards both before and after termination of a license. The Uranium Mill Tailings Control Act amends several sections of the Atomic Energy Act. The following four paragraphs discuss some of these amendments.

A new section 83 that covers ownership and custody of tailings and tailings disposal areas is added. Before a new license or license renewal issued after October 1981 can be terminated, the licensee must clean up the site and transfer ownership of the tailings to the federal or a state government. In addition, for new licenses issued after October 1981 three options are provided for ownership of the land used for tailings disposal. These options are: 1) ownership by the United States, 2) ownership by a state at the state's option, and 3) private ownership if the NRC determines that government ownership is not necessary.

A new section 161x that covers financial arrangements for decommissioning and long-term care is added. The new section provides authority to require that financial surety arrangements be made by licensees to assure completion of site cleanup and reclamation prior to termination of the license. Financial arrangements for long-term care may also be required if necessary. The act stipulates that the need for long-term care of tailings disposal sites should be minimized to the extent possible.

Section 274 is expanded to require state standards that are equivalent to, or more stringent than, NRC standards for tailings disposal sites. The amended section describes procedures for state rulemaking paralleling basic federal procedures, and mandates the preparation of a written environmental analysis for each license.

A new section 275 is added that grants authority to EPA to promulgate general standards for protection of the environment from both radiological and nonradiological hazards from mill tailings. The NRC is responsible for enforcement of the EPA-promulgated standards.

The GEIS on uranium milling provides an informational and decisional base for the preparation of regulations covering decommissioning; decontamination; site reclamation; transfer of title on termination of operations; future site use; and maintenance, monitoring, and emergency measures for uranium mill tailings piles. Major institutional questions addressed in the document include:

- need for land use controls and site monitoring at tailings disposal sites
- methods of providing financial surety that tailings disposal and site decommissioning are accomplished by the mill operator
- need for and funding of long-term care that may be necessary at tailings disposal sites.

The basis for the recommendations contained in the GEIS on uranium milling is that government ownership and continued surveillance of mill tailings disposal sites may be necessary to confirm that sites are not disrupted by unexpected natural erosion or human activity. Decommissioning of remaining sections of the mill site should ensure their unrestricted use. However, a mill tailings pile constitutes a low-level waste burial site containing very long-lived material. As a prudent measure of protection, continued control of tailings disposal sites should be exercised, including control of land use and periodic inspection, to confirm that the tailings and tailings isolation are not being disrupted by human activities or natural weathering processes. Such control should be provided through government ownership and custody of disposal sites after a licensee has satisfied decommissioning requirements and the license is terminated.

An NRC task force recommendation(2) (not adopted by the Commission as policy) proposes that the federal government assume responsibility for the perpetual care of all decommissioned LLW burial sites. This would be accomplished through federal ownership of the lands on which burial grounds are located. Specifically, the recommendation proposes the following:

> "The NRC should initiate action in cooperation with appropriate Federal and State agencies to increase Federal control over the disposal of low-level waste by:
>
> a. Requiring
>   - Joint Federal/State approval of new disposal sites
>   - NRC licensing, with State participation, of current and new disposal sites
>   - Federal ownership of land for all disposal sites
>
> b. Establishing a Federally administered perpetual care program."

The NRC has recently prepared a Low-Level Waste Branch Position(10) entitled "Low-Level Waste Burial Ground Site Closure and Stabilization." The Branch Position sets forth interim performance objectives for LLW burial ground site closure and stabilization. These performance objectives are intended to provide guidance for a site operator in developing site closure and stabilization plans to prepare a site for transfer to a custodial government agency. The custodial agency will be needed until the site can be released for unrestricted use. Major provisions of the Branch Position deal with 1) measures to stabilize the site to place it in a condition such that the need for active ongoing maintenance is eliminated and only passive surveillance and monitoring are required during the long-term care period that follows license termination, and 2) assurance of the availability of funds to complete the site closure and stabilization plan.

The conclusion that can be drawn from the documents reviewed here is that continued (i.e., long-term) care of some LLW burial grounds for an extended time period may be necessary following site closure and termination of the operating license. The period of long-term care could extend for a few hundred years and would depend on the inventory of buried radionuclides and on the condition of the site at license termination. Long-term care would likely include site inspection and maintenance, environmental monitoring, and site security. Conditional use of the land that does not disturb the waste or compromise site stabilization features might be allowed. Regulatory guidance provided by the NRC documents cited above and by recent mill tailings legislation and the GEIS for uranium milling indicates that long-term care is probably best provided through government control of the burial site. Government control would commence upon termination of the operating license, after stabilization activities are completed by the site operator.

5.2 REGULATIONS AND GUIDANCE THAT PROVIDE A BASIS FOR FORMAL DECOMMISSIONING CRITERIA

Several federal agencies have jurisdiction that can affect the decommissioning of nuclear facilities, including LLW burial grounds. The principal agencies with such jurisdiction include the NRC, the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the DOE.

The influence of the NRC on decommissioning policy comes through its role as licensing agency for the construction and operation of nuclear facilities and regulator (in cooperation with agreement states) of the possession and use of radioactive material.

The EPA is the federal government's chief environmental regulator.(11) The EPA Administrator is to advise the President on radiation matters that directly or indirectly affect the public health. In addition, the EPA provides guidance to all federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with the states.(12) The EPA is therefore responsible for establishing generally applicable environmental standards for radioactive material outside the boundaries of property subject to the control of NRC licensees.

The DOT has broad responsibilities in the areas of packaging and shipping of radioactive material. They are responsible for promulgating and enforcing safety standards governing packaging and shipping containers, as well as the labeling, classification, and marking of all packages. The DOT also implements safety standards for the mechanical condition of carrier equipment and the qualifications of carrier personnel. Under terms of a "Memorandum of Understanding" between the DOT and the NRC,(13) the NRC develops performance standards for package designs and reviews package designs for fissile materials and Type B quantities of other radioactive materials (except for low specific activity materials). The DOT requires NRC approval to use these packages.

The DOE owns and operates several LLW burial grounds in the United States (see Section 3.1.2). A recommendation has been made that DOE own and operate all shallow-land burial sites.(14) (Legislation(8) described in Section 5.1 for control of uranium mill tailings piles provides for DOE custodianship of decommissioned tailings piles owned by the federal government.) Accordingly, the DOE may play an important role in planning for the future decommissioning of these facilities.

The following sections review existing regulatory guidance in the areas of radiation exposure limits, nuclear materials transportation, and financial requirements applicable to the development of specific criteria and regulations for decommissioning LLW burial grounds.

5.2.1 Radiation Exposure Limits

As described in Section 8.1, there is currently no specific regulatory guidance on permissible levels of radioactivity that can remain in a decommissioned LLW burial ground, or on the acceptable annual dose to individuals living on or near a decommissioned LLW burial site. However, regulatory guidance does exist that could form the basis for regulations related to acceptable radiation exposure levels for a decommissioned site.

The basic radiation standards that apply to all NRC licensees are given in Title 10, Part 20 of the Code of Federal Regulations.(15) For unrestricted areas,(a) it is specified that no individual should receive a dose(b) to the

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(a) "Restricted Area" means any area to which access is controlled by the licensee, for purposes of protection of individuals from exposure to radiation and radioactive materials.

(b) Throughout this section, the term "dose" may generally be taken to mean the more rigorous term "dose-equivalent." The latter, expressed in units of rem or millirem, implies a consistent basis for estimates of consequential health risk, regardless of rate, quantity, source, or quality of the radiation exposure.

whole body in excess of 0.5 rem in any one calendar year. 10 CFR 20 also gives limiting concentrations in air and water for many radionuclides, for both the working environment and for unrestricted areas. These concentration limits are calculated, assuming continuing exposure and standard physiological parameters, to give doses no higher than either those specified above or 1.5 rem per year to non-specified organs of the body. It is further expected that the average dose from all modes of exposure to "a suitable sample of an exposed population group" should not exceed one-third of the limiting dose criteria.

The EPA has authority under the Safe Drinking Water Act to regulate permissible levels of radioactivity in public drinking water supplies. Regulations establishing maximum radioactive contaminant levels were issued in July, 1976,(16) and are now effective. They establish maximum contaminant levels for radium-226, radium-228, gross alpha particle radioactivity, and beta particle and photon radioactivity from man-made radionuclides in community water systems. These regulations are given in Title 40 of the Code of Federal Regulations.(17)

Under the Clean Air Act Amendments of 1977,(18) the EPA has some regulatory authority for radioactive emissions into the air. These 1977 amendments create an important statutory exception to NRC's primary jurisdiction over radioactive emissions from licensed nuclear facilities. Radioactive emissions into the air (presumably including effluents from decommissioning) are subject to the Clean Air Act, in addition to remaining under control of the NRC. The EPA Administrator is to determine by August 9, 1979, whether air emissions of radioactive materials will endanger public health. If he makes an affirmative determination, EPA may issue standards for air quality; however, these standards are subject to disapproval by the NRC. By February, 1980, EPA and NRC are to enter into an interagency agreement with respect to those sources or facilities that are subject to NRC jurisdiction.

The EPA has issued proposed guidelines on dose limits for persons exposed to transuranic elements in the general environment.(19) The guidelines propose that the annual alpha radiation dose rate to members of the critical segment of the exposed population, as a result of exposure to transuranic elements in the general environment, should not exceed one millirad[a] per year to the lung or 3 millirad per year to the bone.

In addition to the references cited above, additional guidance that could be interpreted as annual dose limit recommendations for decommissioned facilities is contained in the following documents:

- Recommendations of the International Committee on Radiological Protection (ICRP), Publication 26.(20)
- 40 CFR 190, Environmental Radiation Protection Standards for the Uranium Fuel Cycle.(21)
- Surgeon General's Guidelines.(22)
- "de minimus" Concentrations of Radionuclides in Solid Wastes (AIF).(23)

None of the above guidance, which provides limits on the dose rate to the public from nuclear facilities, was proposed specifically for decommissioned property. However, the guidance could reasonably serve as basis for the development of regulations defining permissible radiation exposure limits for conditional or unrestricted use of decommissioned facilities such as LLW burial grounds.

5.2.2 Nuclear Materials Transportation

One of the options for decommissioning of LLW burial grounds is to exhume the buried waste, repackage it, and ship it to another site (a deep geologic disposal site or another shallow-land burial ground) for disposal.

The transportation of nuclear fuel and waste is regulated principally by the DOT and the NRC. The regulations of the DOT are found in Title 49 of the Code of Federal Regulations, primarily in 49 CFR Parts 170-189, "Hazardous Materials Regulations." The regulations of the NRC are found in Title 10 of

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(a)The rad is defined as the energy imparted to matter by ionizing radiation per unit mass of irradiated material. One rad equals 0.01 joule/kilogram of absorbing material.

the Code of Federal Regulations, primarily in 10 CFR 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions." These regulations are applicable both to persons who ship radioactive materials as they package and offer such materials for transportation, and to carriers of radioactive materials as they load and transport such materials in their vehicles. The regulations provide protection from the hazards of radiation, both to transport workers and the general public.

Primary reliance for safety in transportation of radioactive material is placed on the packaging. The DOT regulations prescribe general standards and requirements for all packages of radioactive material, and for labeling, handling, and storage of those packages by carriers. For packages that contain no significant fissile radioactive material and only small quantities of other radioactive materials, the DOT standards and requirements provide adequate assurance of containment and shielding of the radioactive material. While these small-quantity packages, termed Type A packages, may fail in accident situations, the radiological consequences would be limited because of the limited package contents.

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

More detailed reviews of federal regulations pertaining to the transport of radioactive material are found in References 24 and 25.

Although federal agencies dominate the regulatory process for the transport of radioactive materials, state governments also exercise some control over these shipments. State highway departments regulate gross vehicle weights, vehicular dimensions, and other parameters for radioactive shipments, as they do for other kinds of shipments. Currently, about half of the states have adopted the DOT Hazardous Materials Regulations to cover intrastate shipments Several states have adopted or proposed additional regulations concerning radioactive materials.(26,27) These regulations include:

- special routing of radioactive shipments
- advance notification for shipments of large quantities of radioactive materials
- state inspections of some types of radioactive shipments
- prohibition of certain types of shipments within the states
- prior approval for radioactive shipments
- requirements of exclusive-use vehicles for radioactive shipments
- use of pilot vehicles
- speed restrictions for radioactive shipments
- specific hours of movement
- accompaniment of all shipments by radiation monitoring personnel.

The variation of regulations between adjacent states often requires special considerations for interstate shipments.

5.2.3 Financial Requirements for Decommissioning

At each of the six commercial LLW burial grounds that have operated in the United States, the site operator has been required to contribute to a state-administered fund to provide for long-term care of the site after the operating license is terminated. Long-term care is presumed to include administrative control, environmental monitoring, and routine site maintenance. The long-term care funds, as presently constituted, are not designed and intended for and do not provide sufficient monies for site stabilization or waste relocation activities that might also be required at the time of site closure. (See Section 5.1 for a discussion of regulatory guidance pertaining to decommissioning activities at the time of site closure.)

Although there are currently no state or federal regulations relating to the assurance of adequate financing for decommissioning of LLW burial grounds, the regulations in 10 CFR 50(28) that pertain to the decommissioning of a production or utilization facility can be considered for guidance. The most directly applicable are 10 CFR 50.33 (f) relating to financial qualifications for facility shutdown and 10 CFR 50.82 relating to applications for license termination.

10 CFR 50.33 (f) requires that the applicant for an operating license provide information to show:

> "that the applicant possesses or has reasonable assurance of obtaining the funds necessary to cover the estimated costs of operation for the period of the license or for five years, whichever is greater, plus the estimated costs of permanently shutting the facility down and maintaining it in a safe condition."

10 CFR 50.82 outlines requirements for terminating a facility license. A formal application must be made to terminate operation of an NRC-licensed facility. The application must specify certain information on planned decommissioning procedures. The regulation authorizes termination procedures, specifies additional conditions, provides for notice to interested persons, and states that if such procedures and conditions are followed a termination of license will be granted. Subsequent responsibility for usage of the site is not addressed.

The NRC's Branch Position on LLW burial ground site closure(10) includes the provision that the funding of decommissioning and long-term care must be addressed in the site closure and stabilization plans developed by LLW burial ground licensees.

5.3 THE NRC PROGRAM FOR DEVELOPMENT OF DECOMMISSIONING REGULATIONS

The NRC is developing a comprehensive set of regulations pertinent to the shallow-land burial of low-level radioactive waste.(29) These will deal with permissible types of wastes,(30) site suitability, and alternative disposal methods, as well as operating, monitoring, decommissioning, postoperational maintenance, and funding requirements.

The NRC is also considering development of a more explicit policy for nuclear facility decommissioning, as well as amending its regulations in 10 CFR Parts 30, 40, 50, and 70 to include more specific guidance on decommissioning criteria for production and utilization facility licensees and byproduct, source, and SNM licensees.(1) One nuclear facility for which specific decommissioning criteria are being considered is an LLW burial ground. An Advance Notice of Proposed Rulemaking, setting forth the NRC's plans for development of regulations for low-level waste burial grounds, including decommissioning requirements, and providing notice of a preliminary draft regulation, 10 CFR Part 61, has been published in the Federal Register.(31)

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, and the National Technical Information Service, Springfield, Virginia 22161.

**Available for purchase from the National Technical Information Service, Springfield, Virginia 22161.

6.0 ALTERNATIVE APPROACHES TO FINANCING DECOMMISSIONING

This section discusses alternative approaches to provide funds for the decommissioning and long-term care of a commercial LLW burial ground. Only alternative mechanisms for assuring the availability of funds are discussed. Legal-institutional issues, such as who should collect the funds and how they should be administered, are outside the scope of the study and are not considered.

All of the existing commercial sites, except the Richland, Washington, site, are on land owned by the state and leased to the site operator. (The Richland site is on land owned by the federal government, leased to the state and subleased to the site operator.) Decommissioning activities that precede the termination of a burial ground operating license are the responsibility of the site operator. License provisions generally specify that, upon completion of burial operations, the site operator will satisfy certain requirements for contouring, landscaping, and fencing the site.(1,2) The ultimate responsibility for long-term care of a waste burial site remains with the state in which the site is located(1,3,4) (or with the federal government in the case of the Richland, Washington site). An NRC task force report(3) has suggested that it may be desirable to have federal land ownership of burial sites and a federally administered long-term care program for all commercial LLW sites. To date, a decision on this concept has not been made.

In each state where a commercial LLW burial ground is located, a long-term care fund has been established. The money is paid to the state by the site operator and is based on per-cubic-foot burial charges. Payments ranged from 5¢/ft^3 to 16¢/ft^3 in 1976. At some sites the payments have been increased periodically to account for cost escalations.

The importance of financial assurance for decommissioning has recently been recognized by the Congress of the United States in the Uranium Mill Tailings Control Act of 1978.(5) A new section, 161x, is added by this legislation to the Atomic Energy Act of 1954. The new section provides explicit authority for the NRC to require that an adequate bond, surety, or other financial arrangement be made by mill licensees to assure site cleanup and reclamation prior to termination of the license. If determined necessary, financial arrangements for long-term maintenance and monitoring may also be made a requirement of license termination.

In the following discussion of financial arrangements for decommissioning LLW burial grounds, Section 6.1 discusses the need for assurance of decommissioning funds. Section 6.2 discusses approaches to funding decommissioning costs. Section 6.3 discusses approaches to providing decommissioning funds in the event of premature closure. Section 6.4 discusses issues associated with provision for contingency costs. Section 6.5 briefly reviews the ability of states to impose financial obligations on nuclear facility owners.

6.1 NEED FOR ASSURANCE OF DECOMMISSIONING FUNDS

A state has an obligation to protect the health and safety of its citizens. In connection with this responsibility, a state in which an LLW burial ground is located has several financial concerns. First, it is concerned that the operator will have sufficient funds to decommission a site when burial operations cease. If an operator defaults or goes bankrupt, the state may have to assume financial responsibility for site decommissioning. Second, adequate financial provision must be made for long-term care of the site. Finally, funds should be available to provide for unexpected contingencies both during the operating life of the facility and before decommissioning is completed.

Burial ground operators are relatively small companies with limited financial resources. If legal proceedings are required to fix the responsibility to pay decommissioning costs, delays may occur that could result in the expenditure of additional funds and the loss of valuable time before the necessary preventive and corrective actions are accomplished at the site. Decommissioning funds that are paid into a trust account outside the control of the operating company provide the best assurance that monies are available for decommissioning activities. A performance bond might also be used to assure the performance of decommissioning activities by the site operator.

6.2 APPROACHES TO PROVIDING FUNDS FOR DECOMMISSIONING AND LONG-TERM CARE

Three principal alternatives exist for meeting the need to provide funds for decommissioning and long-term care:

1) creation of a decommissioning and long-term care fund during the operating lifetime of a burial ground by periodic payments into a reserve fund
2) payment of anticipated decommissioning and long-term care costs into an account prior to the start of burial ground operations
3) payment of decommissioning and long-term care costs when incurred (i.e., after site closure).

Alternatives 1 and 2 both require a good decommissioning plan and cost estimate. Alternative 3 is the only option available for an existing burial ground for which no reserve fund was established and whose operating life is over. Various combinations of these alternatives are also possible. As discussed earlier in this section, all presently operating LLW sites have established long-term care funds, although the adequacy of the funds may be questioned.

The analysis in this section assumes that decommissioning account monies contemplated by alternatives 1 and 2 would be kept separate in an earmarked fund. If a unit of government acts as the fund steward, it is also possible that decommissioning and long-term care funds could be deposited in the general fund. This should not present a problem as long as the government unit assumes responsibility for ultimately providing the funds and credits the decommissioning account with a reasonable interest return on the deposited funds.

To discuss and compare the alternatives, it is useful to establish some evaluation criteria. Four criteria that seem to be pertinent to evaluating the alternatives are:

1) the extent to which decommissioning is financially assured
2) the extent to which those who benefit from operation of the burial ground pay its decommissioning costs

3) the present value cost of the option

4) the ease and cost of administering the option.

The criteria clearly vary in importance. Importance values are not quantitatively determined for this analysis. However, it is the consensus of the authors that criterion 1 is most important, criterion 4 is least important, and criteria 2 and 3 are of approximately equal and intermediate importance.

6.2.1 Creation of a Decommissioning and Long-Term Care Fund During the Operating Life of the Burial Ground

This option contemplates the formation of a fund to generate enough income during the operating life of the burial ground to pay anticipated decommissioning and long-term care costs. Payments would be made into an account permanently outside the control of the burial ground operator. This approach is currently used by all of the states that license and regulate LLW burial grounds to accumulate funds for long-term care. In most instances the funds are placed in a separate trust account. However, in at least one state the money is deposited in the state's general fund. The trust fund approach is also used by New Mexico(6) for uranium mills.

Payments to the sinking fund would most likely be based on volume of waste buried. The charge per unit of waste buried would be determined by dividing the total estimated decommissioning and long-term care costs (including a reasonable contingency factor) by the volume of waste expected to be buried at the site. This charge could be adjusted to take credit for compound interest earned by investing the fund during and after the plant operating life.

Payments into the fund could be adjusted regularly, perhaps every year. One obvious reason for change could be to provide for cost escalation. In addition, many other variables can change with time. For example, the rate of return achieved by the fund stewards will almost certainly change. The total burial ground capacity and burial rate may change over time. The real (i.e., nonescalated) decommissioning cost can also be expected to change over time because of technological innovations and new regulatory requirements. It is also possible that the expected life of the burial ground will change. All of these changes can be periodically accounted for by adjustments to the sinking fund payment. If such changes are not severe or are regularly reflected in the payments, the value of the fund should be close to that needed when the burial ground is closed. The procedure for calculating annual payments, plus some illustrative calculations, are shown in Appendix E of Volume 2.

A variety of entities could be designated to provide stewardship for the fund. Possibilities include state government, the federal government, or a private organization such as a bank. Currently, the states provide their own stewardship. An independent "Decommissioning Assurance Agency" could also be chartered by each state or by the federal government to retain and invest the fund and perhaps oversee activities and disperse payments to those conducting the activities. The pooling of decommissioning funds into such a centralized agency could help to ensure decommissioning performance even if a particular facility operator defaults in some manner. The agency would act in a fiduciary capacity for the public. Its governing board might be composed of representatives of the public, government, power-consuming industries, and power-producing industries. By including various interest groups, tendencies to overestimate or underestimate costs and the annual payments needed to fund the costs should be minimized. Payments and interest received by the stewardship entity should be exempt from federal income tax, either because the entity is a creation of the U.S. or a state government (Internal Revenue Code, Section 115) or is an exempt scientific entity (Section 501[c]).

An advantage of the annual payment approach is that it should generally ensure that decommissioning activities actually occur. With funds set aside to cover the costs, the question of who should pay them is alleviated and arguments about responsibility are less likely to occur.

Another advantage of the approach is that it can be administered in a way that is equitable to all burial ground users. As long as increases in estimated decommissioning costs are reflected in adjusted payment schedules, all burial ground users should pay their approximately proportional share of costs in dollars of approximately equivalent buying power. Exact sharing of costs would be virtually impossible because of changes in operational life of a burial site or changes in expected decommissioning costs caused by technological innovation and/or new regulatory requirements.

Several difficulties associated with this option should be recognized. None of them is insurmountable. One difficulty is that a sinking fund will not accumulate sufficient funds if a burial ground is shut down prematurely. Methods of dealing with the financial problems of premature shutdown are discussed in Section 6.3. Another difficulty relates to the care and investment of the fund itself. Professional management of the fund, as well as controls on the investments made by the fund, would be desirable. For example, the fund might be limited to investment bonds and notes issued by agencies of the U.S. government and municipal and private bonds with a sufficiently high rating (e.g., AA or higher). The fund steward will be faced with the same problem other investors have: i.e., how can assets be invested to earn a return that at least matches the rate of cost escalation? If the fund is not able to match the rate of cost escalation, the payments to the fund (in year of startup dollars) will have to be increased over time at a rate that exceeds the rate of escalation. Another difficulty associated with the option is that decommissioning costs must be estimable with reasonable accuracy in order to provide a basis to calculate appropriate payments to the fund. Although revised estimates can be made and reflected in the fund payments later in the burial ground lifetime, the initial estimate is especially important if the site will have a relatively short operating life.

6.2.2 Prepayment of Anticipated Decommissioning and Long-Term Care Costs

The general framework of the prepayment alternative is similar to the sinking fund option discussed in Section 6.2.1. A trust fund would be established. Fund stewards would invest the monies until required for decommissioning. The difference is that the present value of anticipated decommissioning and long-term care costs would be paid into the fund prior to operation of the burial ground. Adjustments to the fund would be required to account for changes in such factors as the trust fund earnings rate versus the decommissioning cost escalation rate, expected burial ground life and capacity, decommissioning technology, and safety and regulatory requirements.

An advantage of this approach is that it provides a high degree of assurance that decommissioning funds will be available when needed. Assuming that appropriate adjustments are made to the fund from time to time, sufficient money should be available for decommissioning, even if the burial ground ceases operation prematurely. (Adjustment to the fund requires both an evaluation of the trust fund earning rate versus the rate of inflation and a re-examination of the technical bases used to determine the costs of decommissioning and long-term care.)

The site operator might prepay decommissioning costs out of retained earnings from past investments, or he might resort to long-term debt financing as though it were a capital expenditure. In either case, the prepayment option could be financially disadvantageous to the site operator. This is because the discount rate utilized by the operator will probably exceed the interest rate obtainable by fund stewards. The discount rate utilized by the operator will be approximately his minimum rate of return on alternative investments. This will almost certainly exceed 10% under today's financial conditions and could be much higher. The fund steward will be able to obtain returns in the 7 to 9% range only by making conservative investments in the current bond and note market.

To the extent that debt funds are used to prepay the present value of decommissioning costs, the borrowing capacity of the operator is reduced and consequently his available supply of funds for capital investment is reduced.

Whether the operator uses retained earnings from past activities or debt financing to prepay decommissioning costs, future users of the site would likely be charged through the pricing mechanism a sufficient amount to enable the operator ultimately to regain his financial position and to retire the interest and principal on any debts incurred. The site operator would therefore only suffer serious financial loss in the event of premature closure or significant underutilization of the site.

6.2.3 Payment of Decommissioning Costs When Incurred

This alternative contemplates delaying payment for decommissioning until the burial ground ceases operation. At this time, the operator would perform required decommissioning and also pay the state the present value of future long-term care costs.

The principal concern with this approach is the possibility that the burial ground operator, as a result of default or bankruptcy, may not pay the costs of decommissioning the site. As long as the site operator is willing and financially able to pay the costs of decommissioning and long-term care, no major problem should arise. If, however, the operator is financially incapacitated and/or unwilling to pay these costs, the burden may fall directly to the state or possibly the federal government, and the required funding would likely have to come from general revenues. The risk of nonperformance is greater with a burial ground than with a shorter life facility and the risk increases if decommissioning is deferred. Another concern is that the direct burial ground beneficiaries may not pay their proportional share of decommissioning costs because the full cost of decommissioning may not be reflected in the burial ground charges.

If this option is selected, it may be desirable to require the site operator to purchase a performance bond or an insurance policy that would ensure the availability of decommissioning funds. This approach is not unprecedented; many states require bonds from coal mining companies to ensure reclamation of strip-mined land. Performance bonds are used by the states of Wyoming and Utah to ensure the reclamation of uranium mining and milling sites when operations at these sites are terminated. The Uranium Mill Tailings Act of 1978(5) recognizes performance bonds as a method of ensuring financial responsibility for the decontamination, decommissioning, and reclamation of mill tailings sites.

There are several problems with obtaining a bond or an insurance policy. The principal difficulty is that surety companies are not likely to be interested in selling a long-term bond because of the many uncertainties affecting their obligation. Yet a long-term bond is needed if a state is to receive decommissioning assurance. If the bond is renewable at given intervals, the bonding company may very well decline renewal if the burial ground operator becomes financially weak. In addition, the guaranteed amount of the bond would have to be readjusted periodically to cover revised decommissioning cost estimates. If the bonding company does not agree ahead of time to automatic escalation of its guarantee, the usefulness of the bond is again substantially decreased. For example, over a 20-year operating life of a burial ground, decommissioning costs would increase four times in nominal dollars(a) assuming 7% annual escalation.

An additional problem with performance bonds is that even if a long-term bond can be obtained, its degree of assurance is only as good as the surety company. Surety companies can become financially incapacitated just as any other company can. Finally, collecting on the bond could be more difficult (possibly requiring litigation) than utilizing funds previously paid into a decommissioning trust fund.

If an operating company is somehow able to obtain a bond, it may have to provide up to 100% collateral.(b) The cost of a bond, if it can be obtained, will likely be on the order of 1 to 2% per year of the guaranteed amount.(8) This is a significant cost burden.

A possible solution to the problem of obtaining a long-term performance bond is to decommission a section of a burial ground (one or several trenches) relatively soon after burial operations in that section have been completed. This would be analogous to short-term bonds obtained to ensure reclamation of a specified limited area of land to be strip mined. One problem with this approach is that the optimum procedures for burial ground decommissioning may not be known until long-term operating experience at the site is available. Another problem is the difficulty of performing piecemeal site stabilization procedures. While some stabilization activities (i.e., trench capping and

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(a) Nominal dollars are dollars of the year in which payments are made.

(b) A task force of the Conference of Radiation Control Directors found that surety companies are reluctant to issue bonds in excess of $1 million unless secured by 100% collateral.(7)

grading and seeding of trenches) can be accomplished on a unit basis, other activities such as contouring the site and establishing drainage and diversion systems for the control of surface water may be best performed after site operations are terminated. A third problem might be the unwillingness of the landowner to accept responsibility for a portion of the site until the entire site is decommissioned.

Another possible approach to decommissioning performance assurance might be for burial ground operators (and operators of other fuel cycle facilities) to make payments to a decommissioning assurance pool. The pool would be obligated to pay for decommissioning a site if the operator defaulted on performance. Setting the appropriate premiums would be difficult. To establish premiums, the pool administrator would have to estimate the likelihood of nonperformance or partial performance and the magnitude of the fund required to complete the decommissioning. It is probable that a decommissioning assurance pool would have to be established by the federal government, and that it would require congressional action.

6.3 FINANCIAL PROVISIONS FOR PREMATURE FACILITY CLOSURE

With the sinking fund and pay-when-incurred options, the state runs the risk that sufficient funds will not have been collected to cover decommissioning and long-term care costs if the burial ground is prematurely closed. If the burial ground operator is financially unable to provide the funds needed for decommissioning and long-term care, the state or the federal government may be required to pay for these activites. No special problem exists with the prepayment option because funds should be available whenever closure occurs. This is the principal advantage of the prepayment approach.

If the sinking fund option is chosen, several alternatives are available to reduce the risk of unavailability of funds in the event of premature closure. These include one or more of the following:

- an initial cash payment to the sinking fund prior to burial ground operation
- higher per unit sinking fund charges (in real, i.e., constant dollars) during early years of operation
- a bond posted by the facility operator
- a decommissioning assurance insurance pool.

The first two options can be considered as combinations of the sinking fund and prepayment options. As discussed in Section 6.2.3, it may be difficult to implement the bond alternative. The fourth option, while feasible, requires additional study and might have to be implemented by the federal government.

6.3.1 Initial Cash Payment

This option contemplates that an initial significant cash payment would be made to the sinking fund prior to startup. The size of the payment could be flexible and might depend on the financial resources of the operator, the probability of premature closure, the extent of anticipated decommissioning problems, the anticipated operating life of the facility, and other factors. An initial payment on the order of 10 to 20% of total estimated decommissioning costs (in year of startup dollars) might be required.

The principal advantage of this option is the increased assurance it provides that the site operator will pay decommissioning and long-term care costs.

The principal disadvantage is the possibility of financial hardship on the operator, as under the prepayment option. Other minor disadvantages are the potential distortion effects of the initial payment on proper recognition of waste burial costs, and having beneficiaries of the burial site pay its decommissioning costs (criterion 2 page 6-3).

6.3.2 Higher Initial Sinking Fund Charges

This option contemplates that payments to the sinking fund in constant dollars would initially be higher than the average unit cost and then would decline with time. The precise sliding scale could be determined by the responsible agency in consultation with the burial ground operator. One option would be to attempt to have constant payments in nominal dollars over the lifetime of the facility. This option could also be utilized in conjunction with an initial cash payment.

The advantages and disadvantages of this option are comparable to those of the initial payment option. The main advantage of the option is the added assurance that it provides during early years of site operation that adequate funds will be available for decommissioning and long-term care. The disadvantage is that burial ground customers during early years of site operation will likely pay a disproportionate share of the decommissioning expenses.

6.3.3 Surety Bonds

The main difficulty with the surety bond (performance bond) approach is the problem of obtaining a long-term commitment from a surety company, as discussed in Section 6.2.3. A decreasing performance bond over a short time period, used to ensure the availability of funds until the reserve account reaches a predetermined value, may be easier to obtain than a long-term bond.

If a suitable bond commitment could be obtained, there are two potential advantages. First, it may be more equitable for the smaller company unable to make a significant initial cash payment. Second, it reduces the distortion effect on waste disposal costs of a high initial cash payment.

6.3.4 Insurance Pool

An insurance pool such as described in Section 6.2.3 is an additional approach to decommissioning assurance. The pool could be set up to assure the availability of decommissioning funds in the event of premature site closure, as well as for operator default. Premium setting would be difficult. The insurance pool concept might require implementation by the federal government and needs further study.

6.4 PROVISIONS FOR CONTINGENCY COSTS

This section provides a brief discussion of the issues associated with contingency cost protection for LLW burial grounds. Contingency costs here do not refer to ordinary cost overruns incurred during decommissioning. These cost overruns can be allowed for by building into the sinking fund payments a reasonable contingency factor. Rather, the concern is with unexpected factors, such as corrective action needed for unexpected offsite radionuclide migration, or unanticipated increased decommissioning requirements caused by changes in anticipated land usage after release of the site.

The concern for unanticipated contingency costs is especially great for LLW burial grounds because of the time period (30 to 40 years) projected for operation of a site, as well as the relatively long time period (up to 200 years) during which administrative control may need to be maintained before the site is released. It is extremely difficult to project what contingencies might occur during these time periods, their probabilities, and the dollar costs of corrective actions. For this analysis, no projection of these contingencies is made.

In practice, it seems likely that the financial burden of unanticipated contingencies after burial ground closure will fall on the state and/or federal government. Since the buried waste originates from throughout the country, the burden may logically fall on the federal government.(a) Given this possibility, one solution may be for the federal government to formally assume an insurer's role for unanticipated contingencies and collect premiums as a surcharge to state-imposed trust fund fees.

There is a possiblity that the former site operator can be required to assume the burden for contingencies after closure. None of the existing license agreements appears to provide for this, however. Requiring the former site operator to pay contingency costs after closure would place a burden on the operator, since he would not be able to collect additional fees from his customers. In the absence of a contractual requirement, the operator who has relinquished the site could only be forced to assume the burden of contingencies if negligent burial practices can be shown. Even this possible remedy may not

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(a) The Federal Disaster Assistance Administration of the U.S. Department of Housing and Urban Development is a possible source of funds in the event of some type of disaster. Although this agency normally provides aid in response to natural disasters, it also occasionally provides assistance for failure in man-made structures, such as the case of the Teton Dam collapse in Idaho in 1976.

be available if a cause of action is initiated after the statute of limitations has expired. Moreover, as the time after closure increases, collection may become more and more difficult because the former site operator may no longer exist as a corporate entity, or because financially he may be unable to pay.

The difficulty of paying for unanticipated costs suggests that regulatory agencies should be diligent in licensing and monitoring burial grounds and in seeking correction of burial practices that may result in problems after a site is closed. In addition, decommissioning cost estimates should include a reasonable contingency. This should help to ensure that adequate decommissioning and long-term care funds can be collected during the operating life of the burial ground.

6.5 POWER OF STATE GOVERNMENTS TO IMPOSE FINANCIAL OBLIGATIONS ON FACILITY OPERATORS

The power of state governments to impose certain financial obligations on nuclear fuel cycle facility operators has been examined in conjunction with a study of financial alternatives for uranium milling operations.(9) The general conclusion of the study was that a state may impose financial requirements as an exercise of its general police power to protect the life, health, and safety of the public. With appropriate legislation, it thus appears that any of the financial alternatives discussed in this section, including establishment of trust funds and bonding requirements, could be implemented. The conclusion applies whether or not the state is an Agreement State under the provisions of the Atomic Energy Act. The uranium milling study also concludes that a state, as a licensing condition, may require a facility operator to transfer ownership of the land to the state at the conclusion of the facility's operating life.

6.6 SUMMARY

Options to providing funds for decommissioning and long-term care of LLW burial grounds include payment of costs before site operations begin, payment during the operating lifetime of the burial ground by contributions to a sinking fund, and payment when decommissioning costs are incurred. The sinking fund approach is currently used by all of the states that license and regulate burial sites, to provide funds for long-term care.

The pre-payment option provides the greatest assurance that the site operator will be financially responsible for decommissioning and long-term care. However, this option may be disadvantageous to the site operator because it deprives him of funds that might be used for capital investment. The pay-when-incurred option provides the least degree of assurance of operator fiscal responsibility. However, a performance bond might be used to ensure operator responsibility if this option were chosen.

For both the pre-payment and sinking fund options an increase in burial ground charges can be used to transfer the cost of decommissioning from the site operator to those who benefit from operation of the site. The pay-when-incurred option may in effect cause those who have not received the benefit of the burial ground to pay for its decommissioning.

If the sinking fund option is chosen, several mechanisms are available to provide financial protection against premature burial ground closure. These include an initial cash payment to the sinking fund prior to the start of operations, higher per unit sinking fund charges during the early years of operation, a performance bond posted by the facility operator, and a decommissioning assurance insurance pool. The insurance pool would involve periodic payments by all burial ground operators (and possibly by other nuclear fuel cycle facility owners) into a common fund that would probably be administered by the federal government. The insurance pool could be used to insure against operator default as well as premature site closure. The concept needs further study.

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3. NRC Task Force Report on Review of the Federal/State Program for Regulation of Commercial Low-Level Radioactive Waste Burial Grounds, NUREG-0217, March 1977.*

4. U.S. General Accounting Office, Issues Related to the Closing of the Nuclear Fuel Service, Inc., Reprocessing Plant at West Valley, New York, EMC-77-26, March 9, 1977.

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6. New Mexico Statutes Annotated, 12-9-5.1, 1977.

7. Task Force Report on Bonding and Perpetual Care of Licensed Nuclear Activities, Conference of Radiation Control Program Directors, p. 21, April 1976.

8. Financial Alternatives for Stabilization, Reclamation, and Long-Term Monitoring and Maintenance of Uranium Mill Tailing Piles, Science Applications, Inc., p. 18, Los Angeles, CA, October 1977.

9. Ibid., pp. 84-90.

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*Available for purchase from the National Technical Information Service, Springfield, Virginia 22161.

7.0 CHARACTERISTICS OF THE REFERENCE BURIAL GROUNDS

Physical and operational characteristics of the six commercial low-level waste (LLW) burial grounds in the United States are summarized in Section 3. As shown in Tables 3.1-2 and 3.1-3, significant differences in physical and operational characteristics exist among these six sites. Because of these differences and because further changes in operating practices and waste inventories may be expected,(1,2) generic facilities are postulated for this study. The characteristics of these postulated facilities are based on the actual characteristics of existing commercial sites.

This section contains a summary of the characteristics of the two LLW burial facilities on which this study is based. The approach taken is to treat the burial ground and the surrounding environment as separate systems. The burial ground with its inventory of buried radioactive waste is described generically. This generic burial ground is then assumed to be located on two reference sites, an arid western site and a humid eastern site, for which representative parameters are chosen. Use of a common radioactive waste inventory for both burial grounds makes it easier to assess the effects of site-related parameters on decommissioning operations.

The climate, geology, and hydrology of the arid western site are chosen to be typical of the Richland, Washington, site. The climate, geology, and hydrology of the humid eastern site are chosen to be typical of the Sheffield, Illinois, site. To simplify the analysis, some averaging of site parameters is made. Each site description provides a basis for evaluating decommissioning methods and costs and for estimating possible environmental impacts. There is no intent to judge these particular sites or environments as being favorable or unfavorable locations for LLW burial grounds. The reference sites are, however, considered to be useful for comparative analysis of decommissioning activities.

As described in this section, some of the physical and operational features of the reference LLW burial facilities may not be the same as those identified for facilities actually located at the specific western and eastern sites. However, the use of representative parameters from these specific locations to describe the environmental features such as the climate, geology, and hydrology should result in a meaningful overall analysis of potential impacts. Burial-ground-specific assessments would be required for the decommissioning of real facilities.

Key assumptions/bases used for the burial ground descriptions are summarized in Section 7.1. The physical and operational characteristics of the burial grounds are described in Section 7.2. The reference radioactive waste inventory that is assumed to be common to both burial grounds is given in Section 7.3. Parameters that describe the meteorology, geology, and hydrology of the two sites at which the generic radionuclide inventory is buried are summarized in Section 7.4. Both sites are assumed to have the same demographic characteristics, which are given in Section 7.5.

Additional site details for the two reference sites are given in Appendix A of Volume 2, and details of the reference radioactive waste inventory are given in Appendix B.

7.1 KEY ASSUMPTIONS/BASES USED FOR BURIAL GROUND DESCRIPTIONS

The following key assumptions/bases are used to describe the reference shallow-land burial facilities:

1) The generic burial grounds operate for 30 years prior to being decommissioned.
2) Current practice is assumed in the design of burial trenches and in the procedures for filling and capping the trenches.
3) A common radioactive waste inventory is postulated for the two burial sites. The inventory consists of a mix of 60% reactor fuel-cycle radioactive waste and 40% non-fuel-cycle waste by volume.
4) All wastes accepted for burial are solids packaged in nonradioactive outer containers. Wastes containing free liquids are assumed to have been dewatered or to have been solidified by incorporation in cement, urea formaldehyde, or other solidification agents prior to burial.

5) Buried wastes are packaged according to current DOT standards. Most wastes are packaged in steel drums or liners, plywood boxes, and fiberboard containers that function primarily to confine the waste during transportation.

6) The chemical or pyrophoric hazards of wastes buried at LLW burial grounds are not specifically considered in this report. In the past, wastes buried at some commercial sites may have included non-radioactive toxic material that was more hazardous than some of the radioactive waste. However, no serious problems have occurred with regard to chemicals or pyrophoric materials buried at commercial LLW sites.

7) Procedures during burial ground operation are assumed to be such that the ground surface is free of radioactive contamination at the time that decommissioning operations begin.

8) No wastes are left unburied at the time that decommissioning operations begin, and all burial trenches are capped.

9) Maintenance of trench caps and grading and seeding of the ground surface as appropriate to control drainage and prevent the accumulation of surface water is assumed to be part of the normal burial ground operating procedure.

10) The climate, geology, and hydrology of the arid western site are representative of the Richland, Washington, site. The climate, geology, and hydrology of the humid eastern site are representative of the Sheffield, Illinois, site.

11) There are no rail facilities at the burial sites. Transportation of radioactive waste to a site is by truck.

12) The only facilities for which decommissioning activities are described are the waste burial trenches. Typical buildings that may be located at a burial site are described in Section 7.2.1. Low levels of surface contamination may be present on floors and walls of some areas of these buildings. Decontamination requirements are expected to be minimal.

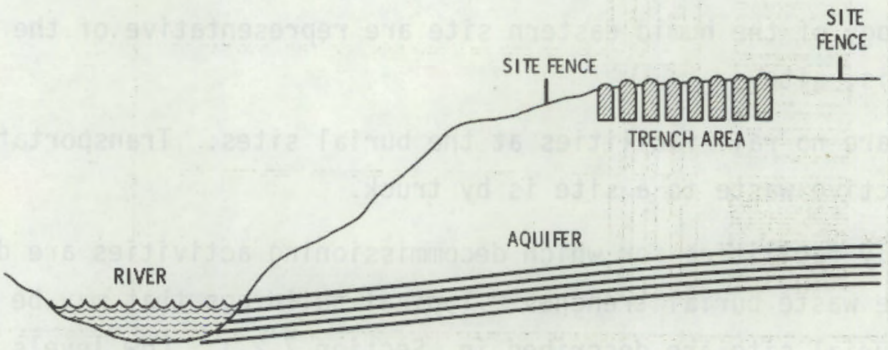
7.2 BURIAL GROUND CHARACTERISTICS

This section summarizes the physical and operational characteristics of the reference burial ground. Characteristics that are common to both the arid western site and the humid eastern site (e.g., size, physical arrangement, and site capacity for waste) are described in Section 7.2.1. Trench design and procedures for filling and capping the trenches are discussed in Section 7.2.2. Construction and filling of slit trenches are discussed in Section 7.2.3. Environmental surveillance activities during burial ground operation are described in Section 7.2.4.

The physical and operational characteristics of existing LLW burial grounds are summarized in Section 3.1. These characteristics form the bases for the generic descriptions presented in this section.

7.2.1 Physical Description of Reference Burial Ground

Figure 7.2-1 shows a generalized cross section of an LLW burial site. The site is assumed to be located on an upland area of generally flat or gently rolling terrain. Soil characteristics and numerical values for distances, flow velocities, and other site parameters important to this study are given in Section 7.4.1 for the arid western site and in Section 7.4.2 for the humid eastern site.



NOTE: DRAWING NOT TO SCALE

FIGURE 7.2-1. Generalized Cross Section of a Low-Level Waste Burial Site

The plot plan for the reference burial ground is shown in Figure 7.2-2. The total site area is 70 hectares,[a] of which about 50 hectares contain burial trenches. The remaining land area is used for buildings, access roads, and a 50-m-wide exclusion area around the site perimeter between the trench area and the site fence. Each site is cleared of trees and brush prior to the onset of burial operations. The total site is fenced with a 1.8-m-high chain link fence that is topped with a three-strand barbed wire outrider.

Transportation of radioactive waste to a burial site is by truck. There are no rail facilities at a site. All onsite roads are gravel. A chain link fence gate is provided for entry to and exit from a site. The gate is closed and locked at the end of each working day during burial ground operations. Signs posted on the gate specify that radiation surveys are required before entering or leaving the controlled area.

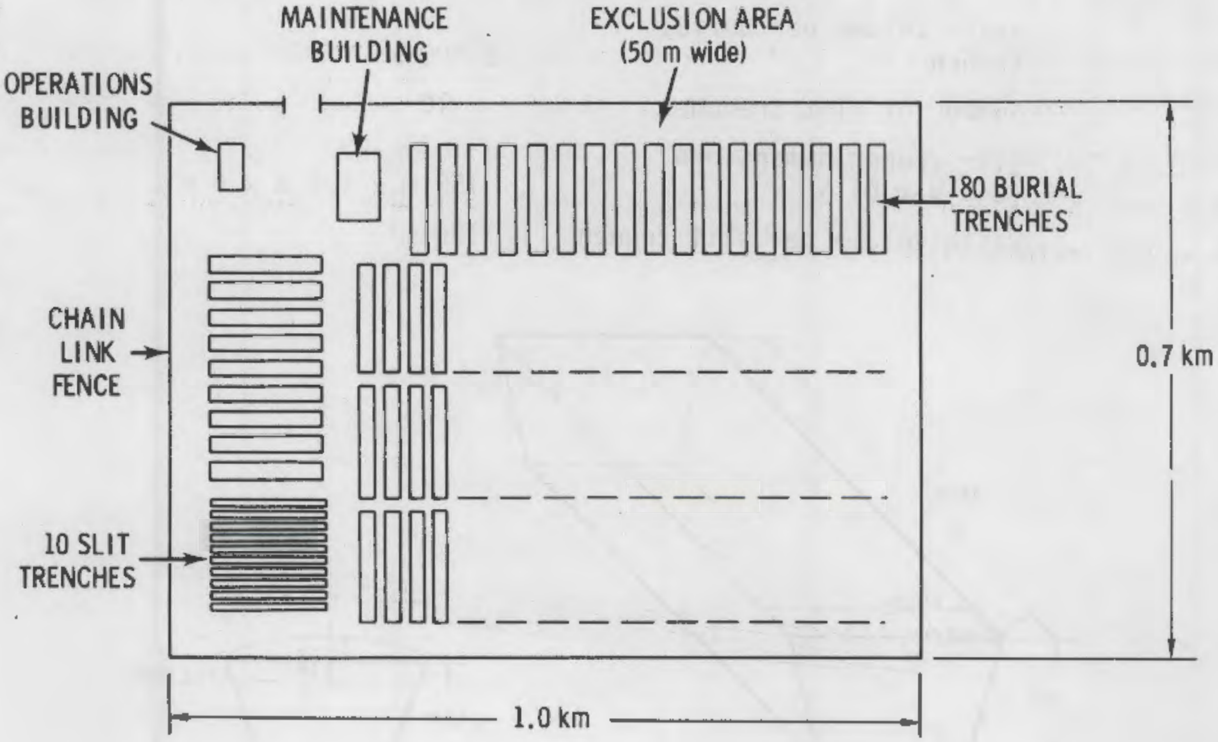


FIGURE 7.2-2. Plot Plan for Reference Burial Ground

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[a] One hectare (ha) equals 10,000 m^2, or 2.47 acres.

Table 7.2-1 lists the parameters that describe the site capacity for radioactive waste. The total site capacity is about 1.5×10^6 m^3 of waste buried in 180 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. Trench dimensions are shown in Figure 7.2-3. A minimum of 3 m between the top edges of adjacent trenches is assumed.

TABLE 7.2-1. Waste Capacity of Reference Burial Ground

Site Parameter	Value
Total area of reference site	70 hectares
Site capacity for waste	1.5×10^6 m^3
Number of burial trenches	180
Burial trench dimensions (L x W x D)	150 m x 15 m x 7.5 m
Waste volume per burial trench	8 300 m^3
Number of slit trenches	10
Slit trench dimensions (L x W x D)	150 m x 1.2 m x 6 m
Waste volume per slit trench	150 m^3

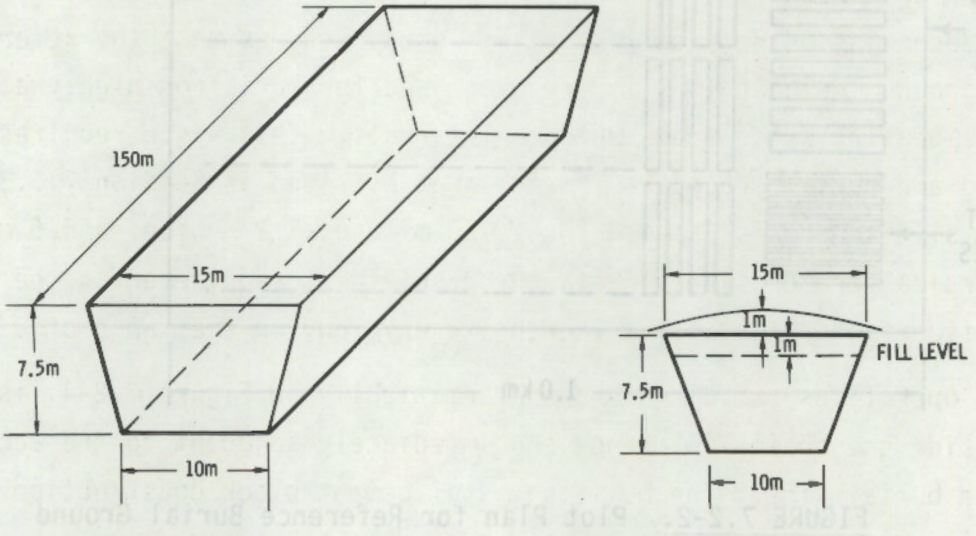

FIGURE 7.2-3. Typical Low-Level Waste Burial Trench

The natural angle of repose of the soil varies for different LLW burial sites across the country. The angle is a function of soil type, soil moisture content, etc. In general, the slope is steeper at eastern sites that at western sites because of the sandy nature of the soil at western sites. Trenches at Barnwell, South Carolina, can be dug with vertical sides because of the high clay content of the soil in that area. For this study, it is assumed that the natural angle of repose of the soil is the same at both the eastern and western sites.

Each trench is filled with waste to within 1 m of the ground surface. The top 1 m of a trench is reserved for fill soil. When a trench is completely filled, it is covered with a trench cap of soil that is mounded to 1 m above the land surface, as shown in Figure 7.2-3. Void spaces between waste packages result in a utilization factor of 0.7 for that portion of a trench that is filled with waste.(1,3) The effective waste volume per trench is therefore about 8300 m^3. For this study, the simplifying assumption is made that six trenches are filled during each of the 30 years of operation of a reference burial ground.

At some commercial sites, high-activity beta-gamma waste is buried separately from other radioactive waste in specially designed dry wells, pits, or slit trenches. To evaluate requirements for exhumation of high-activity waste, in case relocation of the waste should be required as part of burial ground decommissioning operations, this study assumes that the reference burial ground includes 10 slit trenches used for burial of highly activated non-fuel-bearing waste from LWR core internals. This waste requires special handling and burial procedures, which are described in Section 7.2.3. A typical slit trench is assumed to be 150 m long, 1.2 m wide, and 6 m deep, with vertical trench sides. Because of shielding requirements, the effective utilization factor for a slit trench is very low, in the range of 0.1 to 0.2.

An operations building, shown schematically in Figure 7.2-4, is located just inside the chain link fence and immediately adjacent to the access road into the burial site. The building is of cement block construction on a concrete pad foundation. It serves as a control point for entrance to and exit from the burial area.

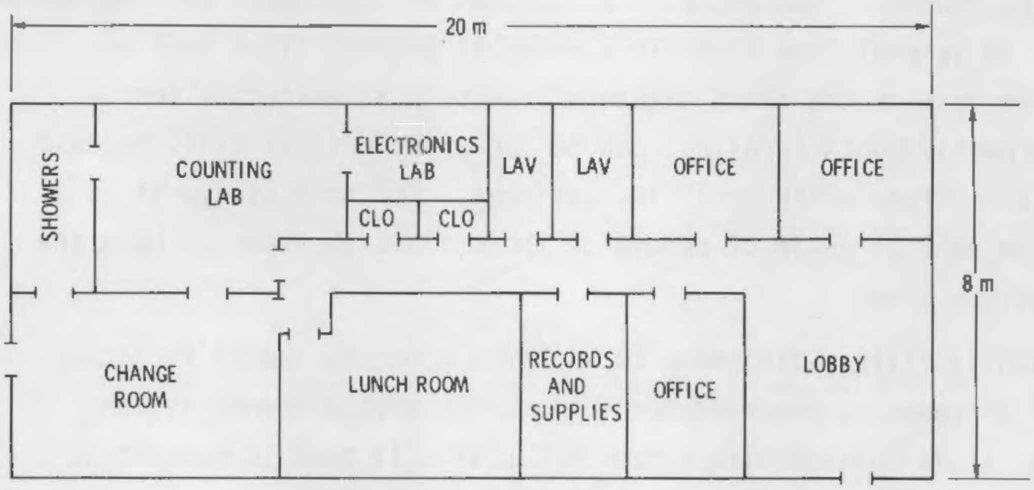

FIGURE 7.2-4. Operations Building Schematic

The operations building provides the following facilities:

- office space for the radiation protection and traffic management staff
- laboratory space for qualitative and quantitative radiation analyses and storage area for radiation protection instruments
- check point for all personnel entering or leaving the burial area
- change room stocked with protective clothing and provided with containers for receipt of potentially contaminated used clothing
- lunch room, toilet, and shower facilities for employees.

Radioactive contamination is expected to be minimal, and it is anticipated that the building can be released for unrestricted use after a thorough radiation survey and minor cleanup using procedures such as scrubbing with a detergent solution.

A maintenance building, shown schematically in Figure 7.2-5, is also located on each site, adjacent to the access road. The building is of steel construction on a concrete pad foundation. It provides inside space, equipment, and other required facilities for the maintenance and servicing of all the mobile equipment used at the site and for radiation survey and decontamination

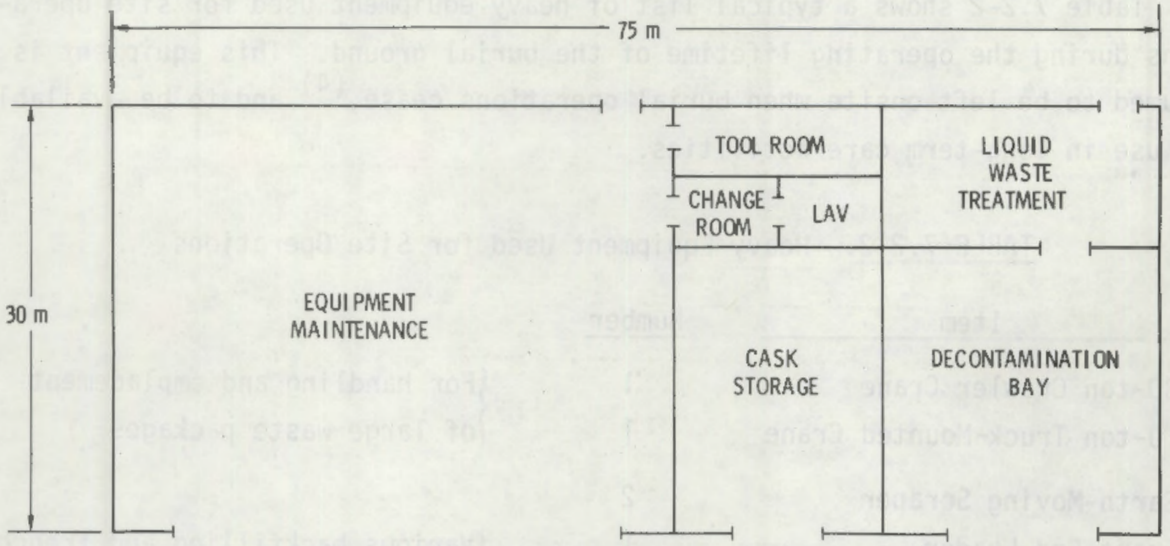

FIGURE 7.2-5. Maintenance Building Schematic

of this equipment and of trucks and casks used to transport waste to the site. Empty cask storage is also provided in the maintenance building.

The maintenance building consists of three areas that accommodate a maintenance shop, a cask storage area, and a decontamination bay. The maintenance shop is a clean area. Vehicles and equipment needing servicing or repair are surveyed and decontaminated before being brought to this area. The cask storage area is also expected to be relatively clean, since casks are normally surveyed and decontaminated prior to storage. The decontamination bay is expected to be moderately contaminated. Even assuming good housekeeping procedures during site operations, it may be necessary to remove some concrete from the floor of the decontamination bay to prepare the maintenance building for unrestricted release.

The decontamination bay contains a liquid hold-up tank and a small evaporator used for treatment of contaminated liquids from the decontamination of casks and equipment. During site operations, the residue from the evaporator is placed in 208-ℓ steel drums, solidified by the incorporation of cement, and disposed of by onsite burial. All waste generated during decommissioning of the maintenance building and all comtaminated equipment from the building is disposed of by onsite burial.

Table 7.2-2 shows a typical list of heavy equipment used for site operations during the operating lifetime of the burial ground. This equipment is assumed to be left onsite when burial operations cease,(4) and to be available for use in long-term care activities.

TABLE 7.2-2. Heavy Equipment Used for Site Operations

Item	Number	
80-ton Crawler Crane	1	For handling and emplacement of large waste packages
10-ton Truck-Mounted Crane	1	
Earth-Moving Scraper	2	Various backfilling and trench completing activities
Front-End Loader	1	
Bulldozer	1	
Dump Truck	1	
Roadgrader	1	
Vibratory Compactor	1	Trench and waste compaction
Farm Tractor, Harrow, Seeder and Mower	1	Trench vegetation and maintenance

7.2.2 Construction and Filling of Burial Trenches

Open trenches are used as the burial facility at both the western and eastern sites. Primarily because of the much heavier precipitation at the eastern site, trench construction details and trench capping procedures are more complex at the eastern site than at the western site.

Because of the low rainfall and highly permeable sediments at the western site, no special precautions are required to prevent standing water from accumulating in a trench or to prevent contact of the waste with water. Trench bottoms are not sloped, and French drains and sumps are not used. Stand pipes are installed but are used only for monitoring purposes. Wastes are covered with soil on an irregular basis and the waste emplaced in a trench may be left for several days without cover if soil shielding is not needed to reduce the level of background radiation. The final trench cover at the western site is excavated earth fill; no special attempt is made to compact the fill or to seal the trench.

Construction details for a typical trench at the eastern site are shown in Figures 7.2-6 and 7.2-7. A one degree (1°) slope is provided in the bottoms of trenches from end to end and from one side toward a 0.6-m x 0.6-m gravel-filled French drain. The French drain runs the entire trench length on the low elevation side to provide for collection of any liquid drainage that might occur. A gravel-filled sump is provided at the low corner of a trench. The bottom of a trench is covered with a 0.6-m layer of sand.

Three 0.15-m-diameter polyvinyl chloride (PVC) stand pipes are installed in a trench, one at each end and one at the midpoint. Each stand pipe is screened at its base, which is located in the French drain. In the event that liquids are observed in a French drain, they are pumped out, solidified, and buried.

To minimize contact with moisture, at the eastern site the waste is covered with soil as it is placed in a trench, and the soil cover is compacted using heavy rolling equipment (e.g., a sheepsfoot, wobbly wheel roller, or vibrating road roller). When a trench is completely filled, it is covered with soil, mounded and compacted to 1 m above the land surface, as shown in Figure 7.2-7. Impermeable soils with high clay content are used in constructing the final cover. The trench cover is then seeded with shallow-rooted ground cover plant species to help control erosion. Drainage fields may also be constructed around the mounded trenches.

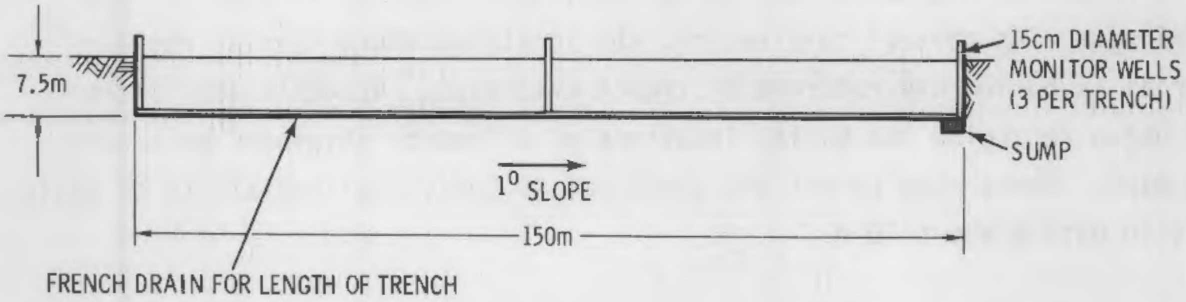

FIGURE 7.2-6. Cutaway View of Typical Trench for Eastern Site

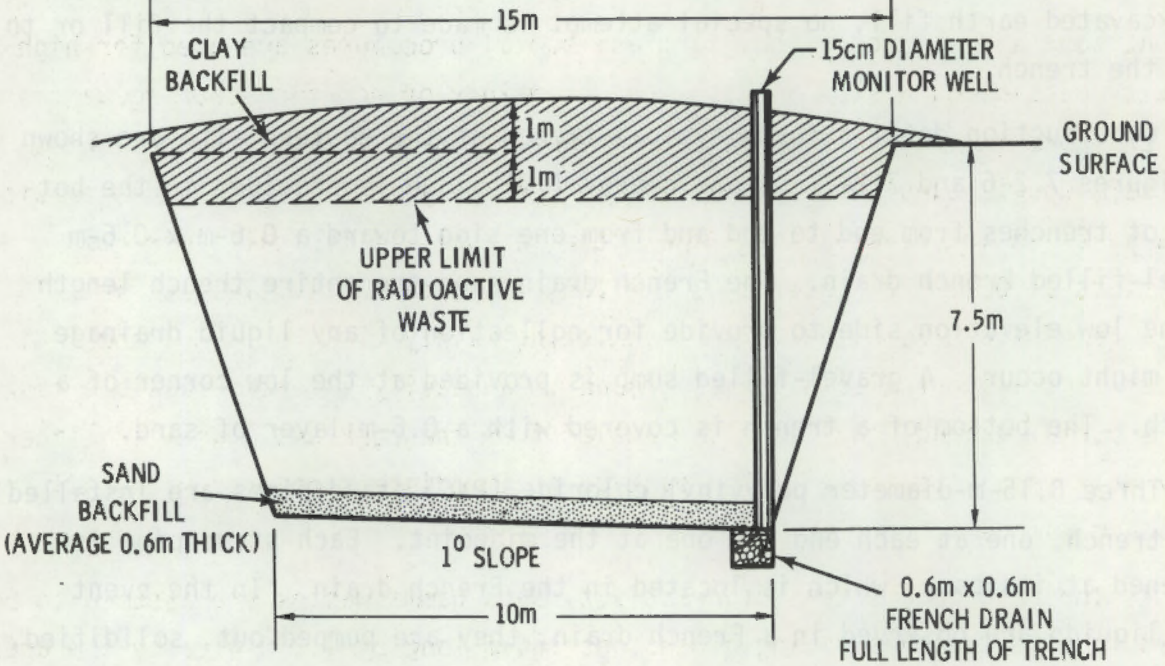

FIGURE 7.2-7. Typical Trench Cross Section for Eastern Site

At both sites, waste packages are emplaced by dumping from above a trench, beginning at the high end. During the early years of commercial burial ground operations, random dumping of wastes was employed. Current burial ground operating procedure provides for some segregation of waste packages, with cement caissons, steel cask liners, and large plywood boxes being stacked and other smaller waste packages, including 208-ℓ drums, being randomly dumped into trenches.

A record of the wastes buried in individual trenches is kept at each burial site. As part of this record, the locations where special nuclear material is buried are recorded on trench grid maps. Recently some sites have begun recording the burial locations of all waste shipments on trench grid maps. These maps permit the positions of individual burials to be designated to within about 10 m.

7.2.3 Slit Trenches

At both sites, special handling and burial procedures are used for high-activity beta-gamma wastes. These consist mainly of non-fuel-bearing wastes from LWR core internals, such as flow channels, in-core shims, control rods, and thermocouple bundles. The wastes are generally collected in a disposable steel liner in the reactor spent-fuel storage pool. A typical liner has dimensions of 0.76 m diameter by 3.6 m long. Typical activities are in the range of 1,000 to 5,000 Ci/m^3, consisting mainly of ^{55}Fe, ^{60}Co, and ^{63}Ni. A liner is transported to a burial ground in a heavily shielded reusable cask. At the burial ground, the liner is removed from the cask and placed in either a dry well or a slit trench. The package is immediately covered with soil for shielding purposes.

At the reference sites, high-activity beta-gamma wastes are assumed to be buried in slit trenches having dimensions 150 m long by 1.2 m wide by 6 m deep. A typical trench is shown in Figure 7.2-8. Burial operations consist of placing a cask vertically in a trench, unloading the cask from the top end, laying the waste package horizontally in the bottom of the trench, removing the cask, and backfilling earthen cover over the waste package. Three layers of waste packages and associated intervening layers of soil, including the trench overburden, comprise the finished trench. The total slit trench inventory consists of 90 disposable liners (about 150 m^3 of waste), containing 1.5 x 10^5 to 7.5 x 10^5 curies of radioactivity.

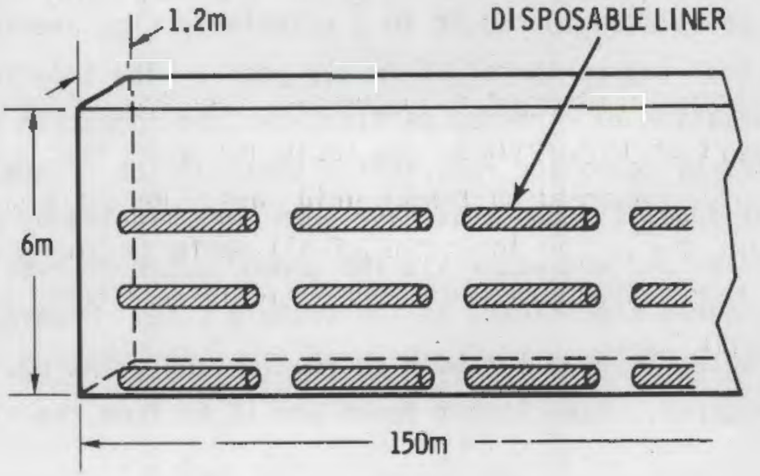

FIGURE 7.2-8. Typical Slit Trench

7.2.4 Environmental Surveillance

Each commercial radioactive waste burial site is required, through its licensing agreement, to conduct an environmental monitoring program to determine if any radionuclide migration from waste emplacements is occurring. The appropriate state regulatory agency performs periodic inspections of monitoring records kept by the site operator and, at some sites, conducts an independent monitoring program. The extent and frequency of the sampling differs for each burial ground, according to the characteristics of the site and the particular operating procedures. Operational environmental sampling requirements at the six commercial LLW burial grounds in the United States are described in Section 9.1.2.

For the two reference sites of this study, postulated environmental sampling programs during burial operations are summarized in Table 7.2-3. These sampling programs are believed to be representative of existing programs at commercial sites. They are also designed to sample critical pathways for the migration of radioactivity from the burial trenches to the environment.

The methodology for identifying significant radionuclide migration pathways that may be critical in terms of their exposure potential is developed in Section 8 for both the western and eastern sites.

The western site is located in a region of low rainfall and high summer temperatures that lead to soil-moisture deficiencies. The depth to ground water is approximately 60 m, and the nearest surface water is 16 km away. Wind erosion is calculated to result in a relatively high average rate of loss of surface soil (approximately 6 mm per year). The important exposure pathways are inhalation of airborne particulates and ingestion of food or water contaminated by deposited radioactive particulates. Ingestion of drinking water or aquatic foods that have been contaminated by radionuclides released to wells or surface water via the ground water or overland flow pathways is not considered significant at the western site. However, because the nearest surface water is used for both recreation and drinking, sampling of this water is required. The closest farms are 16 km from the site.

TABLE 7.2-3. Environmental Sampling Programs at the Reference Sites During Waste Burial Operations

	Arid Western Site				Humid Eastern Site			
Sample Type	Sample Locations Number	Sample Locations Description	Frequency	Number of Samples Annually	Sample Locations Number	Sample Locations Description	Frequency	Number of Samples Annually
Water - Onsite Wells	6	Three wells along site perimeter and hydrologically down gradient from burial ground. Three wells within burial area.	Semi-annual	12	12	Four wells along site perimeter and hydrologically down gradient from burial ground. Eight wells within burial area.	Quarterly	48
Offsite Wells	3	Two wells within 10 km of disposal site at locations which are (or could be) used for potable water supplies, watering of livestock, or crop irrigation. One well located hydrologically up gradient from site to serve as control.	Annual	3	5	Four wells within 10 km of disposal site at locations which are (or could be) used for potable water supplies, watering of livestock, or crop irrigation. One well located hydrologically up gradient from site to serve as control.	Semi-Annual	10
Surface Water	2	One site downstream of point of effluent entry into river. One site upstream to serve as control. Four samples at each location.	Semi-annual	16	4	One site downstream of point of effluent entry into river. One site downstream at first point of withdrawal of water for public use. One site in nearby lake. One site upstream to serve as control. Four samples at each location.	Quarterly	64
Air Particulates - Onsite	1	Along site perimeter in most prevalent downwind direction.	Continuous, with weekly filter changes	52	1	Along site perimeter in most prevalent downwind direction.	Continuous, with weekly filter changes	52
Offsite	2	One site within 10 km of burial ground in most prevalent downwind direction. One site for control 15 km from burial ground in least prevalent wind direction.	Continuous, with weekly filter changes	104	2	One site within 10 km of burial ground in most prevalent downwind direction. One site for control 15 km from burial ground in least prevalent wind direction.	Continuous, with weekly filter changes	104
Soil - Onsite	4	Two sites at same locations used for air particulate samples. Two sites within burial ground.	Annual	4	4	Two sites at same locations used for air particulate samples. Two sites within burial ground.	Annual	4
Offsite	2	At same locations used for air particulate samples.	Annual	2	2	At same locations used for air particulate samples.	Annual	2
Vetetation - Onsite	4	Near locations used for onsite soil samples.	Annual	4	4	Near locations used for onsite soil samples.	Annual	4
Small Mammals - Onsite	4	At convenient locations within burial ground.	Annual	4	4	At convenient locations within burial ground.	Annual	4
Offsite	4	At locations within 5 km of burial ground.	Annual	4	4	At locations within 5 km of burial ground.	Annual	4
Game Birds - Onsite or Offsite	4	At convenient locations within 10 km of burial ground.	Annual	4	4	At convenient locations within 10 km of burial ground.	Annual	4
Milk - Offsite	--	--	--	--	3	Two samples from cows fed on fodder and pasturage within 15 km of site. One sample from a local dairy representative of a milkshed for the area.	Quarterly	12
Fish - Offsite	1	Game fish from river located 16 km from burial ground.	Quarterly	4	4	Game fish from lakes, rivers, and streams in the burial ground environs that may be subject to seepage or direct surface runoff.	Quarterly	16
Farm Crops - Offsite	--	--	--	--	3	Samples of meat, poultry, eggs and fresh produce from farms within 15 km of burial ground.	Annual	3
Direct Radiation	3	Same locations as used for air particulate sampling. Three dosimeters at each location.	Monthly	108	3	Same locations as used for air particulate sampling. Three dosimeters at each location.	Monthly	108

For the eastern site, the critical pathways are water and food pathways. This site is located in a region of moderately high rainfall. Ground water is encountered at a depth of about 10 m, and a moderate-size surface stream is only 1 km away. (Several small creeks that drain the site empty into this stream.) The area around the site is used extensively for farming (especially as pasture for dairy cows), and for recreation. Therefore, the sampling of milk, fish, and farm crops is important at this site. Because of the significance of the water pathway and the extensive agricultural activities in the area, the environmental monitoring program postulated for the eastern site is more complex than the one postulated for the western site.

Environmental monitoring programs must be developed on a site-specific basis that takes into account the radionuclide inventory at the site, site-specific critical pathways for the release of radionuclides to the environment, and land-use and other human activities carried out near the site. The sampling schedules shown in Table 7.2-3 are presented only as examples of programs at the reference sites, to serve as bases for cost estimates of environmental monitoring requirements, and should not be used to define environmental sampling requirements at specific existing or future sites. An addendum to this report will develop technical bases useful for formulating and implementing environmental surveillance programs at future LLW disposal sites.

The sampling programs described in Table 7.2-3 are carried out by the site operator, with annual inspections of records and equipment performed by the appropriate state regulatory agency. Analysis of environmental samples is performed by a company that specializes in this work. Measured radioactivity levels exceeding a predetermined value (usually twice that of the control sample) require notification of the site operator and applicable government agencies, and additional analyses to determine the specific radionuclides involved.

7.3 REFERENCE WASTE INVENTORY

This section summarizes information about the form and composition of radioactive wastes buried at commercial sites, and describes the reference radionuclide inventory assumed for this study. Waste inventory details are given in Appendix B of Volume 2.

7.3.1 Waste Form and Composition

Radioactive wastes buried at commercial sites contain a broad spectrum of materials, ranging from low-specific-activity radiopharmaceuticals to high-specific-activity power reactor activation and fission products. These wastes originate from hospitals, educational institutions, pharmaceutical manufacturers, industrial research and production facilities, and from the commercial nuclear power industry (reactor operation, fuel fabrication, and spent fuel storage). When commercial burial grounds were first opened in the mid-1960s, most of the radioactive wastes accepted for burial were non-fuel-cycle wastes. In 1975, an estimated 61% of the waste volume accepted for burial at commercial sites was reactor fuel-cycle waste, and only 39% was non-fuel-cycle waste.(1) By the year 1990, it is projected that nuclear-fuel-cycle waste will account for about 80% of the total waste volume buried annually at commercial sites.

Non-fuel-cycle radioactive waste consists of paper trash, packing material, protective clothing, broken glassware, plastic sheeting and tubing, expended scintillation cocktail (usually in the form of solidified or absorbed liquids), animal carcasses, obsolete equipment, and building rubble. Most of this waste has low specific activity. Waste from medical and educational institutions is estimated to have an average specific activity of less than 0.1 Ci/m^3.(5)

Nuclear fuel-cycle waste includes many of the waste categories listed above, as well as higher activity waste, such as spent ion-exchange resins, filters, filter sludges, solidified evaporator bottoms, shielding, piping, instrumentation, control rods, and neutron-activated materials. Most of this waste (approximately 98%) comes from nuclear reactor operations. Approximately 80% of the annual solid radioactive waste volume generated at fuel-cycle facilities results from the processing of liquid streams to reduce the radioactivity level in effluents.(2) Reference 2 gives estimates of percentages and average specific activities for several categories of solid radioactive waste from light water power reactor operation. The average specific activity of this waste ranges from a fraction of a curie per cubic meter to hundreds of curies per cubic meter. This information is summarized in Table 7.3-1. Based on information in the table and assuming a PWR:BWR ratio of 2:1, the estimated average specific activity of soild radioactive waste from light water power reactor operation is 11 Ci/m^3.

TABLE 7.3-1. Estimated Percentages and Average Specific Activities for Solid Radioactive Wastes from LWR Operation (from Reference 2)

Waste Category	Percent of Total Radioactive Waste Volume		Estimated Average Specific Activity (Ci/m^3)	
	PWR	BWR	PWR	BWR
Solidified Liquids	76.7	46.4	1.6	1.4
Demineralizer Resin	6.8	7.3	160	70
Filter/Demineralizer Sludge	---	35.4	---	7.1
Cartridge Filters	1.5	---	18	---
Trash	15.0	10.9	0.035	0.035
Totals or Averages	100.0	100.0	12.4	8.3

Wastes are buried as received in the packages used to transport them. Non-fuel-cycle wastes are usually packaged in 208-ℓ steel drums, plywood boxes, and fiberboard containers, as are fuel-cycle wastes that do not require shielding during transport. Radioactive wastes, such as demineralizer resins and cartridge filters, that require shielding during transport are packaged in 208-ℓ drums or in disposable steel liners that vary in volume from 1 to 10 m^3.

During the first years of operations of commercial sites, some radioactive liquids were accepted for burial. Current regulations at all commercial sites require that liquid waste be solidified prior to burial. Liquid wastes commonly are treated at their source in one of three ways: mixing dewatered waste with concrete, a urea formaldehyde polymer, or some other solidification agent; dewatering and mixing with an adsorbing agent; or dewatering alone.

As a result of disposal operations carried out in the 1960s and early 1970s, some transuranic (TRU) waste is buried at all of the commercial sites except the Barnwell site. In September 1974, the Atomic Energy Commission (AEC) issued a proposed rule(6) that would have limited burial of TRU wastes at commercial sites to concentrations not greater than 10 nCi/gram of waste. Although the rule was not formally implemented, all the commercial burial sites except the Richland site took steps to limit the burial of transuranium nuclides. In 1974, the states of New York and Kentucky imposed limitations on the burial of TRU wastes and the licensee (Nuclear Engineering Company) voluntarily placed the 10 nCi/gram limit on wastes at the Sheffield, Illinois, site. In September, 1975, the state of Nevada placed the same limitation on TRU wastes. Since the initial licensing of the Barnwell site in 1971, South Carolina has prohibited the burial of TRU-contaminated wastes (except americium-241). Currently, only the Richland site will accept wastes with transuranic alpha-emitting contamination above 10 nCi/gram of waste.

Tables of waste volumes and amounts of byproduct, source, and special nuclear material[a] buried at the six commercial LLW burial sites in the United States are given in Appendix B of Volume 2. As of December 31, 1976, 423,000 m^3 of waste, which included 3,787,000 Ci of byproduct material, 951,000 kg of source material, and 1,678,000 g of special nuclear material, had been buried at these sites. The average specific activity (not corrected for decay) of buried byproduct material at the six sites was 8.95 Ci/m^3.

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[a] Radioactive wastes buried at commercial sites are classified into three categories defined as follows:(10)
Byproduct material (reported in curies) refers to any radioactive material except source material and special nuclear material obtained during the production or use of source or special nuclear material and includes fission products and other radioisotopes.
Source material (reported in kilograms) refers to thorium, natural or depleted uranium or any combination thereof. Source material does not include special nuclear material.
Special nuclear material (reported in grams) refers to plutonium, ^{233}U, uranium containing more than the natural abundance of the isotope 235, or any material artificially enriched with any of the foregoing substances. Special nuclear material does not include source material.

Isotopic compositions of radioactive wastes buried at Morehead, Kentucky,(7,8) and at West Valley, New York,(9) have been summarized from radioactive shipment records for these sites. A major problem with the published inventories for both of these sites is that significant fractions of the radioactivity are reported as "not specifically identifiable" or "mixed fission products." Table B.2-2 of Volume 2 compares the inventories reported for these sites with the inventory reported for one trench (Trench 14) at Sheffield, Illinois, and with the reference burial ground inventory assumed for this study.

7.3.2 Reference Radionuclide Inventory

Volumes and specific activities for the different categories of waste assumed to be present in a reference trench are given in Table 7.3-2. Data in this table are based on the following assumptions:

- The total waste volume per trench is 8300 m^3.
- The ratio of reactor fuel-cycle to non-fuel-cycle waste is 60:40 by volume.

TABLE 7.3-2. Characterization of Waste in Reference Trench

Contaminated Material	Waste (m^3)	Volume (%)	Specific Activity (Ci/m^3)
Fuel-Cycle Waste			
Solidified Liquids[a]	3 320	40.0	2.0
Demineralizer Resin[a]	370	4.5	160
Filter/Demineralizer Sludge[a]	580	7.0	10
Cartridge Filters	40	0.5	20
Trash	670	8.0	0.1
Subtotal	4 980	60.0	
Non-Fuel-Cycle Waste			
Trash	3 320	40.0	0.1
Total	8 300	100.0	

[a] Solidified in concrete, urea formaldehyde, or some other solidification agent.

Fuel-cycle waste characteristics are based on estimates of percentages and average specific activities for the categories of solid radioactive waste from light water power reactor operation. These estimates are given in Table 7.3-1.

Published reports of isotopic mixtures in low-level waste at existing burial grounds or in reactor radioactive waste do not provide the consistent and comprehensive set of data needed to project radioactivities for the reference burial ground inventory. The radionuclide inventory for this study is therefore based on an unpublished generic burial ground inventory prepared by staff at the NRC. The reference inventory is listed in Table 7.3-3. It assumes a mix of 60% reactor fuel-cycle radioactive waste and 40% non-fuel-cycle waste. Inventory details are given in Appendix B of Volume 2. The reference inventory is derived from the NRC inventory described in Appendix B by applying a normalization factor based on an estimated byproduct specific activity of 9.0 Ci/m^3. Isotopes with half lives less than 0.1 years or with a percentage contribution to the total inventory smaller than 0.01% have generally been omitted. Exceptions are ^{99}Tc, ^{129}I, ^{135}Cs, and ^{226}Ra, which are included because of their possible consequences if released to the environment.

Table 7.3-3 lists both the as-buried inventory for a single trench (i.e., the inventory at the time of waste burial) and the total inventory of all the trenches at the time of site closure. The total trench inventory assumes 30 years of burial ground operation with 1/30 of the waste being buried each year. Allowance is made for radioactive decay and for growth of radioactive daughters. Calculational details are given in Appendix B.

The burial ground inventory in Table 7.3-3 does not include material buried in slit trenches (see Section 7.2.3). Waste in these trenches consists mainly of non-fuel-bearing components from LWR core internals. Typical activities at the time of burial are in the range of 1,000 to 5,000 Ci/m^3. Reference 11 provides estimates of radioactivity levels in major activated reactor components at the time of reactor shutdown. Based on this information,

TABLE 7.3-3. Reference Radionuclide Inventory

Isotope	Half Life (Years)	Average Activity in Waste (Ci/m^3)	As-buried Activity per Trench (Ci)	Total Burial Ground Inventory at Time of Site Closure (Ci)
^{3}H	1.2×10^{1}	1.6×10^{-1}	1.3×10^{3}	1.1×10^{5}
^{14}C	5.7×10^{3}	5.0×10^{-3}	4.2×10^{1}	7.6×10^{3}
^{51}Cr	7.6×10^{-2}	5.7×10^{-1}	4.7×10^{3}	3.0×10^{2}
^{54}Mn	8.3×10^{-1}	3.3×10^{-1}	2.7×10^{3}	1.9×10^{4}
^{55}Fe	2.6×10^{0}	5.7×10^{-1}	4.7×10^{3}	1.0×10^{5}
^{58}Co	2.0×10^{-1}	5.7×10^{-1}	4.7×10^{3}	5.2×10^{3}
^{60}Co	5.3×10^{0}	1.7×10^{0}	1.4×10^{4}	6.2×10^{5}
^{59}Ni	8.0×10^{4}	1.7×10^{-2}	1.4×10^{2}	2.5×10^{4}
^{63}Ni	9.2×10^{1}	3.2×10^{0}	2.6×10^{4}	4.2×10^{6}
^{65}Zn	6.7×10^{-1}	2.7×10^{-2}	2.2×10^{2}	1.2×10^{3}
^{90}Sr	2.8×10^{1}	6.4×10^{-3}	5.3×10^{1}	6.7×10^{3}
^{90}Y(a)	7.3×10^{-3}	---	---	6.7×10^{3}
^{95}Zr	1.8×10^{-1}	2.7×10^{-2}	2.2×10^{2}	2.0×10^{2}
^{99}Tc	2.1×10^{5}	4.3×10^{-5}	3.6×10^{-1}	6.5×10^{1}
^{106}Ru	1.0×10^{0}	2.7×10^{-2}	2.2×10^{2}	1.9×10^{3}
^{106}Rh(a)	9.5×10^{-7}	---	---	1.9×10^{3}
^{124}Sb	1.6×10^{-1}	6.6×10^{-3}	5.5×10^{1}	3.8×10^{1}
^{125}Sb	2.7×10^{0}	6.6×10^{-3}	5.5×10^{1}	1.3×10^{3}
^{129}I	1.7×10^{7}	8.5×10^{-6}	7.0×10^{-2}	1.3×10^{1}
^{134}Cs	2.0×10^{0}	6.4×10^{-1}	5.3×10^{3}	9.4×10^{4}
^{135}Cs	3.0×10^{6}	4.3×10^{-5}	3.6×10^{-1}	6.8×10^{2}
^{137}Cs	3.0×10^{1}	1.1×10^{0}	9.1×10^{3}	1.2×10^{6}
^{144}Ce	7.8×10^{-1}	2.7×10^{-2}	2.2×10^{2}	1.4×10^{3}
^{144}Pr(a)	3.0×10^{-5}	---	---	1.4×10^{3}
^{222}Rn(b)	1.0×10^{-2}	---	---	2.1×10^{2}
^{226}Ra	1.6×10^{3}	1.5×10^{-4}	1.2×10^{0}	2.1×10^{2}
^{230}Th	8.0×10^{4}	9.4×10^{-5}	7.8×10^{-1}	1.4×10^{2}
^{232}Th	1.4×10^{10}	1.1×10^{-5}	9.1×10^{-2}	1.6×10^{1}
^{235}U	7.1×10^{8}	4.3×10^{-5}	3.6×10^{-1}	6.5×10^{1}
^{238}U	4.5×10^{9}	9.4×10^{-4}	7.8×10^{0}	1.4×10^{3}
^{237}Np	2.1×10^{6}	6.1×10^{-8}	5.1×10^{-4}	9.2×10^{-2}
^{238}Pu	8.6×10^{1}	4.3×10^{-4}	3.6×10^{0}	6.0×10^{2}
^{239}Pu	2.4×10^{4}	5.7×10^{-5}	4.7×10^{-1}	8.5×10^{1}
^{240}Pu	6.6×10^{3}	8.9×10^{-5}	7.4×10^{-1}	1.3×10^{2}
^{241}Pu	1.3×10^{1}	2.2×10^{-2}	1.8×10^{2}	1.6×10^{4}
^{242}Pu	3.8×10^{5}	3.2×10^{-7}	2.6×10^{-3}	4.7×10^{-1}
^{241}Am	4.6×10^{2}	4.0×10^{-5}	3.3×10^{-1}	5.1×10^{2}
^{243}Am	8.0×10^{3}	2.8×10^{-6}	2.3×10^{-2}	4.1×10^{0}
^{242}Cm	4.4×10^{-1}	3.3×10^{-3}	2.7×10^{1}	9.4×10^{1}
^{244}Cm	1.8×10^{1}	2.5×10^{-4}	2.1×10^{0}	2.2×10^{2}

(a) Short-lived daughter of parent with same mass number.
(b) Short-lived daughter of ^{226}Ra.

an estimate has been made of the relative activity levels for the principal isotopes assumed to be present in waste buried in a slit trench. This assumed radionuclide inventory is shown in Table 7.3-4.

TABLE 7.3-4. Radionuclide Inventory for a Slit Trench (fractional activity at time of burial)

Radionuclide	Half Life (Years)	Fractional Activity
^{54}Mn	8.3×10^{-1}	4.0×10^{-2}
^{55}Fe	2.6×10^{0}	5.0×10^{-1}
^{59}Fe	1.2×10^{-1}	2.0×10^{-2}
^{58}Co	2.0×10^{-1}	5.0×10^{-2}
^{60}Co	5.3×10^{0}	3.5×10^{-1}
^{59}Ni	8.0×10^{4}	3.0×10^{-4}
^{63}Ni	9.2×10^{1}	4.0×10^{-2}

7.4 REFERENCE SITE CHARACTERISTICS

This section summarizes pertinent geologic, hydrologic, and meteorologic characteristics of the arid western and humid eastern sites used as reference sites for this study. Data presented in this section represent average values for site parameters found in current literature describing the Richland, Washington, site (the reference western site) and the Sheffield, Illinois, site (the reference eastern site).

The decision to base reference site characteristics on real sites does not imply any intent on the part of the authors of this report to judge the suitability of these sites for shallow-land disposal of radioactive waste. The site data that are presented should be understood as simply being representative of arid western and humid eastern sites, respectively.

Water constitutes a major potential transport mechanism for the migration of radioactivity from LLW burial sites. Some general characteristics of western sites that determine the effectiveness of water as a transport mechanism include:

- low annual precipitation with evaporation greatly in excess of precipitation
- great depth to ground water
- soil with moderate to high permeability and relatively low adsorptive capacity
- relatively great distance from the burial ground to the point of groundwater discharge into surface streams.

Some general characteristics of eastern sites that determine the effectiveness of water as a transport mechanism include:

- high annual precipitation
- shallow depth to ground water
- soil with low permeability and relatively high adsorptive capacity
- relatively short distance from the burial ground to the point of groundwater discharge into surface streams.

At any site the potential exists for interstitial permeability and adsorptive capacity to be bypassed by flow along subsurface sand and gravel lenses, joints, and fractures. The potential for this to occur must be determined on a site-specific basis. Hence, the possible presence of lenses, joints, and fractures is not specifically included in these reference site descriptions.

7.4.1 Arid Western Site

The geologic and hydrologic characteristics of the reference western site are summarized in Section 7.4.1.1. Meteorological data for this site are summarized in Section 7.4.1.2. Data for the reference western site are based on published reports(12-16) of the Hanford (Richland, Washington) site.

7.4.1.1 Geology and Hydrology

A generalized cross section that shows the geology of the reference western site is presented in Figure 7.4-1. Parameters that describe the geology and hydrology of this site are listed in Table 7.4-1.

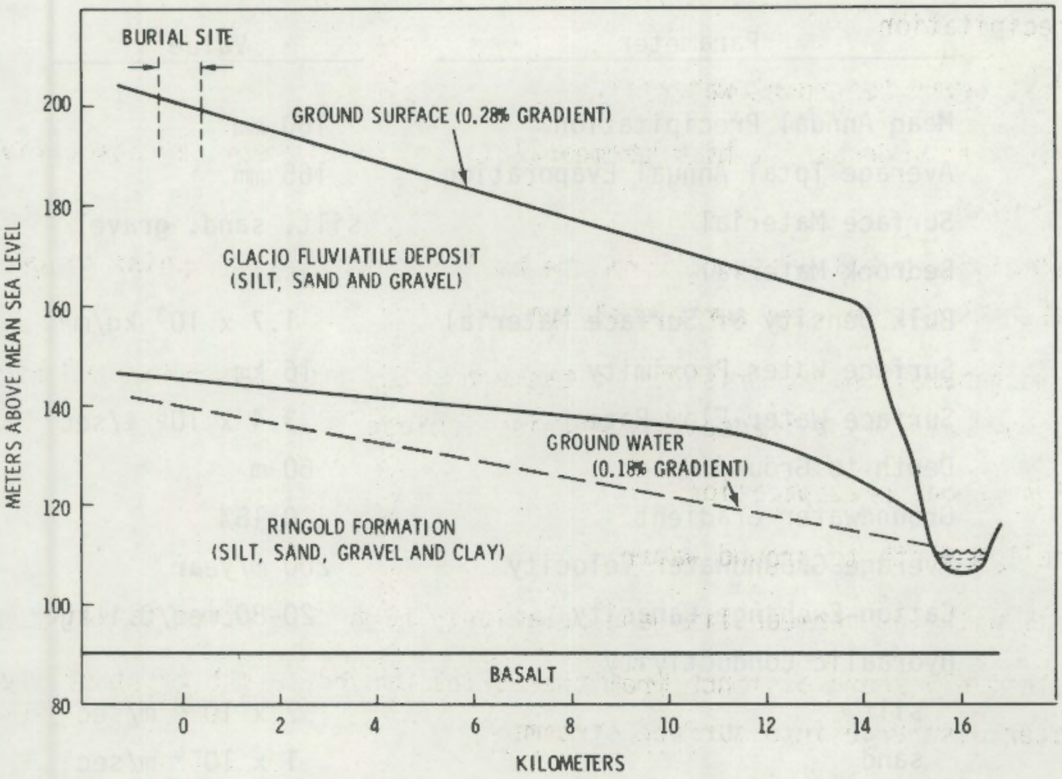

FIGURE 7.4-1. Generalized Cross Section of Reference Western Site

The topography of the western site is generally flat or gently sloping. Surficial materials are mainly sand and gravel of glaciofluvial deposits. These deposits are predominantly stream-laid lenticular beds of granule and pebble gravel, cobble gravel, and boulders in a sandy matrix. Overlying the glacial deposits in some places are mounds of dune sand and loess, a windblown cover of silt.

Underlying the glaciofluvial surface deposits and directly overlying the bedrock are a series of nearly horizontal beds of silt, sand, clay, and gravel. The most common type of material is weakly lithified siltstone in beds up to 3 m thick, with some interbedded fine sand.

TABLE 7.4-1. Site Characteristics for the Reference Western Site

Parameter	Value
Mean Annual Precipitation	160 mm
Average Total Annual Evaporation	165 mm
Surface Material	silt, sand, gravel
Bedrock Material	basalt
Bulk Density of Surface Material	1.7×10^3 kg/m^3
Surface Water Proximity	16 km
Surface Water Flow Rate	3.4×10^6 ℓ/sec
Depth to Ground Water	60 m
Groundwater Gradient	0.18%
Average Groundwater Velocity	200 m/year
Cation Exchange Capacity	20-80 meq/0.1 kg
Hydraulic Conductivity	
silt	7×10^{-6} m/sec
sand	1×10^{-4} m/sec
gravel	3×10^{-4} m/sec
Effective Porosity	
silt	0.20
sand	0.30
gravel	0.35
Distribution Coefficient, K_d[(a)]	
Strontium	20 ℓ/kg
Cesium	100 ℓ/kg
Ruthenium	400 ℓ/kg
Uranium	20 ℓ/kg
Plutonium	200 ℓ/kg
Americium	1200 ℓ/kg

(a) Isotopes included in this list are those for which distribution coefficients are reported in the literature. An expanded set of distribution coefficients for all of the isotopes considered in this study is given in Table C.2-3 of Volume 2.

The distance from the ground surface to bedrock at the burial site is in excess of 100 m. Bedrock consists mainly of basaltic lava flows, 3 to 60 m in individual thicknesses. Interposed between some flows, particularly in the upper part of the formation, are volcanic ash, palagonite, and some sedimentary rocks.

The predominant vegetation is sagebrush and cheatgrass. Spiny hopsage and rabbitbrush may be intermingled with sagebrush shrubs. The general sparseness of herbaceous cover tends to favor invasion by tumbleweeds.

Mule deer, elk, cottontail rabbits, coyotes, badgers, porcupines, raccoons and weasels are scattered throughout the area but rarely frequent the burial site. Small mammals, particularly the Great Basin pocket mouse, deer mice, and ground squirrels are abundant, and are the most likely to invade the burial ground.

The hydrology of the reference site is marked by very low precipitation and high summer temperatures, which lead to soil moisture deficiencies and a resulting low rate of groundwater recharge by direct infiltration. The precipitation that infiltrates the soil is probably used to replenish deficiencies in soil moisture at relatively shallow depths. These deficiencies result both from sparse precipitation and from a high rate of evapotranspiration during the summer months.

Ground water occurs in the intergranular openings in the glaciofluvial surface deposits and the lacustrine deposits of sand, clay, and gravel that underlie the surface deposits. In the burial site vicinity, the water table is located about 60 m below the ground surface. Recharge is mainly the result of precipitation runoff from the mountains several kilometers west and southwest of the site. The average rate of groundwater flow at the site is probably about 0.45 to 0.6 m/day.

No ponds or lakes exist in the immediate vicinity of the burial site. The nearest surface water is a large river located about 16 km from the site. The measured flow rate of the river varies on a seasonal basis from a low of about 1.0 x 10^6 ℓ/sec to a high of about 4.5 x 10^6 ℓ/sec. The long-term average annual flow is about 3.4 x 10^6 ℓ/sec. The height of the burial ground above the river is such that flooding cannot be considered a potential problem.

7.4.1.2 Meteorology

Table 7.4-2 gives averages of climatic elements for the reference western site based on rainfall records for the period 1912 to 1970 and wind speed records for the period 1945 to 1970.(13) Figure 7.4-2 shows average monthly precipitation amounts for this period, and Figure 7.4-3 shows average monthly wind speed.

TABLE 7.4-2. Average Climatic Elements for the Reference Western Site

Month	Average Daily Maximum Temperature (°C)	Average Daily Minimum Temperature (°C)	Mean Monthly Precipitation (mm)	Mean Monthly Snow (mm)	Prevailing Wind Direction	Mean Monthly Wind Speed (km/hr)	Mean Relative Humidity (%)
January	2.6	-5.5	23.6	132	NW	10.1	75.7
February	7.4	-2.7	15.7	58	NW	11.2	69.9
March	13.6	1.0	9.1	8	WNW	13.4	55.8
April	19.1	4.5	10.2	T	WNW	14.4	46.7
May	24.2	8.9	11.4	T	WNW	14.1	42.7
June	28.4	13.1	14.5	0	WNW	14.7	39.6
July	33.2	16.1	3.6	0	WNW	13.8	31.8
August	31.8	15.1	4.8	0	WNW	12.8	34.8
September	26.4	10.4	7.6	0	WNW	12.0	40.6
October	18.5	4.9	14.7	T	WNW	10.7	57.8
November	9.2	-0.3	21.6	30	NW	9.9	72.9
December	4.0	-3.3	21.8	94	NW	9.6	80.4

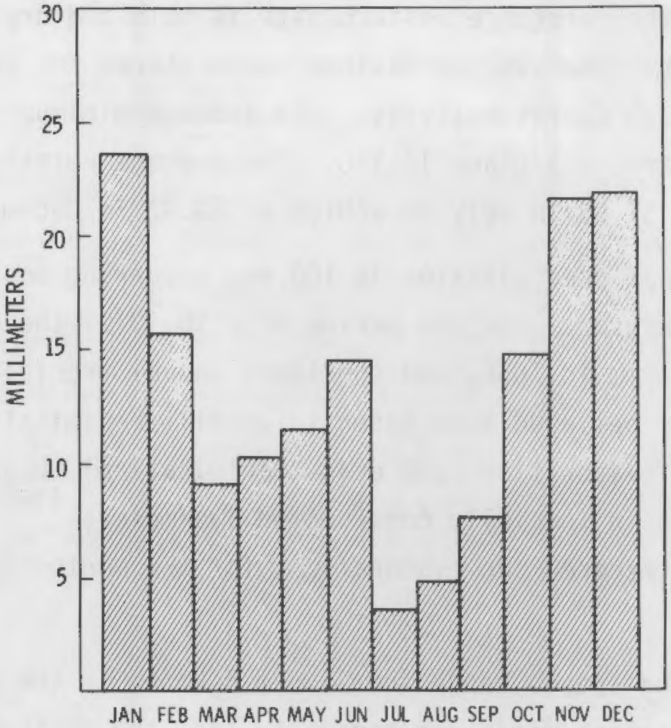

FIGURE 7.4-2. Average Monthly Precipitation Amounts for the Reference Western Site

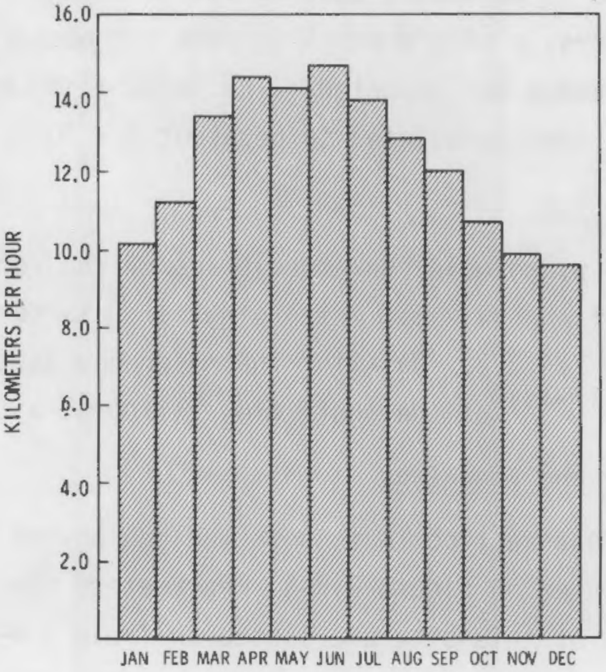

FIGURE 7.4-3. Mean Monthly Wind Speed for the Reference Western Site

The climate of the reference western site is mild and dry with occasional periods of high winds. The average maximum temperatures for January and July are 2.6°C and 33.2°C, respectively. The average minimum temperatures for the same months are -5.5°C and 16.1°C. The average relative humidity varies from a low of 31.8% in July to a high of 80.4% in December.

The average annual precipitation is 160 mm, occurring mostly in the late fall and early winter. For the period 1912 to 1970, the greatest annual precipitation was 291 mm in 1950, and the least annual precipitation was 83 mm in 1967. It is believed that essentially all precipitation returns to the atmosphere by evaporation (and evapotranspiration), based on measurements made since 1971 in specially constructed lysimeters.(15) The long-term average (22 years of record) pan evaporation, for the months April through October, is 134 mm.

Mean monthly wind speeds range from about 8 km/hr in the winter to 15 km/hr in the summer. Prevailing winds are generally from the northwest, and strongest winds are from the southwest. Peak wind gusts exceeding 65 km/hr have been observed at least once in every month of the year. Tornadoes are infrequent in the region and tend to be small, causing little damage when they occur. During the past 30 years, a single small tornado was observed in the vicinity of the site, but no damage was reported. The probability of a tornado striking the burial ground has been calculated to be about 1 x 10^{-5}/year.(15)

7.4.2 Humid Eastern Site

The geologic and hydrologic characteristics of the reference eastern site are summarized in Section 7.4.2.1. Meteorological data for this site are summarized in Section 7.4.2.2. Data for the reference eastern site are based on published reports(17-19) of the Sheffield, Illinois, site.

7.4.2.1 Geology and Hydrology

A generalized cross section that shows the geology of the reference eastern site is presented in Figure 7.4-4. Parameters that describe the geology and hydrology of this site are listed in Table 7.4-3.

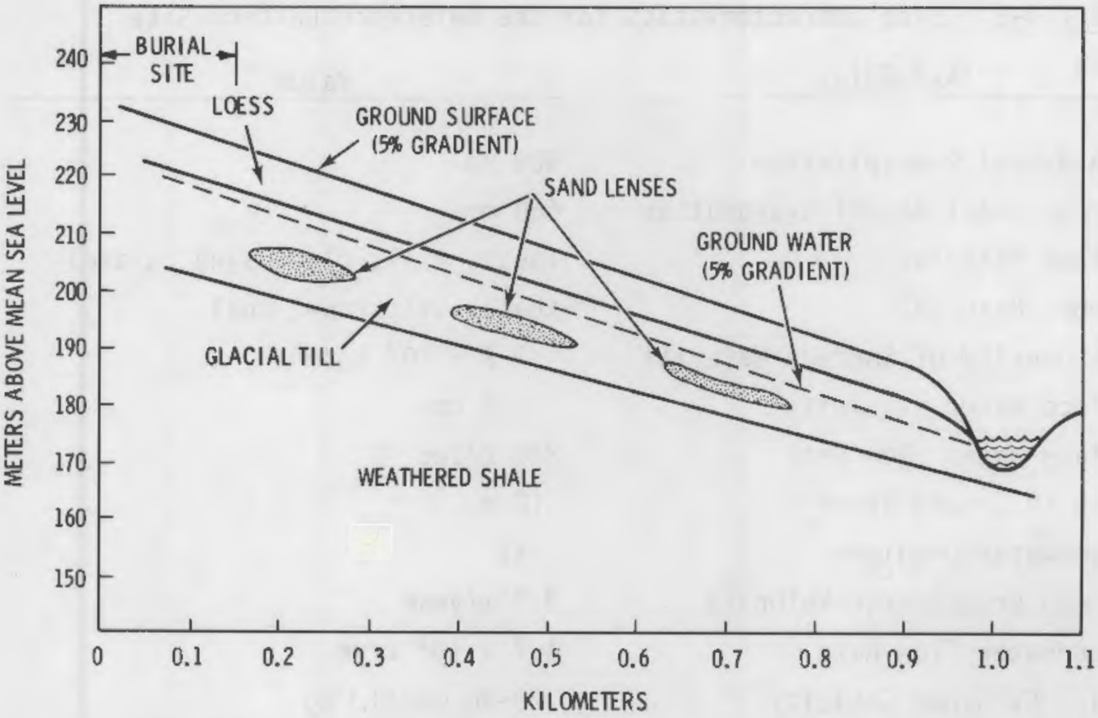

FIGURE 7.4-4. Generalized Cross Section of Reference Eastern Site

The eastern site is located on rolling terrain. The surficial geologic materials at the site consist of windblown silt (loess) over glacial till and clay deposits. These materials have a maximum thickness of about 30 m and directly overlie sedimentary rocks of the Pennsylvanian period.

The loess generally consists of a firm-to-stiff brown clay silt with a trace of fine sand. It was derived from fine sediment carried by glacial meltwater and subsequently picked up and redeposited by the wind. The thickness of the loess deposit varies from about 1 to 12 m at the site.

The glacial drift beneath the loess consists mainly of silty, sandy, pebbly clay (till) that was deposited directly by glacial ice. The till often resembles the underlying shale bedrock from which it was derived during glaciation. Sand lenses have been found at several positions within the glacial materials. The sands encountered vary in texture from very silty fine sand to course sand and gravel.

TABLE 7.4-3. Site Characteristics for the Reference Eastern Site

Parameter	Value
Mean Annual Precipitation	909 mm
Average Total Annual Evaporation	660 mm
Surface Material	loess, till, clay, sand, gravel
Bedrock Material	shale, siltstone, coal
Bulk Density of Surface Material	1.7×10^3 kg/m^3
Surface Water Proximity	1.0 km
Surface Water Flow Rate	220 ℓ/sec
Depth to Ground Water	10 m
Groundwater Gradient	5%
Average Groundwater Velocity	3.7 m/year
Groundwater Flow Rate	4.7×10^7 ℓ/yr
Cation Exchange Capacity	20-80 meq/0.1 kg
Hydraulic Conductivity	
loess	2×10^{-8} m/sec
till	3×10^{-8} m/sec
sand	3×10^{-5} m/sec
shale	2×10^{-7} m/sec
Effective Porosity	
loess	0.20
till	0.02
sand	0.30
shale	0.15
Distribution Coefficient, K_d (a)	
Cobalt	350 ℓ/kg
Strontium	10 ℓ/kg
Cesium	40 ℓ/kg

(a) Isotopes included in this list are those for which distribution coefficients are reported in the literature. An expanded set of distribution coefficients for all of the isotopes considered in this study is given in Table C.2-3 of Volume 2.

The bedrock that underlies the glacial deposits consists primarily of shale, with some coal, siltstone or sandstone, and thin beds of limestone.

Glacial deposits of the kind (loess and till) found at the burial site generally have low permeability to water, provided they do not contain thick beds of relatively well-sorted sand and gravel. Field permeability tests(19) have confirmed that the glacial sediments at the site do have a relatively low permeability to percolating ground water. However, the movement of water in these materials is sometimes controlled by the presence of sand lenses and joints and fractures that usually occur in these deposits.

The land bordering the site is used primarily for agricultural (mainly pasture) and recreational purposes. Major crops grown in the area include alfalfa, soybeans, corn, and oats. A recreational area that includes a small lake used for boating and fishing is located about 10 km from the site. Vegetation in the area was originally identified as supporting a climax deciduous forest. While isolated pockets of this vegetation still exist, nearly all of the accessible virgin woodland areas in the region have been burned, cut or plowed. Mammals most likely to be found on the site include native rats and mice. Other mammals that might be occasional visitors are raccoons and opossums.

The eastern site is characterized by a relatively shallow water table. For this study the water table is assumed to be 10 m below ground surface. Recharge to the site groundwater system occurs by infiltration of precipitation through the surficial deposits to saturated zones in the glacial till and weathered shale. Computations indicate that about 65 mm of water percolate into the groundwater system during the average year in the area of the site.

A small stream that drains the site is located about 1.0 km from the site boundary. There is no historical record of flooding of the site. However, a combination of rapid snow melt and high rainfall could result in potentially serious surface runoff problems.

7.4.2.2 Meteorology

Table 7.4-4 gives averages of climatic elements for the reference eastern site based on meteorological data for the 47-year period 1929 to 1975.(17)

TABLE 7.4-4. Average Climatic Elements for the Reference Eastern Site

Month	Average Daily Maximum Temperature (°C)	Average Daily Minimum Temperature (°C)	Mean Monthly Precipitation (mm)	Mean Monthly Snow (mm)	Prevailing Wind Direction	Mean Monthly Wind Speed (km/hr)	Mean Relative Humidity (%)
January	-1.1	-10.6	42.2	225	WNW	17.1	70
February	1.3	-8.3	32.8	245	WNW	17.8	69
March	7.2	-3.1	65.3	252	WNW	19.2	69
April	16.3	4.1	97.0	120	NW	19.5	66
May	22.2	10.1	99.6	4	E	16.6	66
June	27.4	15.7	112.3	0	S	14.7	67
July	29.6	17.7	115.8	0	E	12.0	71
August	28.8	16.7	85.6	0	E	11.5	72
September	24.4	11.8	97.5	0	S	13.0	74
October	18.9	6.0	68.3	84	S	14.6	68
November	8.9	-1.0	47.5	198	WNW	17.1	72
December	1.4	-7.5	45.0	213	WNW	16.8	76

Figure 7.4-5 shows average monthly precipitation amounts for this period, and Figure 7.4-6 average monthly wind speed.

The reference eastern site has a continental climate, with a wide temperature range throughout the year. Summers are characterized by occasional periods of intense heat and high humidity and winters by periods of extreme cold accompanied by moderate-to-high winds. The average maximum temperatures in January and July are -1.1°C and 29.6°C, respectively. The average minimum temperatures for the same months are -10.6°C and 17.7°C. The average relative humidity stays at about 70% throughout the year.

The average annual precipitation is 909 mm, occurring mostly as rain during the late spring and summer months. Monthly precipitation amounts in excess of 250 mm have been recorded during summer months on numerous occasions during the past 50 years, with the maximum recorded monthly precipitation being 361 mm in September, 1970. The months of December through March are months of moderate snowfall, with an average of 200 to 250 mm of snow falling during each of these months. Maximum snowpack accumulation at the site occurs

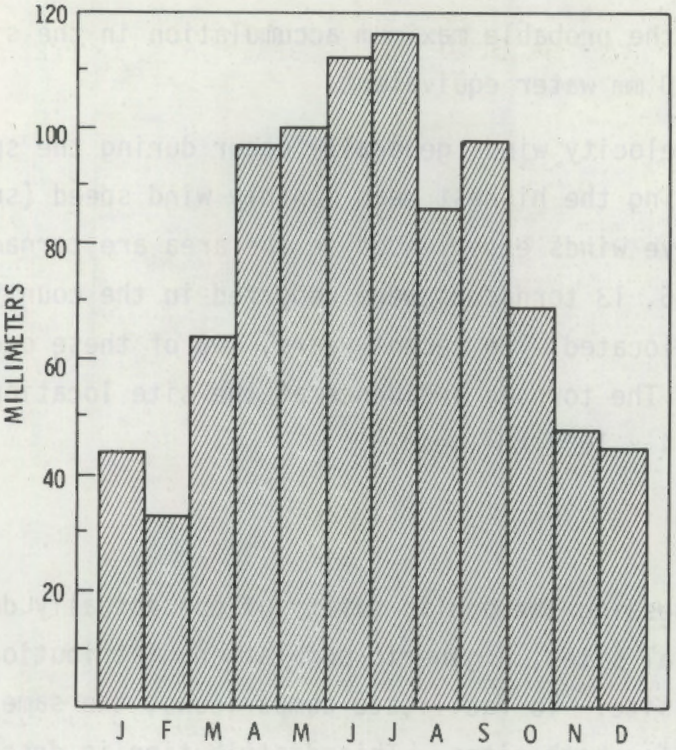

FIGURE 7.4-5. Average Monthly Precipitation Amounts for the Reference Eastern Site

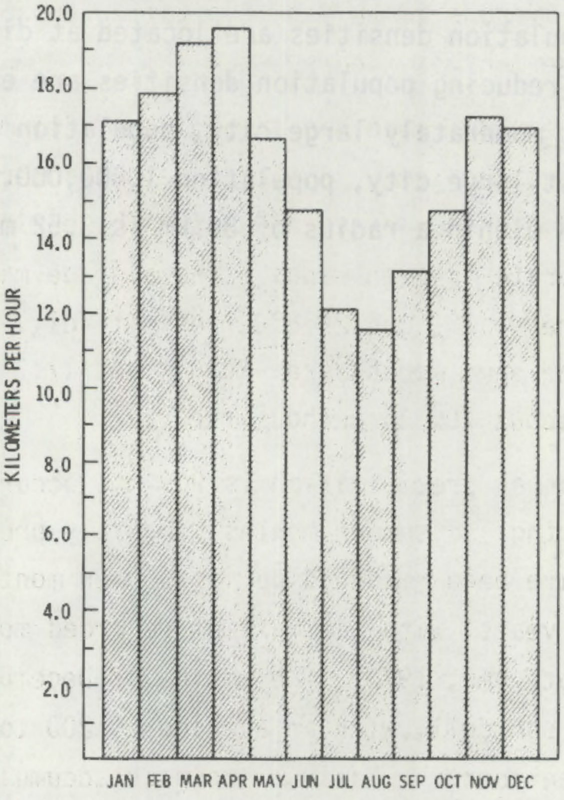

FIGURE 7.4-6. Mean Monthly Wind Speed for the Reference Eastern Site

during March, and the probable maximum accumulation in the site area is estimated to be 250 mm water equivalent.

The highest velocity winds generally occur during the spring, with the month of April having the highest mean monthly wind speed (see Table 7.4-4). The most destructive winds experienced in the area are tornadoes. During the period 1950 to 1975, 13 tornadoes were reported in the county where the reference site is located. In recent years, two of these occurred within 8 km of the site. The tornado incidence at the site location for the period 1953 to 1972 is $1.4 \times 10^{-4}/\text{km}^2$-year.(17)

7.5 DEMOGRAPHY

To aid in assessing the public safety of conceptually decommissioning the reference LLW burial sites, a generic population distribution is assumed for the area around a site. To facilitate comparisons, the same population distribution is used for both sites. This distribution is described in detail in Appendix A of Volume 2 and summarized in the following paragraph.

The site is located in a rural area that has a relatively low population density. Higher population densities are located at distances 16 to 64 km away, and gradually reducing population densities are encountered out to 177 km. The closest moderately large city, population 40,000, is about 32 km distant. The closest large city, population 1,800,000, is about 48 km away. The total population within a radius of 80 km is 3.52 million.

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8.0 ANALYSIS OF RELEASE CONDITIONS USING PATHWAY METHODOLOGY

The purpose of this section is to describe and demonstrate an analysis of release conditions for LLW burial grounds after burial operations cease. The analysis uses pathway methodology and is based on the concept of an allowable annual dose to the maximum-exposed individual. For an LLW burial ground where a subsurface radioactive inventory remains, release conditions may include a combination of waste relocation requirements, site/waste stabilization procedures, institutional controls, and property-use restrictions for the general public. The acceptability of a set of release conditions for a particular site is determined based on comparisons of calculated maximum annual doses to an annual dose limit.

Some uncertainties in the analysis are discussed in Section 8.1. Definitions are given in Section 8.2. Existing guidance on annual dose limits is summarized in Section 8.3. The technical approach for determining release conditions is described in Section 8.4. Example release criteria calculations for the reference western and eastern sites are presented in Section 8.5.

8.1 ANALYSIS UNCERTAINTIES

The methodology used to determine release conditions for a decommissioned LLW burial ground consists of comparing an established annual dose limit to the calculated maximum annual organ doses resulting from the residual inventory. Organ doses are calculated for a hypothetical maximum-exposed individual. Results and conclusions derived from this pathway methodology approach depend on 1) the burial ground radionuclide inventory, 2) the models used to evaluate potential exposure pathways and to estimate doses to the maximum-exposed individual, and 3) the parameter values used in the models. Some of the uncertainties that exist in inventories, models, and parameters are discussed below. Because of these uncertainties, a generally conservative approach is attempted in this study that may result in conservative (high) estimates of doses to the maximum-exposed individual.

Results of the pathway analysis for the reference western and eastern sites raise questions about the feasibility of unrestricted release of these sites. Therefore, criteria are developed that would permit conditional release of the sites. It must be emphasized that these results apply specifically to the reference sites and to the assumed radionuclide inventory and are subject to the uncertainties described below. Land use limitations for individual real sites should not be inferred from these results. The methodology presented in this study must be reapplied and the doses recalculated for each burial ground which has different inventory and different site characteristics. This must be done using site-specific parameters to draw any conclusions about possible acceptable public uses of those decommissioned sites.

8.1.1 Inventory Uncertainties

Three radionuclide inventory-related factors affect the results of radioactive dose calculations: 1) isotopic mixture, 2) radioactivity concentration of the waste (Ci/m^3), and 3) total radioactivity buried (Ci). The isotopic mixture of the waste inventory (the percent that each isotope contributes to the total radioactivity) affects the critical exposure pathways, the critical organs, and the year in which the annual dose is greatest. The inhalation and farm product ingestion doses are both directly related to the concentration of specific radionuclides in the waste. Radionuclide concentrations in the nearby river and in water from an onsite well and the external dose from onsite activities are all directly related to the total radioactivity buried.

A generic radionuclide inventory is used for this study. The decision to use a generic inventory was made because data on radionuclide inventories at existing commercial sites are incomplete and because such data as are available indicate that significant differences exist in isotopic compositions of waste buried at the different commercial sites. The reference inventory chosen for this study includes both reactor and institutional waste. It differs from current burial ground inventories through 1) the inclusion of a significant amount of reactor decommissioning waste and 2) a greater total amount of radioactivity because of an assumed 30-year operating lifetime for the reference burial grounds.

Differences between the reference radionuclide inventory and the radionuclide inventories at the six commercial sites in the United States are discussed in Appendix B of Volume 2. The assumed radioactivity of the reference site is one or two orders of magnitude greater than the actual radioactivity buried at individual real sites. Specific activities of radioactive byproduct wastes buried at the six commercial sites range from a factor of 4 greater to an order of magnitude smaller than the byproduct specific activity assumed for the reference site.

It is of interest to give some consideration to inventories that could be allowed in future burial grounds to permit unrestricted release of these sites after a finite control period. Consequently, examples of modified inventories for the reference western and eastern sites are given in Table 8.4-2. Pathway analysis considerations lead to the conclusion that unrestricted release of the reference burial grounds containing these modified inventories would be possible 200 years after site closure. Comparison of the original reference inventory of Table 7.3-3 with the modified inventories indicates the sensitivity of burial ground release conditions to the presence in the waste of long-lived or highly soluble radionuclides.

8.1.2 Modeling Uncertainties

The modeling of radionuclide transport and the subsequent calculation of critical organ doses have many uncertainties. The modeling analysis used for this study is believed to be within the framework of the acceptable state of the art for performing such calculations. Clearly, what is required is additional modeling validation to resolve the many uncertainties that can now only be qualitatively inferred. Additional research programs, described in Section 15, directed toward a comparison of measured and predicted results and based on real sites in terms of radionuclide inventory and site/waste stabilization techniques are a necessary prerequisite to further progress in this area.

Where uncertainty exists, an attempt is made to err on the side of conservatism. However, in some instances assumptions are made that may not be conservative. Examples of possible nonconservatisms are the assumption that corrosion of slit trench canisters and of the stainless steel components inside the canisters is minimal during the 200-year period of administrative control of the site, and the neglect of the effect of chelating agents in increasing the mobility of certain radionuclides. Such assumptions are made because of the inadequacy of the data base that would lead to meaningful quantitative results.

Radionuclide migration via the groundwater pathway is simulated by use of the MMT (Multicomponent Mass Transport) model.(1) Results obtained through use of the model are sensitive to the values of input parameters, as discussed below.

There are no well established models for treating overland flow. In this study, to account for overland flow by the MMT model, the burial trenches are assumed to be saturated with water. All of the water flowing through the burial trenches arrives at the surface and flows overland in a small stream to the river 1 km from the site. Since no significant sorption is assumed for this case, it is far too conservative to use the same leach times that were used for groundwater modeling. Hence, longer leach times, recommended by preliminary data from the Waste Isolation Safety Assessment Program,(2) are used. (See Section C.2.4.1 for additional details.) The assumptions made for overland flow result in conservatively high estimates of the curies of radioactivity that are leached from the burial ground and reach the river via this pathway.

The calculated maximum annual doses are based on the ICRP Publication 2(3) and the ICRP Publication 10A(4) metabolic models, the ICRP Task Group Lung Model,(5) and standard man parameter values. To the best of our knowledge, there are no reported assessments of the accuracy of dose calculations using these models and parameter values. Dose results are usually presented with no indication of the error associated with their use. Present insights into the degree of uncertainty involved are very limited and qualitative.(6)

8.1.3 Parameter Uncertainties

Many uncertainties exist in the parameter values used with the MMT model to simulate radionuclide migration via the groundwater pathway. Order of magnitude uncertainties exist in values for soil permeability, dispersion coefficients, distribution coefficients (K_d), and leach times. Some of these parameter values are relatively easy to measure in the laboratory, but extremely difficult to measure under field conditions. Section C.2.4 of Volume 2 contains a discussion of distribution coefficient measurements. Because of measurement uncertainties, conservative values have generally been used for the model parameters in this study. However, as noted above, the effect of chelating agents on K_d values has been ignored, and this may be a nonconservative assumption.

Leach rates are influenced by many factors including the characteristics of the radionuclide and the waste material, the properties of the leachant, and the environment in which leaching occurs. Specific field data on the leachability of radionuclides from waste buried in LLW burial grounds are not available. Published leach rate data come mainly from laboratory experiments in which small samples are leached by distilled water or by actual or simulated disposal-environment water. The leach times used in this study are discussed in Section C.2.4 of Volume 2. Section C.2.4 also contains a discussion of the effect of a change in leach time on predicted radionuclide concentrations in the surface stream of the reference eastern site.

8.2 DEFINITIONS

Definitions for some of the terms used to describe the pathway methodology are given below. Additional definitions and terminology are found in Appendix C of Volume 2 and in the Glossary.

Organs of Reference

Organs of reference are the specific organs of the human body for which radiation doses are calculated. In this study, the lungs, bone, thyroid glands, lower large intestine (LLI) of the GI-tract, and total body are selected as the critical organs of reference. The total body is the head and trunk of the human body, including active blood-forming organs, lenses of eyes, and gonads.

Exposure Pathways

Exposure pathways are the potential routes by which radionuclides or radiation may reach people. Exposure pathways of concern in calculating the dose to individuals located on the decommissioned burial ground are described in Section 8.4.2.

Maximum-Exposed Individual

This individual receives the maximum radiation dose to an organ of reference. The maximum-exposed individual is assumed to reside at the decommissioned LLW burial ground 24 hours a day. Maximized exposure pathway parameters are used.

Annual Dose

The annual dose is the radiation dose equivalent calculated during any year of continuous exposure. It is the sum of the doses received during the year of interest from all pathways, including the dose resulting in that same year from the intake of radionuclides during previous years. The highest value found is referred to as the maximum annual dose. The maximum annual dose is determined separately for each organ of reference. For ingested emitters, this methodology differs from the method of calculating the 50-year committed dose equivalent from 1 year's intake often used in performing environmental dose assessments of operating facilities.

Class W and Y Material

These materials include radionuclides that are slowly removed from the pulmonary region of the lung by gradual dissolution in extracellular fluids, or by translocation in particulate form to the GI-tract, blood, or lymphatic system. Class W represents material with maximum clearance half-times(a) in the lungs from a few days to a few months, and Class Y is used to describe material with maximum clearance half-times ranging from 6 months to several years.(5) The translocation class, as described by the Task Group Lung Model,(5) depends on the chemical nature of the compound inhaled. Material class assumptions for the reference waste inventory are given in Table C.1-1, Appendix C.

Class D Material

These materials include radionuclides that are dissolved upon contact with extracellular fluids and translocated to the blood. Class D material is expected to exhibit maximum clearance half-times of less than 1 day.(5) (See Table C.1-1 for material class assumptions.)

(a) The clearance half-time is the time required for the body to eliminate one-half of the organ burden of a given radionuclide. It does not include the effects of radioactive decay.

8.3 EXISTING GUIDANCE ON ANNUAL DOSE LIMITS

Some guidance currently exists defining the levels of radioactive surface contamination acceptable to the NRC for the termination of operating licenses.(7,8) Other suggested guidance is directed toward specific types of facilities or toward accident situations involving radioactivity.(9-14) There are currently no unique regulations or specific guidance on the acceptable annual dose to individuals living on or near a decommissioned LLW burial ground. Guidelines that could be interpreted as annual dose limit recommendations for the cases of interest to this study include:

1. Recommendations of the International Commission on Radiological Protection (ICRP), Publication 9.(15)
2. Recommendations of the International Commission on Radiological Protection (ICRP), Publication 26.(16)
3. Appendix I of 10 CFR 50, Guides for Design Objectives for Light-Water-Cooled Nuclear Power Reactors (NRC).(17)
4. 40 CFR 190 Environmental Radiation Protection Requirements for Normal Operations of Activities in the Uranium Fuel Cycle (EPA).(18)
5. 40 CFR 141 National Interim Primary Drinking Water Regulation (EPA).(19)
6. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment (EPA).(20)
7. Surgeon General's Guidelines (DHEW).(21)
8. "de minimus" Concentrations of Radionuclides in Solid Wastes (AIF).(22)

None of these guidelines, which provide limits on dose rate to the public from nuclear facilities, was proposed specifically for decommissioned property. The guidelines do, however, suggest different annual dose limits, or an equivalent to an annual dose limit, ranging from annual doses to the total body of 1 to 500 mrem per year, and from 3 mrem to 3 rem per year for individual internal organs.

It is not within the scope of this study to propose or recommend annual radiation dose limits for public exposure. An annual dose limit of 50 mrem to the maximum-exposed individual is assumed for the purpose of demonstrating the site release criteria methodology. Selection of this annual dose limit is not intended, nor should it be inferred, as a recommendation for limiting radiation exposure of the public from decommissioned nuclear facilities.

8.4 TECHNICAL APPROACH

The basic premise for the analysis of burial ground release conditions described in this study is that no member of the public will receive a radiation dose from a decommissioned facility in excess of a limit yet to be established by U.S. regulatory agencies. Discussions of use categories for decommissioned LLW burial grounds and of the methodology for determining release conditions for a decommissioned site are contained in the following subsections.

8.4.1 Definition of Use Categories

During the planning stages of decommissioning, a variety of future uses may be considered for the LLW burial ground. Three general use categories are considered in this study:

Restricted Use

Restricted use permits only nuclear activities to be conducted at the decommissioned LLW burial ground. The exposure of workers and the public is controlled by the restrictions imposed by the nuclear license.

Conditional Use

Conditional use of the decommissioned burial ground is an interim condition that may permit limited public use of the site for activities that do not disturb the waste, assuming that controls to ensure public safety can be adequately enforced. The interim period lasts until the important radionuclides in the waste decay to insignificant levels or until additional decommissioning procedures reduce the radiation dose to levels that permit unrestricted use. The enforcement of conditional use controls or restrictions, such as physical barriers or signs and other radiation exposure controls, may require some form of nuclear licensing or zoning laws.

The problems with shallow-land burial of low-level radioactive waste and uranium mill tailings are similar, as explicitly indicated in the draft GEIS on uranium mill tailings.(23) The Uranium Mill Tailings Control Act(24) requires government ownership of tailings and tailings disposal sites and allows for conditional release with surveillance as an acceptable situation. (See Section 5.1 for a discussion of the Uranium Mill Tailings Control Act.) It is reasonable to expect that existing LLW burial grounds can be treated in a similar way. Government ownership and continued surveillance of these LLW burial sites may be necessary to confirm that the sites are not disrupted by natural forces, such as erosion, or by human activity.

Unrestricted Use

Unrestricted use of the decommissioned burial ground means that the potential exposure to members of the public from buried nuclear waste will not exceed the annual dose limit that may be established by U.S. regulatory agencies. Decommissioning a site will, in general, result in the unrestricted release of land areas that the public had been denied use of during the operational life of the burial ground.

We have not attempted to define all of the possible specific uses that may fall into each of these use categories. The ability to enforce the license restrictions required for the first two categories for long periods of time requires ongoing surveillance. Each potential use restriction will require its own specific analysis. Furthermore, the restriction can best be assured if the responsibility lies with a government agency. Release conditions acceptable for members of the public may include some combination of the three general use categories defined above.

8.4.2 Potential Exposure Pathways

The potential exposure pathways considered in this study are shown in Figure 8.4-1. The rectangular boxes represent locations where radionuclide concentrations can be measured. The circles identify the various potential transport mechanisms through which the radionuclides may be moved about in the environment. The dashed lines indicate potential exposure pathways to people. The most direct radiation exposure pathway from buried radionuclides

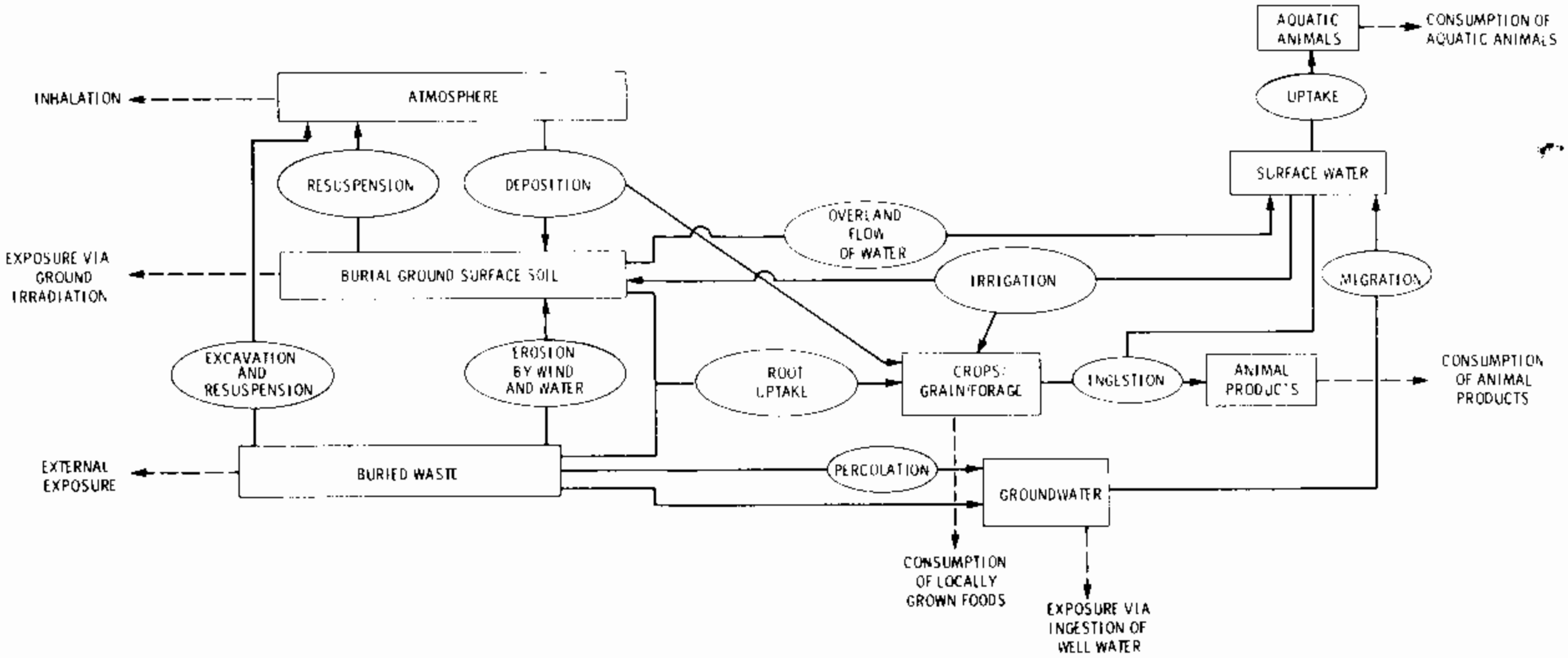

FIGURE 8.4-1. Potential Environmental Exposure Pathways at a Low-Level Waste Burial Ground

is direct irradiation of an individual located on the burial ground. The remaining potential exposure pathways result from release mechanisms discussed in Section 10. These release mechanisms can be classified as geomorphological, hydrological, biological, and human activity.

Geomorphological release mechanisms cause surface exposure of buried radioactive waste as a result of shaping or reshaping of the earth's surface by natural forces. Once the waste is exposed, resuspension by surface winds becomes a significant environmental transport mechanism. Inhalation of the resuspended radioactive material may occur, and crops grown locally may be contaminated from deposition of the resuspended radionuclides. If the contaminated crops are consumed by humans, internal exposure via ingestion results. External exposure from submersion in the resuspended radioactive material is not considered to be an important exposure pathway.

Hydrological release mechanisms are those in which radionuclide migration results from the movement of water through the burial site. These mechanisms include direct contact of the waste with ground water, percolation of rain water through the waste into the ground water, and overland flow of infiltrated water from the waste trenches to a nearby surface stream or river. The potential exposure pathways that may result from these release mechanisms include:

- ingestion of water from a well drilled on the burial site into the shale formation below the waste or ingestion of water from a nearby river
- ingestion of aquatic foods taken from a nearby river contaminated by radionuclides released through the ground water or by overland flow
- ingestion of crops irrigated with contaminated water taken from the river
- direct irradiation from crop fields irrigated with contaminated river water and from soil contaminated by overland flow of radionuclides
- inhalation of resuspended radionuclides deposited on crop fields by irrigation or by overland flow
- ingestion of foods contaminated by the deposition of resuspended irrigation and overland flow deposits.

The dose contribution from recreational activities around the river is insignificant due to the small number of hours spent in this exposure mode.

The biological action of root uptake of radionuclides from the buried waste and from waste in the topsoil may establish a link to humans via the ingestion of locally grown crops. Ecological pathways involving the movement of waste material by waterfowl, burrowing animals, blowing weeds, etc., are not considered in this study.

A potential exposure pathway also exists where individuals ingest contaminated animal products. The animal products are contaminated by the animals' consumption of contaminated river water, forage, or grain. The food eaten by the animal can become contaminated by deposition of resuspended radioactive material, by irrigation with contaminated river water, and by root uptake.

The last release mechanism considered is human activity. Excavation into the radioactive waste burial ground may release significant quantities of radionuclides into the atmosphere. The two most important exposure pathways during this event are inhalation and direct irradiation from the uncovered waste. If a slit trench is uncovered, external exposure from the waste canisters becomes the important pathway to the intruder during the first 125 years after burial.

The models used to estimate the radiation dose via these potential exposure pathways are discussed in Appendix C of Volume 2. Because of the different time-dependence of each of the release mechanisms, the exposure pathways are not all operable during the same time periods.

8.4.3 Determination of Maximum Annual Radiation Dose

To determine release conditions for a decommissioned LLW burial ground this study uses the concept of the maximum annual dose to an organ of reference of a maximum-exposed individual. The maximum-exposed individual is assumed to live and work on the decommissioned site, to eat all of his food from crops and animal products grown on the site, and to drink water from a well drilled on the site.

The annual dose to an organ of reference is the radiation dose equivalent delivered to that organ during the year of interest from all internal and external exposure pathways plus the dose equivalents delivered during that same year from radionuclides internally deposited during previous years. The maximum annual dose is the largest of the annual doses delivered to an organ of reference during a specified time period. For this study, a 50-year exposure period is assumed for an individual who lives and works on the decommissioned site.

If internal exposure from inhalation or ingestion is the dominant dose contributor, the maximum annual dose may not occur in the first year. The annual dose to internal body organs from internally deposited radionuclides tends to increase for a time after the start of continuous exposure to a radioactively decaying source until a maximum is reached. The annual dose then tends to decrease with time due to radioactive decay, a decrease in the exposure-pathway-dependent radionuclide concentrations, and biological elimination of radionuclides deposited in the organ.

The maximum annual dose to the maximum-exposed individual is the largest annual dose that can be conceived of to any person having unrestricted access to the decommissioned burial ground. This concept provides a conservative approach to determining potential public uses of a decommissioned site. Additional details on the procedure for calculating the maximum annual dose are found in Section C.4 of Volume 2.

To illustrate the methodology for predicting release conditions, in the absence of specific regulatory guidance on permissible public exposure limits from a decommissioned LLW burial ground, an annual dose limit of 50 mrem is assumed. This dose limit is compared to the calculated maximum annual dose to each organ of reference of the maximum-exposed individual who resides on the site.

8.4.4 Radionuclide Source Terms

The reference radionuclide inventories used to calculate exposure from water pathways and from geomorphological, biological, and human activity pathways are shown in Table 8.4-1. These inventories are based on the reference burial ground inventory described in Section 7.3.

TABLE 8.4-1. Reference Radionuclide Inventory

Radionuclide	Total As-Buried Activity at the Reference Burial Ground (Ci)	Average Radionuclide Concentration in the Burial Trenches at Time of Site Closure (pCi/m³)[a]
^{3}H	2.3×10^{5}	5.2×10^{10}[b]
^{14}C	7.6×10^{3}	3.6×10^{9}[b]
^{51}Cr	8.5×10^{5}	1.4×10^{8}
^{54}Mn	4.9×10^{5}	8.9×10^{9}
^{55}Fe	8.5×10^{5}	4.7×10^{10}
^{58}Co	8.5×10^{5}	2.4×10^{9}
^{60}Co	2.5×10^{6}	2.9×10^{11}
^{59}Ni	2.5×10^{4}	1.2×10^{10}
^{63}Ni	4.7×10^{6}	2.0×10^{12}
^{65}Zn	4.0×10^{4}	5.6×10^{8}
^{90}Sr	9.5×10^{3}	6.1×10^{9}
^{95}Zr	4.0×10^{4}	9.4×10^{7}
^{99}Tc	6.5×10^{1}	3.1×10^{7}
^{106}Ru	4.0×10^{4}	1.8×10^{9}
^{124}Sb	9.9×10^{3}	1.8×10^{7}
^{125}Sb	9.9×10^{3}	6.1×10^{8}
^{129}I	1.3×10^{1}	6.1×10^{6}
^{134}Cs	9.5×10^{5}	4.4×10^{10}
^{135}Cs	6.8×10^{2}	3.2×10^{8}
^{137}Cs	1.7×10^{6}	5.6×10^{11}
^{144}Ce	4.0×10^{4}	6.6×10^{8}
^{226}Ra	2.2×10^{2}	9.9×10^{7}
^{230}Th	1.4×10^{2}	6.6×10^{7}
^{232}Th	1.6×10^{1}	7.5×10^{6}
^{235}U	6.5×10^{1}	3.1×10^{7}
^{238}U	1.4×10^{3}	6.6×10^{8}
^{237}Np	9.2×10^{-2}	4.3×10^{4}
^{238}Pu	6.5×10^{2}	2.8×10^{8}
^{239}Pu	8.5×10^{1}	4.0×10^{7}
^{240}Pu	1.3×10^{2}	6.1×10^{7}
^{241}Pu	3.2×10^{4}	7.5×10^{9}
^{242}Pu	4.7×10^{-1}	2.2×10^{5}
^{241}Am	5.9×10^{1}	2.4×10^{8}
^{243}Am	4.1×10^{0}	1.9×10^{6}
^{242}Cm	4.9×10^{3}	4.4×10^{7}
^{244}Cm	3.8×10^{2}	1.0×10^{8}

(a) Based on a total trench volume of 2.13 million m³.

(b) Plants obtain the majority of their ^{14}C and tritium from the air. Therefore, root uptake is ignored for these two isotopes.

To determine radionuclide source terms for water pathways, the total radionuclide inventory on the burial site is assumed to be available for hydrological transport. Thus, for hydrological calculations, the as-buried activity per trench is multiplied by the total number of burial trenches at the site (180).

Radionuclide source terms for geomorphological, biological, and human activity pathways are based on the average radionuclide concentration in the waste trenches. This concentration is calculated by dividing the total burial ground inventory at the time of site closure, presented in Table 7.3-3, by the total volume of all the burial trenches (2.13 million m^3). The resulting average radionuclide concentrations are converted to pCi/m^3 and are listed in Table 8.4-1. Additional details of radionuclide concentrations for air and water pathways are given in Appendix C.2 of Volume 2.

The waste buried in slit trenches consists of activation products, mainly ^{55}Fe, ^{60}Co, and ^{63}Ni, in the form of high-quality stainless steel components (flow channels, in-core shims, control rods and thermocouple bundles) encapsulated in steel canisters. It is assumed that corrosion is minimal during the period of administrative control of the site and thus external exposure is the only important exposure pathway. The typical radionuclide inventory for a slit trench and the trench dimensions are given in Table 7.3-4 and Section 7.2.3.

Unrestricted release of the reference burial grounds with the radionuclide inventory shown in Table 8.4-1 is calculated to result in maximum annual doses to the maximum-exposed individual that exceed the assumed dose limit of 50 mrem/yr. (Dose calculations are summarized in Sections 8.5.2 and 8.5.3 for the western and eastern sites, respectively.) Use of the reference radionuclide inventory of Table 8.4-1 leads to conditional release conditions with use restrictions as discussed in Sections 8.5.2 and 8.5.3.

Table 8.4-2 shows a modified radionuclide inventory that would permit unrestricted release of the reference sites 200 years after burial ground closure. The inventory in this table is altered by limiting it to short-lived radionuclides and by restricting the quantities of ^{90}Sr and ^{137}Cs buried at the sites. For the first 200 years after burial ground closure, stabilization

TABLE 8.4-2. Modified Reference Radionuclide Inventory

	Western Site		Eastern Site	
Radionuclide	Total As-Buried Activity at the Reference Burial Ground (Ci)	Average Radionuclide Concentration in the Burial Trenches at Time of Site Closure (pCi/m^3)[(a)]	Total As-Buried Activity at the Reference Burial Ground (Ci)	Average Radionuclide Concentration in the Burial Trenches at Time of Site Closure (pCi/m^3)[(a)]
^{3}H	2.3×10^{5}	5.2×10^{10}	2.3×10^{5}	5.2×10^{10}
^{51}Cr	8.5×10^{5}	1.4×10^{9}	8.5×10^{5}	1.4×10^{9}
^{54}Mn	4.9×10^{5}	8.9×10^{9}	4.9×10^{5}	8.9×10^{9}
^{55}Fe	8.5×10^{5}	4.7×10^{10}	8.5×10^{5}	4.7×10^{10}
^{58}Co	8.5×10^{5}	2.4×10^{9}	8.5×10^{5}	2.4×10^{9}
^{60}Co	2.5×10^{6}	2.9×10^{11}	2.5×10^{6}	2.9×10^{11}
^{65}Zn	4.0×10^{4}	5.6×10^{8}	4.0×10^{4}	5.6×10^{8}
^{90}Sr	9.5×10^{4}	6.1×10^{9}	9.5×10^{4}	6.1×10^{9}
^{95}Zr	4.0×10^{4}	9.4×10^{7}	4.0×10^{4}	9.4×10^{7}
^{106}Ru	4.0×10^{4}	1.8×10^{9}	4.0×10^{4}	1.8×10^{9}
^{124}Sb	9.9×10^{4}	1.8×10^{7}	9.9×10^{4}	1.8×10^{7}
^{125}Sb	9.9×10^{3}	6.1×10^{8}	9.9×10^{3}	6.1×10^{8}
^{134}Cs	9.5×10^{5}	4.4×10^{10}	9.5×10^{5}	4.4×10^{10}
^{137}Cs	1.7×10^{6}	5.6×10^{11}	1.7×10^{6}	5.6×10^{11}
^{144}Ce	4.0×10^{4}	6.6×10^{8}	4.0×10^{4}	6.6×10^{8}

(a) Based on a total trench volume of 2.13 million m^3.

and long-term care of a site are assumed to limit the migration of radioactivity to levels below regulatory limits. Public use of the site would be prohibited during this period, or allowed on a conditional use basis. At the conclusion of a 200-year period of long-term care the site could be released for unrestricted use. Doses to the maximum-exposed individual from unrestricted release of a site with the radionuclide inventory of Table 8.4-2 are summarized in Sections 8.5.2.2 and 8.5.3.2.

8.5 ANALYSIS OF RELEASE CONDITIONS FOR THE REFERENCE SITES

Determining release conditions for the reference LLW burial grounds is a procedure that is necessarily linked with other decommissioning considerations. The relationship between the objectives of this study, site-specific studies, and the release criteria methodology is shown in Figure 8.5-1.

Methodology for determining release conditions for a decommissioned building was developed and demonstrated in three previous studies.(25-27) Release conditions for buildings are not addressed in this study. The interested reader should refer to these three referenced studies for further information on this subject.

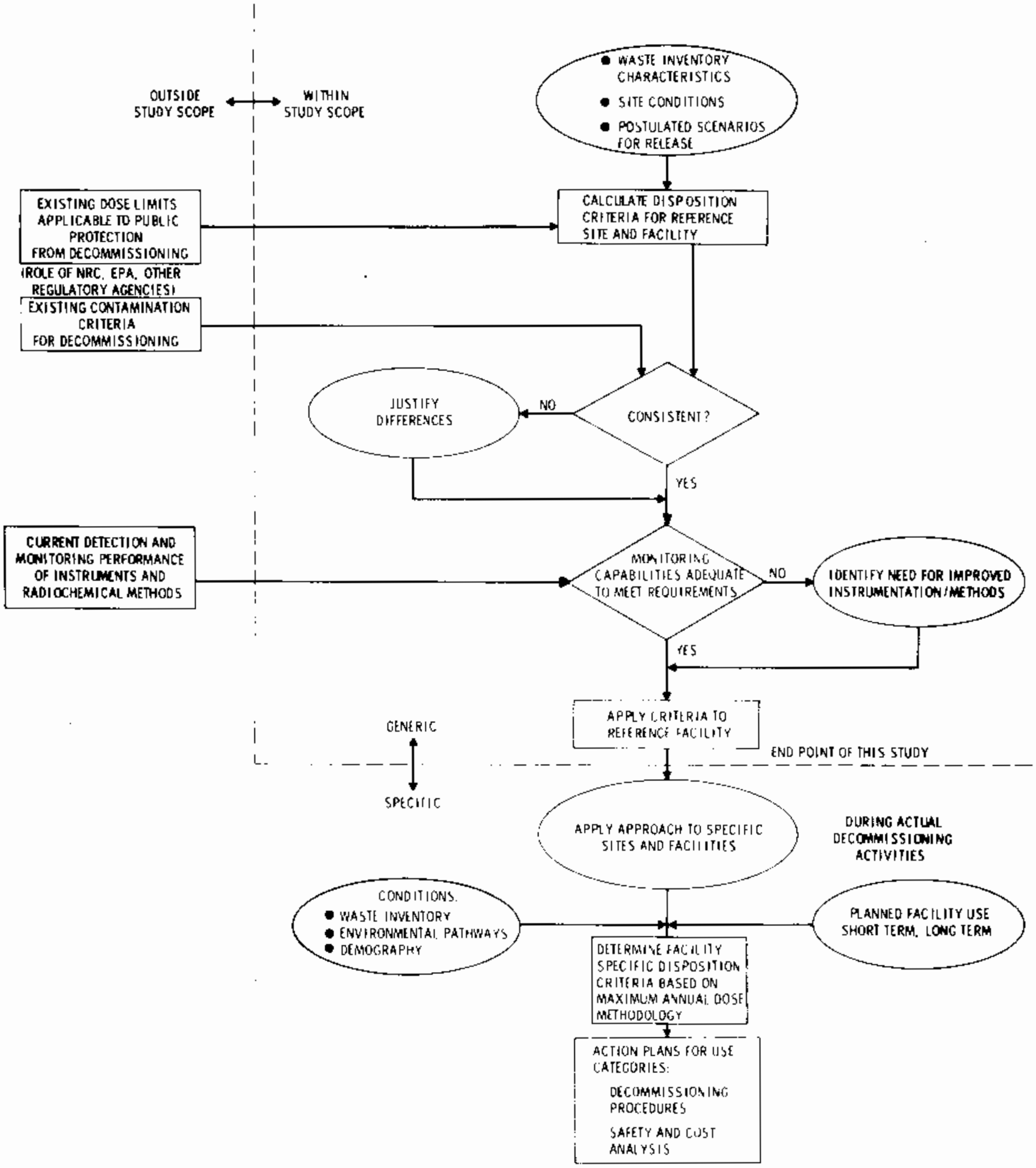

FIGURE 8.5-1. Relationships Between Release Criteria and Other Decommissioning Considerations

The methodology used in this study to determine release conditions for a decommissioned LLW burial ground consists of comparing calculated maximum annual doses to the organs of reference of a maximum-exposed individual to an established annual dose limit. Doses to the maximum-exposed individual are calculated for all important potential exposure pathways. For demonstration purposes in this study, the annual dose limit is assumed to be 50 mrem. If, for a particular use scenario, maximum annual doses do not exceed the annual dose limit, the scenario may be used to define conditions for the conditional or unrestricted release of the site. The waste inventories shown in Tables 8.4-1 and 8.4-2 are used to demonstrate the methodology.

The radionuclide ^{226}Ra presents a unique problem in determining site release conditions and requires separate consideration. The ^{222}Rn daughter is a noble gas and does not bind chemically or physically to the soil. Once formed by a decay of the ^{226}Ra parent, a portion of the gas can diffuse through the soil and into the atmosphere where it can be inhaled. The rate of ^{222}Rn emanation from the buried waste increases as the overburden is eroded away. The most restrictive ^{226}Ra concentration in the soil acceptable for public use of the site is based on inhalation of ^{222}Rn daughters in homes built on top of the contaminated soil.(28) This exposure pathway should be assessed separately from the others to ensure that current guidelines for ^{226}Ra are met, such as recommended by the Surgeon General(21) and Healy.(28) In the Environmental Protection Agency's proposed guidelines on hazardous waste, the limiting ^{226}Ra concentration proposed for solid waste is 5 pCi/g.(29)

8.5.1 Bases for Analysis of Release Conditions

Following are key bases and assumptions used to analyze release conditions for the reference LLW burial grounds. These bases and assumptions should be carefully examined before applying the methodology of this section to specific real sites. Literature references and derivations for numerical values of key parameters listed in this section are presented in Appendix C of Volume 2. The key bases and assumptions are:

1. Two use scenarios are considered in determining release conditions. One is based on conditional release of a decommissioned site after

200 years and uses the radionuclide inventory of Table 8.4-1. The second is based on unrestricted release of a site after 200 years and uses the radionuclide inventory of Table 8.4-2.

2. Maximum annual doses are calculated to a maximum-exposed individual who remains on the site 24 hours per day. This individual is assumed to: 1) live in a house built on the site, 2) consume all of his food from crops and animal products grown on the site, 3) drink water from a well drilled on the site, and 4) work at onsite construction (excavation) for 2000 hours during 1 year of the 50-year exposure period. The diet for the maximum-exposed individual is given in Appendix A of Volume 2.

3. The assumed annual dose limit for the maximum-exposed individual is 50 mrem.

4. On the surface of the site, it is assumed that any radioactive spills that occurred during burial operations are cleaned up. If significant residual contamination does exist on the surface of the burial ground at site closure, the methodology developed in previous decommissioning studies in this series (References 25-27) can be used to calculate the levels of residual radioactivity that are acceptable on the surface.

5. Unrestricted property release assumes that buildings are constructed on the site and that the site is farmed and is subject to wind and water erosion. Potential annual soil losses from erosion are estimated to be about 40 MT per acre for the western site and about 55 MT per acre for the eastern site. An average erosion rate of 7 mm per year is used for both sites.

6. It is assumed that a package in which waste is buried will lose its integrity shortly after burial.(30,31) Therefore, no credit is taken for packaging of the waste. Exposure from water pathways is calculated on the assumption that the total radionuclide inventory at the burial site is available for leaching and hydrological transport. Exposure from geomorphological, biological, and human activity pathways is based on the average radionuclide concentration in the waste trench.

7. The buried waste is uniformly mixed in the trenches. Random distribution of the radionuclides is assumed. The volume of soil between adjacent waste trenches is taken into account when calculating waste concentrations in the soil.

8. Excavation occurs to a depth of 3.5 m during onsite construction. The dose from external exposure to the uncovered waste is calculated assuming 300 hours of exposure.

9. An annual average mass loading factor of 0.0001 g/m^3 is used to predict air concentrations from local wind resuspension. During the excavation scenario, the mass loading factor is increased to 0.01 g/m^3. Ten percent of the resuspended particles from onsite excavation are assumed to be of respirable size.

10. For LWR fuel cycle waste, 1% of the material is assumed to be available for plant uptake and resuspension for the first 400 years after site closure.(30) For structural decommissioning waste (^{60}Co, ^{59}Ni, ^{63}Ni), the same fraction of 1% is assumed to apply for the first 1000 years.

11. Ninety percent of the plant root system is assumed to be in the top 0.15 m of soil. One percent of the plant roots are assumed to penetrate the soil to depths greater than 1 m.

12. A 1000-year leach time is used for radionuclides leaching from structural decommissioning waste into the ground water. One-hundred years is assumed as the leach time to ground water for radionuclides from other forms of waste material. A 10,000-year leach time from all waste forms is used for overland flow. Section C.2.4 gives a more detailed discussion of leach times.

13. The water pathway is not a probable means of exposure at the western site because of the long travel time to the water table and the low rainfall that eliminates potential for overland flow. These conclusions are discussed in Appendix C.

14. At the eastern site, drinking water is assumed to be obtained from a well drilled into the shale formation beneath the burial ground. The

groundwater concentrations calculated in Appendix C for the assumed groundwater model are adjusted to account for the full groundwater flow of 47 million ℓ/yr at this depth.

15. The eastern site is not irrigated.
16. Site characteristics are summarized in Section 7.4.1 for the western site and in Section 7.4.2 for the eastern site.

8.5.2 Analysis of Release Conditions for the Western Site

The water pathway is determined in Section C.2.4 to be negligible for the western site. Therefore, the exposure pathways considered are inhalation, direct external exposure, and ingestion of foods grown on the released decommissioned burial ground. Two scenarios are evaluated to determine release conditions: 1) conditional release of a decommissioned site after 200 years, using the radionuclide inventory given in Table 8.4-1, and 2) unrestricted release of a decommissioned site after 200 years, using the radionuclide inventory of Table 8.4-2.

8.5.2.1 Conditional Release

Potential doses to a maximum-exposed individual who lives and works on the western burial ground following release of the site for public use are summarized in Table 8.5-1. Long-term care of the site is assumed for 200 years prior to site release, and the 3-m overburden is maintained during this period. The burial site inventory used for dose calculations is given in Table 8.4-1. Details of potential doses to the maximum-exposed individual are presented in Section C.5 of Volume 2.

The doses shown in the first data column in Table 8.5-1 are calculated on the basis that the maximum-exposed individual occupies the site immediately after it is released for public use. This individual lives and works at the site (possibly at farming) but does not excavate the site. The dominant exposure pathway is ingestion of locally grown food. The doses in this column represent the maximum annual dose during the first 50 years following site release. All doses are smaller than the assumed 50 mrem annual dose limit, except for the maximum bone dose, which is approximately a factor of 2 larger than the dose

TABLE 8.5-1. Maximum Annual Doses for Different Release Scenarios - Release of Western Site 200 Years After Site Closure

Organ of Reference	Maximum Annual Dose During First 50 Years After Site Release - No Excavation (mrem)	Maximum Annual Dose During First 50 Years After Site Release - Excavation Permitted (mrem)	Maximum Annual Dose[a] Assuming Total Erosion of Trench Overburden (mrem)
Total Body	3.8	380	1 300
Bone	81	460	33 000
Lungs	0.0081	380	50
Thyroid	0.053	380	380
GI-LLI	0.012	380	5

(a)Calculated at 650 years after site closure.

limit. Conditional release of the western site is therefore shown to be a viable use category, provided that excavation is prohibited and measures are taken to maintain the overburden and prevent root penetration into the buried waste. The major contributors to dose are ^{63}Ni and ^{210}Pb. Nickel-63 is present in the burial ground as a radioactive component of reactor decommissioning waste. Lead-210 is a radioactive daughter of ^{226}Ra. The rate of plant root uptake is more than an order of magnitude greater for ^{210}Pb than it is for ^{226}Ra.

The doses given in the second data column assume that the maximum-exposed individual works for 1 year (2000 hours) at excavation activities on the site. These doses include contributions from both inhalation and external exposure. They are clearly in excess of the 50 mrem/year dose limit and illustrate that excavation should not be allowed when the site is conditionally released. Most of the doses from site excavation are from external exposure to the gamma radiation from ^{137}Cs.

Soil erosion is expected to result in an increase in the dose received by the maximum-exposed individual. To determine the effects of soil erosion, as a limiting case, the last data column in Table 8.5-1 shows the calculated dose to the maximum-exposed individual, assuming total erosion of the 3-m overburden. Based on the erosion rate of Section C.2.1, total erosion of the overburden is calculated to occur approximately 450 years after site release. Radionuclides that contribute most of the dose are ^{230}Th, ^{226}Ra, ^{210}Pb, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Am.

While it is unlikely that conditions at the site would result in total removal of the overburden (wind action could result in a deposit of soil eroded from other areas as well as erosion of the trench cover), comparison of calculated doses to the maximum-exposed individual during the first 50 years immediately following release of the site to calculated doses 450 years after site release demonstrates the importance of maintaining an adequate layer of overburden to prevent both the penetration of crop roots into the waste and the dispersal of radionuclides resulting from human activities or wind action. Institutional controls may be necessary to restrict human activities at a conditionally released site and to maintain an adequate depth of overburden.

The importance of restricting the total inventory of long-lived radionuclides in the buried waste is also demonstrated by the calculations summarized in Table 8.5-1. Encapsulation of waste containing long-lived radionuclides to prevent release of the radioactivity to the environment may be necessary.

A conditional use of the decommissioned LLW burial ground at the western site would be possible provided the following actions are enforced:

1. Stabilize the ground surface to minimize surface erosion.
2. Control the type of farming or other land use at the site to prevent the growth of deep-rooted plants.
3. Restrict activities that result in excavation of the site.

Enforcement of these actions would very likely limit the maximum annual dose to the maximum-exposed individual to less than 50 mrem.

8.5.2.2 Unrestricted Release

An inventory that would permit unrestricted release of the western burial site 200 years after site closure is given in Table 8.4-2. The potential doses to a maximum-exposed individual residing on the decommissioned western burial site containing this inventory are given in Table C.5-4 and are summarized in Table 8.5-2 for the organs of reference. Since the doses are all

TABLE 8.5-2. Maximum Annual Doses from all Exposure Pathways - Western Site with Modified Inventory Released 200 Years After Site Closure

Organ of Reference	Maximum Annual Dose (mrem)
Total Body	38
Bone	40
Lungs	38

below the assumed annual dose limit of 50 mrem, unrestricted release after 200 years is permitted for this scenario. The maximum annual dose of 40 mrem is received by the bone in the first year after release of the site.

8.5.3 Analysis of Release Conditions for the Eastern Site

The exposure pathways considered for the eastern site include those described previously for the western site plus ingestion of locally grown crops and aquatic foods that are contaminated by radionuclide transport along water pathways, and ingestion of drinking water from an onsite well drilled into the near-surface aquifer beneath the site. Evaluation of the water exposure pathways is based on the assumption that the entire burial ground inventory of radioactive waste is available for leaching into the aquifer beneath the burial ground or into the stream that is assumed to inundate the burial ground for overland flow calculations. (See Section C.2.4.1 for a description of the overland flow model.)

The scenarios evaluated for the eastern site to determine release conditions are the same as those evaluated for the western site--namely conditional release after 200 years, using the radionuclide inventory of Table 8.4-1, and unrestricted release after 200 years, using the inventory given in Table 8.4-2. Measures to prevent erosion, control surface water drainage, and minimize infiltration of water into the trenches are assumed to have been part of long-term care prior to release of the site. Details of radionuclide concentrations in the aquifer and radionuclide release rates into the nearby river from transport of radionuclides through the aquifer and from overland flow are given in Sections C.2 and C.5 of Volume 2.

8.5.3.1 Conditional Release

Potential doses to the maximum-exposed individual who lives and works on the conditionally released eastern site containing the inventory of Table 8.4-1 include those doses described in Section 8.5.2.1 for conditional release of the western site plus doses from water pathways summarized in Table 8.5-3. Annual doses from water pathways are highest during the first 50-year exposure period after release of the property, before ^{90}Sr and ^{137}Cs have decayed to insignificant levels. The critical organs for water-pathway doses are the total body and the bone.

The doses shown in the first data column of Table 8.5-3 are from ingestion of of aquatic foods from the nearby river that is contaminated by radionuclide transport along the aquifer beneath the site. (See Section 7.4.2 for a description of the eastern site.) All of the doses in this column are smaller than the assumed 50 mrem annual dose limit, except for the maximum bone dose, which is calculated to be about a factor of 2 larger than the dose limit. The dominant radionuclide that contributes to aquatic food doses is ^{14}C.

The doses shown in the second data column of Table 8.5-3 result from drinking water from a well drilled into the contaminated near-surface aquifer beneath the site. Dose calculations assume that the maximum-exposed individual obtains all of his water from this well. Total body and bone doses are several orders of magnitude higher than the assumed 50 mrem annual dose limit. The dominant

TABLE 8.5-3. Contributions to the Maximum Annual Doses from Water Pathways - Release of Eastern Site 200 Years After Site Closure

Organ of Reference	Ingestion of Aquatic Foods from Nearby River Contaminated by Radionuclide Transport Along Aquifer (mrem)	Drinking of Water From Well Drilled into Contaminated Aquifer Beneath Site (mrem)	Ingestion of Aquatic and Locally Grown Foods Contaminated by Overland Flow (mrem)
Total Body	19	120 000	830
Bone	93	520 000	12 000
Lung	0.000018	220	110
Thyroid	1.8	80	0.96
GI-LLI	0.0	11	65

radionuclides that contribute to the very large annual doses are ^{14}C, ^{63}Ni, ^{90}Sr, ^{137}Cs, and ^{226}Ra. Uranium, thorium, and the transuranics contribute most of the dose to the lower large intestine. The dose to the thyroid is from ^{129}I. Dose calculations for the drinking water pathway are very sensitive to assumptions made about leach rates from the burial ground and to the assumed dilution factor within the aquifer. Conservative assumptions have been made to obtain the numbers reported in Table 8.5-3. However, since estimated doses are several orders of magnitude larger than the assumed annual dose limit, it is obvious that conditional release of the eastern site should include a restriction against drilling a well into the near-surface aquifer underneath the site.

The doses shown in the last data column of Table 8.5-3 are from ingestion of aquatic foods and locally grown foods that are contaminated by overland flow. There are no well-established models for treating overland flow. The model used in this study assumes that the site is inundated by water that leaches radioactivity from the trenches and carries the material overland to the nearby river. Because of uncertainty in the values of sorption to be used with the model, sorption is conservatively assumed to be negligible during overland flow. Calculated total body and bone doses are several orders of magnitude higher than the assumed 50 mrem annual dose limit. The dominant radionuclides that contribute to the dose are ^{63}Ni, ^{90}Sr, ^{137}Cs, ^{226}Ra, ^{210}Pb, and ^{238}U and its daughters. The dose to the thyroid is from ^{129}I. Doses calculated for the overland flow pathway are sensitive to assumptions made in modeling this pathway and to assumed leach rates. The high doses shown in Table 8.5-3 reflect the conservatism of the model and leach rate assumptions. However, the dose rates illustrate the importance of measures to control ground and surface water and to prevent inundation of the burial trenches. Since many of the radionuclides that contribute to doses from overland flow have long half-lives, water-control measures would be required for many years.

A conditional use of the decommissioned LLW burial ground at the eastern site would be possible provided the following actions are enforced:

1. Stabilize the ground surface to minimize surface erosion.
2. Control the type of farming and other land use at the site to prevent the growth of deep-rooted plants and to control surface water runoff.
3. Restrict activities that result in excavation of the site.
4. Prohibit the use of water from shallow wells drilled on or near the site.
5. Maintain site drainage features to prevent inundation of burial trenches with water.
6. Stabilize the waste to minimize leaching to the aquifer, or control the use of aquatic organisms and water from nearby streams.

Enforcement of these actions would very likely limit the maximum annual dose to the maximum-exposed individual to less than 50 mrem.

8.5.3.2 Unrestricted Release

An inventory that would permit unrestricted release of the eastern burial site 200 years after site closure is given in Table 8.4-2. The potential doses to a maximum-exposed individual residing on the decommissioned eastern burial site containing this inventory are given in Table C.5-6 and are summarized in Table 8.5-4. Unrestricted release of the site would be permitted for this scenario, since the maximum annual dose is below 50 mrem.

TABLE 8.5-4. Maximum Annual Doses from All Exposure Pathways - Eastern Site with Modified Inventory Released 200 Years After Site Closure

Organ of Reference	Maximum Annual Dose (mrem)
Total Body	23
Bone	24
Lungs	7.2

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**Available for purchase from the National Technical Information Service, Springfield, Virginia 22161.

9.0 ENVIRONMENTAL SURVEILLANCE AND RECORDS MAINTENANCE

Decommissioning of an LLW burial ground involves placing the facility in such a condition that future risk to the public from the facility is within acceptable bounds. Program objectives for environmental surveillance and records maintenance activities that support this decommissioning objective include:

- evaluation of the adequacy and effectiveness of confinement systems at the site
- detection of changes in and evaluation of long-term trends of concentrations of radionuclides in the environment, with the intent to detect radionuclide migration and initiate appropriate actions
- collection of data on the history of contaminants released to the environment, with the intent of discovering previously unconsidered pathways and modes of exposure
- demonstration of compliance with applicable regulations and legal requirements concerning releases to the environment
- maintenance of a data base and records system to support the above activities:

This section summarizes environmental surveillance and records maintenance requirements during decommissioning and long-term care of the reference LLW burial grounds. The information in this section provides a basis for estimating the costs of post-operational environmental monitoring and records maintenance programs. Cost estimates are presented in Section 12.

Environmental surveillance and records maintenance programs at existing commercial sites are reviewed in Section 9.1. Environmental surveillance requirements during decommissioning and long-term care are summarized in Section 9.2. Records maintenance requirements for decommissioning and long-term care are summarized in Section 9.3. Additional details of monitoring and record keeping procedures at existing sites are presented in Appendix D of Volume 2.

An addendum to this report will develop technical bases useful for formulating and implementing environmental monitoring programs at future LLW disposal sites. The addendum will provide guidance on sampling locations, frequency, pathway (e.g., air, surface water, ground water, biota), and analytical sensitivity levels for future programs. For this decommissioning report, the operational monitoring programs postulated for the reference burial sites are believed to be representative of existing programs. These reference operational monitoring programs are described in Section 7.2.4.

9.1 EXISTING PROGRAMS AT COMMERCIAL SITES

This section reviews regulatory guidance pertaining to environmental monitoring and records maintenance at LLW burial grounds and summarizes current practice at the six commercial sites.

9.1.1 Regulatory Requirements

The status of regulatory requirements for decommissioning an LLW burial ground is reviewed in Section 5. Additional details on regulations that can have an impact on environmental monitoring and records maintenance requirements during decommissioning are provided here.

There is presently no specific regulatory guidance on permissible levels of radioactivity that can remain in a decommissioned LLW burial ground or on permissible releases of radioactivity from a retired facility. However, regulations and other guidance that could form the bases for such decisions do exist, and these could be used to define environmental surveillance and records maintenance requirements for retired shallow-land burial facilities. These regulations and other guidance are listed in Table 9.1-1.

The basic radiation standards for licensees, given in 10 CFR 20,(1) presently provide a regulatory upper limit for radiological impacts from nuclear facilities, including decommissioned LLW burial grounds. The standards could be changed at some future time, either by numerical definition of "as low as reasonably achievable" (ALARA), or by extending the Environmental Protection Agency's (EPA) environmental radiation standards for nuclear power

TABLE 9.1-1. Summary of Regulations and Guidance Related to Environmental Surveillance and Records Maintenance

Identification	Description	Reference Number
10 CFR 20	Radiation standards for licensees	1
40 CFR 141	Radioactivity standards for drinking water	2
40 CFR 50	National ambient air quality standards	3
---	NRC proposed rule on transuranic waste disposal	4
---	ERDA guidelines for decontamination of facilities and equipment for release	5
NUREG-0456	Classification of radioactive wastes for disposal	6
40 CFR 250	Proposed EPA guidance for hazardous waste site control	7
EPA 520/4-77-016	Proposed EPA guidance for transuranic elements in the environment	8
ANSI N13.12-1978	Release guidance for radioactive materials	9
Regulatory Guide 4.5	Sampling for analysis of plutonium in soil	10
Regulatory Guide 4.6	Analysis for strontium-89, -90 in the environment	11
Regulatory Guide 4.15	Quality assurance for radiological monitoring programs	12
NRC Branch Position	Performance criteria for LLW burial ground site closure	13

operations(14) to include waste management and decommissioning. EPA's proposed general waste management criteria(15) help to provide a framework for radiological considerations, but do not specify limits or radiation doses. The Nuclear Regulatory Commission (NRC) is developing a radioactive waste classification system(6) appropriate for use in the regulation of radioactive waste disposal. The purpose of this system is to classify radioactive wastes according to the type and duration of containment required for their disposal. This classification system might also be used as a basis for development of regulations pertaining to radiation dose limits from operating or retired burial facilities.

Some guidance on environmental surveillance and records maintenance requirements for LLW burial ground site closure is provided in a recent Branch Position(13) by the NRC. The Branch Position specifies performance objectives to be implemented by a burial ground licensee prior to license termination and transfer of a site to a custodial government agency. The performance objective for environmental surveillance specifies that the licensee must "Demonstrate that the release of radionuclides through air and ground and surface water pathways are at or below acceptable levels. Acceptable levels for water are those set forth in 10 CFR Part 20, Appendix B, at the site boundary and EPA drinking water limits at the nearest water supply. Acceptable levels for air are a small fraction of those in 10 CFR Part 20, Appendix B. The EPA environmental standard for disposal of low-level wastes should be used when available."

The performance objective for records maintenance specifies that the licensee shall "Compile and transfer to the custodial agency complete records of site maintenance and stabilization activities, trench elevation and location (in USGS coordinates), trench inventories, and monitoring data for use during custodial care for unexpected corrective measures and data interpretation."

9.1.2 Current Practices at Commercial LLW Burial Sites

Operational environmental monitoring at the six commercial LLW burial grounds includes sampling of water, soil, vegetation, and air. Table 9.1-2, adapted from a report by the General Accounting Office,(16) indicates the extent and frequency of existing licensee monitoring programs. Monitoring is performed by the site operator, with sampling frequencies usually specified

TABLE 9.1-2. Licensee Monitoring Programs at Commercial LLW Burial Grounds

	Sampling Frequency					
Sample Media	Beatty	Richland	Barnwell	Morehead	Sheffield	West Valley
Onsite Ground Water	Monthly	Quarterly	Semi-annually	Monthly	Quarterly	Quarterly
Offsite Surface Water	Semi-annually	Semi-annually	Annually	Quarterly	Quarterly	Weekly
Soil	Semi-annually	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
Vegetation	Semi-annually	Quarterly	Annually	Quarterly	Quarterly	Annually
Air	None	None	Continuous	Continuous	Continuous	Continuous

by licensing agreements. Each licensing agency performs routine audits of the licensee's monitoring program, and may also conduct independent monitoring programs at the sites under its jurisdiction.

Water from onsite wells is sampled on schedules that vary from monthly to semi-annually, with the majority of the sites collecting and analyzing ground water on a quarterly schedule. Offsite surface water sampling schedules vary from weekly to annually, with the arid western sites sampling semi-annually and most of the eastern sites sampling on a quarterly schedule. Most sites perform soil sampling on a quarterly schedule. Vegetation sampling schedules vary from quarterly to annually, with the majority of the sites on a quarterly schedule. Vegetation samples are collected offsite at all locations. Morehead, Kentucky, also collects vegetation samples onsite. Air sampling depends on the site location. The eastern sites sample air on a continuous basis, but the western sites do not routinely sample air.

Samples collected from the various media described above are analyzed for gross alpha, gross beta, and tritium. In addition, air samples are analyzed for iodine. Gross analyses in excess of 30 pCi/ℓ alpha and 60 pCi/ℓ beta undergo specific gamma analyses to identify the radionuclides involved.

Examples of results of the environmental monitoring program at one of the commercial sites are shown in Appendix D of Volume 2 to provide additional detail on this activity.

Written records of waste disposals are maintained at all commercial sites. Most of the information for these disposal records is provided by the shipper on a Radioactive Shipment Record (RSR) form. While the specific records format varies slightly with different sites, the basic data includes package type, volume, weight, principal radionuclides and quantities, chemical and physical form of the waste, and package radiation dose. Site operators are generally restricted from opening packages onsite to verify package contents. One difficulty encountered in the analysis of existing commercial site inventories arises from the frequent use of terms like "byproduct material" and "mixed fission products" on shipment records rather than identifying the specific radionuclide content of packaged wastes.

Recent studies(17,18) of the radioactive waste inventory buried at the Morehead, Kentucky, site emphasize the need for improvements in the record keeping system for the accountability of radioactive waste. Reference 17 contains specific recommendations for improvements in inventory record keeping, including recommendations as to the form and format of waste inventory records.

A summary of the volumes and activities of radioactive wastes buried at the six commercial sites to December 31, 1976 is presented in Section B.1 of Volume 2. An example RSR form is given in Appendix D of Volume 2.

9.2 ENVIRONMENTAL SURVEILLANCE DURING DECOMMISSIONING AND LONG-TERM CARE

The primary intent of environmental surveillance during decommissioning is to ensure that the decommissioning activities do not cause significant transport of radioactivity from the site, resulting in an unacceptable health hazard to the public. During long-term care, environmental surveillance serves to verify the radionuclide-confinement capability of the burial ground and to identify problem situations requiring remedial action.

Post-operational environmental monitoring programs should normally be extensions of the program carried out during burial ground operations, with appropriate additions to or deletions from the base program to account for differences between operational and post-operational (decommissioning and long-term care) activities at the site. This assumes that the monitoring program during burial ground operations has been properly designed to monitor the critical pathways for movement of radioactivity from the site and to sample for those radionuclides identified as significant contributors to dose. During decommissioning operations, additional sampling of soil and air would likely be required because of site activities that disrupt the trench cover or that result in an increase in airborne particulate matter. Environmental monitoring requirements for long-term care should be reduced from those for burial ground operations, because decommissioning activities that precede long-term care should improve the radionuclide-confinement capability of the site. It will, however, be necessary to continue the operational sampling frequency during the first few years of long-term care to verify the effectiveness of decommissioning procedures. The level of monitoring effort could then be reduced.

9.2.1 Environmental Surveillance During Site/Waste Stabilization

Stabilization of a burial ground site involves movement of, modification of, and addition to surface soils, but no intentional uncovering or exhumation of buried wastes. Therefore, the environmental monitoring program during stabilization is postulated to be similar to that during waste burial operations. The operational monitoring programs for the reference western and eastern sites are described in Section 7.2.4.

Special samples or sample analyses may be required during stabilization, at the discretion of the responsible government agency or the health and safety supervisor at the site. Examples of possible additions and changes to the operational monitoring program are:

- Onsite Soil Samples. Because burial ground surface soils might be disrupted during stabilization, onsite soil samples are taken more often to detect any changes in soil radioactivity levels caused by possible disruption. The samples are taken weekly in the areas of greatest soil disruption.
- Air Samples. For the operational monitoring program, air samplers are located onsite and offsite, in the prevailing downwind direction. If stabilization activities involve soil movement that results in an increased dust loading in the air, additional onsite and offsite air samplers may be required. Since weekly filter changes are specified for the normal operating program, the sampling frequency would probably not be increased during site stabilization.
- Vegetation Samples. Sampling of onsite vegetation is continued during stabilization, at the same frequency as for burial operations, to determine the extent of radionuclide assimilation by plants. However, because site vegetation is disrupted during stabilization, it may be necessary to obtain the samples at special sample points designated during the planning and preparation phase.

9.2.2 Environmental Surveillance During Waste Relocation

Waste relocation involves considerable movement and disruption of burial ground soils and wastes. However, stringent measures are taken to control radionuclide migration and prevent significant releases during such operations (see Section 11). Therefore, the environmental monitoring program during waste relocation is postulated to be similar to that during burial operations, with some additions as noted below. The health physics technicians at the site during decommissioning collect the required samples and forward them to the contracted laboratory for analysis.

Additions to the operational monitoring program during waste relocation activities include:

- Onsite Soil Samples. Because of the soil disruption caused by exhumation activities, more onsite soil samples are taken during waste relocation to detect any changes in soil radioactivity levels caused by the decommissioning activities. The extra samples are taken in the areas of greatest soil disruption, according to specifications prepared during planning and preparation. Samples are taken weekly.
- Air Samples. Additional air samples are required during waste relocation activities. Two additional samplers are located offsite, in the prevailing downwind direction, at locations within 10 km of the burial ground. Air samplers are also located onsite in the vicinity of excavation operations. Filters are changed weekly, or more often if necessary. A continuously recording exposure-rate instrument is installed near the work area to detect sudden changes in airborne radioactivity.
- Vegetation Samples. These are taken at the same frequency as during normal burial operations. However, because some disruption of site vegetation is inevitable during waste relocation, special sampling locations may be specified.

9.2.3 Environmental Surveillance During Long-Term Care

Environmental surveillance programs for long-term care must be developed on a site-specific basis that takes into account the radionuclide inventory at the site, site-specific critical pathways for the movement of radionuclides to the environment, and decommissioning activities that preceded long-term care. Site stabilization activities are designed to reduce the migration of buried radionuclides from the site. If these site stabilization activities are effective, it should be possible to reduce the level of environmental sampling activity required during long-term care from that required during site operation. However, it will be necessary to maintain environmental sampling and analysis efforts at the same level for a few years to evaluate the effectiveness of site stabilization or other decommissioning procedures. In particular, those surveillance activities that monitor critical pathways or that check for the presence in the environment of radionuclides known to be significant contributors to dose will need to be maintained for several years.

The environmental sampling schedule during long-term care for the reference sites of this study is shown in Table 9.2-1. To provide a basis for estimating long-term care costs, it is assumed that the monitoring program for the first 25 years after site stabilization is similar to that for normal burial operations shown in Table 7.2-3. After 25 years, the program is reduced to about one-fourth of the original level by reducing the number of sample locations and/or the sampling frequencies. The environmental sampling programs shown in Table 9.2-1 are chosen to reflect the importance of the critical pathways identified in Section 8.3. For the western site, wind erosion plays an important role in determining the containment capability of the site, and water pathways are relatively unimportant. For the eastern site, water pathways dominate.

9.3 RECORDS MAINTENANCE DURING DECOMMISSIONING AND LONG-TERM CARE

During the decommissioning and subsequent long-term care of an LLW burial site, all activities should be documented and accurate records of the project maintained in a repository designated by the responsible agency. This ensures a complete understanding of activities at the site and aids in the planning of future activities. Documents retained should include the Master Decommissioning Plan (see Section 10.5.1), decommissioning and long-term care procedures and drawings, QA documents, records of site inspections and maintenance activities during long-term care, and environmental surveillance records.

TABLE 9.2-1. Postulated Environmental Sampling Schedule During Long-Term Care

	Arid Western Site						Humid Eastern Site					
	0-25 Years After Stabilization			26-200 Years After Stabilization			0-25 Years After Stabilization			26-200 Years After Stabilization		
	Number of Sample Locations	Sampling Frequency	Total Annual Samples	Number of Sample Locations	Sampling Frequency	Total Annual Samples	Number of Sample Locations	Sampling Frequency	Total Annual Samples	Number of Sample Locations	Sampling Frequency	Total Annual Samples
Water - Onsite Wells	6	Semi-annual	12	2	Annual	2	12	Quarterly	48	6	Semi-annual	12
Offsite Wells[(a)]	3	Annual	3	2	Annual	2	5	Semi-annual	10	3	Annual	3
Surface Water[(a,b)]	2	Semi-annual	16	2	Annual	8	4	Quarterly	64	3	Semi-annual	24
Soil - Onsite	4	Annual	4	2	Annual	2	4	Annual	4	2	Annual	2
Offsite	2	Annual	2	1	Annual	1	2	Annual	2	1	Annual	1
Air - Onsite	1	Continuous, with weekly filter changes	52	1	Continuous, with filter changes at 4-week intervals	13	1	Continuous, with weekly filter changes	52	1	Continuous, with filter changes at 4-week intervals	13
Offsite[(a)]	2		104	1		13	2		104	1		13
Vegetation - Onsite	4	Annual	4	2	Annual	2	4	Annual	4	2	Annual	2
Small Mammals - Onsite	4	Annual	4	2	Annual	2	4	Annual	4	2	Annual	2
Offsite	4	Annual	4	1	Annual	1	4	Annual	4	1	Annual	1
Game Birds - Offsite	4	Annual	4	2	Annual	2	4	Annual	4	2	Annual	2
Milk - Offsite	--	--	--	--	--	--	3	Quarterly	12	2	Semi-annual	4
Fish - Offsite	1	Quarterly	4	--	--	--	4	Quarterly	16	2	Semi-annual	4
Farm Crops - Offsite	--	--	--	--	--	--	3	Annual	3	2	Annual	2
Direct Radiation[(a,c)]	3	Monthly	108	2	Quarterly	24	3	Monthly	108	2	Quarterly	24

(a) One sample location used as control.
(b) Four samples taken at each location.
(c) Three dosimeters at each location.

All stabilization procedures that improve the ability of the site to adequately contain the buried waste and that reduce the requirements for long-term care should be carefully documented. This includes documentation of site stabilization activities during the operating lifetime of the site as well as those activities performed at the time of site closure.

For waste relocation, radioactive shipment records resulting from removal and shipment of wastes should be retained. Waste relocation records make use of data from the original Radioactive Shipment Records prepared when the waste was first buried, and are therefore only as accurate as the originals. Records that indicate clearly the scope and extent of waste relocation activities and the condition of the site at the conclusion of these activities should also be prepared.

In addition to the documentation of decommissioning and site maintenance activities, all environmental data collected at the site should be maintained in the records repository. Environmental surveillance data include information about sampling locations and frequencies, procedures used to prepare samples for counting and to count the samples, the results of sample analyses, and data evaluation to determine the adequacy and effectiveness of confinement systems or to demonstrate compliance with applicable regulations concerning releases to the environment. Information about quality assurance programs and procedures should also be kept with environmental surveillance records. Quality assurance records include:

- required performance specifications for equipment
- calibration procedures and the results of calibration checks
- listings of analytical audit samples and cross-check programs
- schedules and results for replicate sampling and procedural audits.

Records must be preserved for the period of long-term care, until a site is released for unrestricted use. Because administrative control of a burial site may be required for many years, it is important that burial ground records be accessible for this time period and that they be preserved in a useable form. Records would be stored in the form judged most appropriate by the responsible agency. Paper copies should be filed in a safe, protected area; they should be used only for temporary record storage. For long-term preservation of records, microfilms could be made; this would also reduce the need for filing space. For record preservation, and to facilitate data evaluation, data requiring repeated, rapid retrieval could be stored in a computer bank as well as in the files.

An example of a program to preserve burial records and make them accessible for future reference was the program carried out at the Morehead, Kentucky (Maxey Flats), site under joint sponsorship of the Kentucky Radiological Health Department (KRHD) and the U.S. Environmental Protection Agency (EPA).(18) The program pertained to the preservation and analysis of waste inventory records, but similar programs could be devised for site inspection and maintenance records or for environmental surveillance records. Under the KRHD-EPA program, information from the Maxey Flats Radioactive Shipment Records was transferred onto magnetic computer tape. The information covered waste burials for the period 1963 to 1972. Information coded onto computer tape included the burial date, the burial location (i.e., trench of burial), the isotope buried, the radioactivity of the buried isotope, and the volume of the waste material buried. A computer program was written that used the burial data and calculated the radioactivity of the waste as of the year 1974.

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10.0 SITE/WASTE STABILIZATION ACTIVITIES

This section describes the methods and procedures for site/waste stabilization and long-term care activities for decommissioning a low-level waste (LLW) burial ground. Prospective site/waste stabilization techniques and their relationships to radionuclide transport mechanisms are summarized in Section 10.1. The selection of stabilization plans for particular sites and factors that affect the selection are described in Section 10.2. The site/waste stabilization plans used for demonstration purposes in this study are outlined in Section 10.3 for the western site and in Section 10.4 for the eastern site. Stabilization support activities are described in Section 10.5. Long-term care activities following stabilization are summarized in Section 10.6. Details of site/waste stabilization activities are presented in Appendix F of Volume 2.

10.1 IDENTIFICATION OF PROSPECTIVE SITE/WASTE STABILIZATION TECHNIQUES

Site/waste stabilization is used to reduce the rate and extent of radionuclide release from buried wastes left in place in a decommissioned LLW burial ground. It is anticipated that such measures may be a part of normal burial ground operating procedures in the future.(1) However, existing LLW sites may require stabilization at the time of site closure.

A number of different approaches, or plans, can be employed to stabilize a burial ground. To select an appropriate plan for a particular site, the dominant radionuclide transport mechanisms capable of initiating a release of radioactivity from the site (i.e., release mechanisms) are identified, and suitable stabilization techniques for dealing with these release mechanisms are cataloged and evaluated. Plans (appropriate combinations of techniques) are formulated and evaluated for their effectiveness in preventing contact of the waste by potential transport mechanisms and in reducing the mobility of the buried radionuclides.

The release mechanisms and associated stabilization techniques considered in this study are listed in Table 10.1-1. Examination of the table shows that, for control of a particular transport mechanism, several stabilization

TABLE 10.1-1. Site/Waste Stabilization Techniques Applicable to Control of Individual Release Mechanisms

SITE/WASTE STABILIZATION TECHNIQUES RELEASE MECHANISMS	A. SUBSURFACE ROCK LAYER	B. SUBSURFACE HARD LAYER	C. SUBSURFACE MEMBRANE	D. SURFACE ROCK COVER	E. SURFACE HARD COVER	F. CAPPING SOIL PROPERTIES MODIFICATION	G. BACKFILL AND COMPACTION	H. SITE TOPOGRAPHY ADJUSTMENT	I. INCREASED CAPPING THICKNESS	J. IMPROVED CAPPING DRAINAGE	K. PERIPHERAL DRAINAGE AND DIVERSION	L. SUMP PUMPING WITH TREATMENT	M. CURTAIN WALL	N. WASTE PERMEABILITY REDUCTION	O. WASTE LEACHABILITY REDUCTION	P. RETENTION MEDIA INJECTION	Q. REVEGETATION	R. VEGETATION MANAGEMENT	S. WIND BREAKS
GEOMORPHOLOGICAL																			
EROSION (WATER)	(a)	(a)	(a)	X	X	X		X									X	X	
EROSION (WIND)	(a)	(a)	(a)	X	X	X		X									X	X	X
SUBSIDENCE		X	X		X		X		X					X					
FROST ACTION						X		X	X	X									
MASS WASTING						X		X		X							X	X	
HYDROLOGICAL																			
GROUND WATER		X	X		(b)	(b)		(b)		(b)	X	X	X	X	X	X			
PERCOLATION		X	X		X	X		X		X	X	X	X	X	X	X			
OVERFLOW		X	X		X	X		X		X	X	X		X	X				
BIOLOGICAL																			
PLANT UPTAKE	X	X	X		X	(c)			X									X	
ANIMAL ACTION	X	X	X	X	X				X										
HUMAN ACTIVITY																			
EXCAVATION	X	X		X	X				X										
AGRICULTURE	X	X	X	X	X				X										

(a) SUBSURFACE LAYERS CAN PROVIDE AN EFFECTIVE LOWER LIMIT TO EROSION DAMAGE.

(b) MAY BE EFFECTIVE IN LOWERING LOCAL WATER TABLE, THUS REDUCING POTENTIAL FOR GROUNDWATER INFILTRATION.

(c) MAY BE EFFECTIVE IN REDUCING OR ELIMINATING PLANT GROWTH.

techniques are available. However, all stabilization techniques that apply to a given mechanism are not equally effective in controlling radionuclide migration from the site.

The release mechanisms and stabilization techniques listed in Table 10.1-1 are described briefly in this section and are discussed in more detail in Section F.1 of Volume 2. Section 10.2 describes the development and evaluation of stabilization plans that utilize these techniques.

10.1.1 Identification of Release Mechanisms

Radionuclides can migrate to the biosphere from an LLW burial ground along a variety of pathways. These pathways utilize one or more radionuclide transport mechanisms, acting in series. In this study, the transport mechanism that initiates radionuclide movement (i.e., the first mechanism in the series) is referred to as a release mechanism. Release mechanisms are shown in Table 10.1-1 and can be conveniently classified according to the following categories: geomorphological, hydrological, biological, and human activity. Radionuclide pathways are discussed in Section 8.

10.1.1.1 Geomorphological Release Mechanisms

Geomorphological release mechanisms are those in which radionuclide movement results directly from the shaping or reshaping of the earth's surface by natural forces. The mechanisms considered in this study are water erosion, wind erosion, subsidence, frost action, and mass wasting. All of these are directly dependent on the climate, topography, soil properties, ground cover, and human activities at or near the site. Geomorphological release mechanisms are briefly described here and discussed in more detail in Section F.1.1.1 of Volume 2.

Erosion (Water). Water erosion is the wearing away of the earth's surface by the action of flowing water. In a burial ground, it can remove overburden and expose buried wastes or contaminated soil, resulting in radionuclide migration from the site. (Contaminated soil may result from package rupture during burial, package deterioration, or the prior action of other release mechanisms.) For the burial ground sites considered in this study, significant water erosion damage is likely only at the humid eastern site.

Erosion (Wind). Wind erosion is similar to water erosion except that the driving force is the movement of air rather than water. It can remove overburden and expose buried wastes, and can also impair the effectiveness of vegetative ground cover. Wind erosion is of greater concern at the arid western site than at the humid eastern site, due to the less cohesive nature of the soil and the sparser, more fragile vegetation cover at the western site.

Subsidence. Subsidence refers to the sinking or collapse of the ground surface, which can expose contaminated soil or buried waste materials. The disruption of the soil caused by subsidence also increases erosion (both wind and water) and moisture percolation rates. Subsidence in burial grounds is a function of burial practices, soil type, and waste packaging and compaction. The rate of subsidence at the two burial ground sites considered in this study is anticipated to be similar.

Frost Action. Frost action refers to stresses that result from the expansion of water freezing in the soil profile. Frost action disrupts the overburden, resulting in increased erosion and moisture percolation rates, and can also expose contaminated soil or buried wastes. The impact of frost damage is considered to be greater for the humid eastern site than for the arid western site but is anticipated to be relatively minor for either site.

Mass Wasting. Mass wasting is the downslope movement of soil and sediment caused by gravity, and ranges from slow creep to rapid landslides. In a burial ground, mass wasting can uncover or disturb buried wastes or overburden materials. The impact of mass wasting is anticipated to be limited at the burial ground sites considered in this study because the overall ground slopes are relatively mild. However, small areas with steep slopes may be subject to localized mass wasting.

10.1.1.2 Hydrological Release Mechanisms

Hydrological release mechanisms are those in which radionuclide migration results from the movement of water through the burial site. Water is the principal mechanism that has been observed to cause radionuclide migration at existing sites. The hydrological release mechanisms considered in this study are ground water, percolation, and overflow. Their effects are directly dependent on the climate, topography, soil and sediment properties, hydrology, and human activities at or near the site, and also on the waste characteristics. Hydrological release mechanisms are briefly described here and are discussed in more detail in Section F.1.1.2 of Volume 2.

Ground Water. Ground water is that part of the subsurface water that is in the zone of saturation. Ground water can infiltrate or intrude into buried wastes, resulting in the leaching and subsequent transport of radionuclides. Ground water can also receive water percolating through buried wastes (see Percolation below). For the burial ground sites considered in this study, groundwater intrusion is likely only at the humid eastern site, because the level of the water table at the western site is far (>50 m) below the bottom of the burial trenches.

Percolation. Percolation is the unsaturated flow of water through the soil profile. Subsurface percolating water can cause leaching and transport of radionuclides. Percolation is of greater concern as a mechanism of leaching and transport at the humid eastern site than at the arid western site because of heavier incident precipitation at the eastern site and the generally higher water table.

Overflow. In some areas, impoundment (trapping) of infiltrating water in burial trenches can result in eventual overflow of this water, increasing the transport of leached radionuclides. The likelihood of radionuclide migration resulting from overflow is greater for eastern than for western sites, because of higher incident precipitation and lower soil permeability in the east. However, because of geological differences between and within sites, the potential for overflow must be evaluated on a site-by-site basis, and generalization is inadvisable.

10.1.1.3 Biological Release Mechanisms

Biological release mechanisms are those in which radionuclide migration results from natural biological processes. The mechanisms considered in this study are plant uptake and animal action. These are directly dependent on the prevalent species, climate, soil and sediment properties, waste characteristics, and burial depth. Biological release mechanisms are described briefly here and are discussed in more detail in Section F.1.1.3 of Volume 2.

Plant Uptake. Plant roots can infiltrate buried wastes and absorb radionuclides that are then transported throughout the plant and made available for subsequent dispersion. Plant roots are also influential in the mechanical breakdown of buried wastes and overburden material, reducing the resistance of the burial ground to other release mechanisms. For all burial sites, radionuclide migration by plant uptake could become a concern unless the overburden depth is maintained and problem species are controlled.

Animal Action. Digging and burrowing animals can penetrate down through the overburden into buried wastes, resulting in the return of radionuclides to the ground surface. Animals may also damage the surface cover (e.g., browsing on vegetation). Thus, animal action can reduce the effectiveness of the burial ground in preventing the action of other release mechanisms. Radionuclide migration from the reference burial sites as a result of animal action is expected to be minimal.

10.1.1.4 Human Activity Release Mechanisms

Future human activities at burial ground sites may disturb radioactive materials, leading to subsequent radionuclide migration. The activities considered in this study are excavation and agriculture. They are described briefly here and are discussed in more detail in Section F.1.1.4 of Volume 2.

Excavation. Excavation into LLW burial grounds disrupts overburden materials and can expose and scatter contaminated soil and buried wastes. Excavation will most likely occur where knowledge concerning the presence or location of buried wastes is lacking. However, knowledge of the presence of buried waste is not a guarantee that excavation will not be performed. The impact of radionuclide movement caused by excavation is dependent on the type and amount of material excavated and the time elapsed since waste emplacement (i.e., the decay of the radionuclide inventory). The potential for radionuclide migration due to site excavation is judged to be significant for any decommissioned LLW site, including the two sites considered in this study.

Agriculture. Agricultural activities (i.e., irrigation, tilling, etc.) in a burial ground disrupt overburden materials and can penetrate into radioactive wastes. The resulting extent of radionuclide migration depends on the type and degree of agricultural use but is judged to be significant in any decommissioned LLW site where agriculture is practiced. (See also Plant Uptake.)

10.1.2 Summary of Prospective Stabilization Techniques

As shown in Table 10.1-1, various stabilization techniques are available that reduce the rate and extent of radionuclide migration caused by the action of specific release mechanisms. Each of these stabilization techniques is briefly described in this section and is discussed in more detail in Section F.1.2 of Volume 2. For decommissioning a particular LLW burial ground, suitable combinations of these techniques can be chosen to provide integrated stabilization plans.

Many of these techniques result in added weight that may compact the waste and cause an increase in trench subsidence during the first few years after stabilization. Maintenance of trenches stabilized by the addition of a soil or rock layer is discussed in Section 10.6.3.

In addition to the stabilization techniques summarized in this section, certain administrative measures can be used to reduce radionuclide movement from a burial site. These measures include site-use controls, exclusion fencing, and placement of permanent markers or monuments. Administrative measures are not considered to be stabilization techniques and are discussed in Section 10.6 as part of long-term care activities.

A. Subsurface Rock Layer. The subsurface rock layer is a 0.3- to 1.0-m-thick layer of rocks or cobbles placed over the soil-covered wastes and topped with a material (e.g., plastic sheeting or a hard surface coating) to prevent soil from sifting down into the void spaces between rocks. The rock layer is then covered with a layer of topsoil at least 0.3 m thick, after which the surface is revegetated or otherwise stabilized.

A subsurface rock layer provides a deterrent to human activity or biological (plant and animal) action that might disrupt buried waste. The layer also provides an effective lower limit to erosion, thus serving as a secondary erosion control.

B. Subsurface Hard Layer. The subsurface hard layer is composed of a hard material (e.g., concrete, asphalt, asphalt-soil, soil cement, or clay) placed to a thickness of about 20 to 200 mm, depending on the material used. After the trench area is compacted to provide adequate support, the layer is placed over the soil-covered wastes and covered with a layer of topsoil at least 0.3 m thick. The surface is then stabilized with a vegetative or other surface cover.

The hard layer provides a deterrent to human activity and to biological (plant or animal) action, and also provides a lower limit to erosion. Depending on the materials and methods used, it can also provide protection against hydrological release mechanisms and subsidence.

C. Subsurface Membrane. The subsurface membrane is a thin membrane composed of plastic, rubber or other composite sheeting or a thinly applied layer of asphaltic, polymeric, or other chemical material. It is placed over the wastes and covered with a layer of topsoil, after which the surface is stabilized.

Depending on the materials used, the membrane provides protection against biological action, hydrological release mechanisms, and subsidence. A lower limit to erosion can also result.

D. Surface Rock Cover. A surface rock cover is a 0.15- to 0.4-m-thick blanket of rocks or gravel placed on the surface of a burial ground. A surface rock cover provides protection against erosion and restricts animal burrowing. Agriculture is essentially eliminated by the rock cover and inadvertent human excavation is deterred.

E. Surface Hard Cover. A surface hard cover is a layer of hard material (e.g., asphalt, concrete, or other suitable material) placed on the surface of a burial ground after the area is compacted to provide sufficient support. Depending on the material used, the degree of structural strength desired, and other variables, the thickness of the layer ranges from about 20 to 200 mm.

The hard cover provides protection against erosion, biological action, percolation, and overflow. Excavation activities are deterred and, if the surface cover has adequate support and is of sufficient structural strength, future subsidence damage is reduced. A certain amount of maintenance is required to ensure the continued effectiveness of the cover, particularly against hydrological action.

F. Capping Soil Properties Modification. The properties of the soil used to provide trench caps for the burial trenches can be modified by incorporating appropriate amounts of various soil amendments (e.g., mineral, chemical, or organic materials) into the surface soils. After this, the surface is revegetated or otherwise stabilized.

Depending on the specific modifications made, this technique can be used to increase precipitation runoff and to reduce erosion, percolation, frost heaving, mass wasting, and plant-root intrusion.

G. Backfill and Compaction. Backfill can be added to the surface of a burial ground to repair areas damaged by subsidence, erosion, mass wasting, etc. After the added material is compacted, the surface is stabilized with a vegetative or other surface cover.

Care must be taken during backfill and compaction operations to avoid the disruption of waste materials that can result from the operation of heavy equipment in unstable areas (i.e., areas prone to subsidence).

H. Site Topography Adjustment. Site topography adjustment is the grading, scraping, or other movement of surface soils to alter site contours. After contouring, the surface is stabilized as desired using appropriate surface stabilization techniques.

Site topography can be adjusted to control water runoff and percolation, and to reduce erosion, frost action, and mass wasting. Care must be taken in the contouring of burial ground sites to avoid disturbance of buried wastes, which can result in inadvertent radionuclide release.

I. Increased Capping Thickness. This technique is simply the addition of more soil to the surface of a burial ground to increase the burial depth of the wastes. After compaction (optional), the surface is graded to preserve the original site contours or to establish new contours. The new surface is then revegetated or otherwise stabilized. This technique is similar to that described above for Backfill and Compaction (item G); but the purpose is to increase the thickness of soil cover over the buried waste rather than to repair damaged surface areas.

Increasing the capping thickness over buried wastes reduces the potential for radionuclide migration due to biological (plant and animal) action, subsidence, frost heaving and human activities.

J. Improved Capping Drainage. Capping drainage is improved by constructing an engineered drainage system (of ditches and/or pipes) on the surface of the burial trench area. The system design results from a civil site survey and an analysis of drainage requirements.

Improved capping drainage reduces the impact of hydrological action and helps to protect against frost heaving and mass wasting.

K. Peripheral Drainage and Diversion. Peripheral drainage and diversion is the interception and diversion of (surface and/or ground) water at or outside of the site boundaries. The system is designed on the basis of a civil survey and a drainage requirement analysis. (This technique is closely related to item J above.)

Peripheral drainage and diversion is useful in routing offsite water safely away from wastes buried at the site, reducing the impact of hydrological action.

L. Sump Pumping with Treatment. This is a method of collecting contaminated trench water and removing radionuclides from it. For this technique, sumps with standpipes are installed in the burial trenches. Pumps, connected by a piping system to a treatment plant, are installed in the sumps when needed. Radionuclides removed from the water at the treatment plant are solidified, packaged, and buried.

Pumping of water from sumps located in the burial trenches, with subsequent water treatment to remove radionuclides, reduces offsite radionuclide migration due to hydrological forces. Obviously, to remain effective, such a system requires continued maintenance and operation.

M. Curtain Wall. A curtain wall is an impervious vertical wall (or trench dam) at the edge of a burial ground, constructed using one of several techniques (e.g., slurry-wall construction, injection grouting, or placement of prefabricated wall sections).

A vertical curtain wall at the edge of a burial ground (or burial trench) prevents horizontal infiltration of water into the site, thus reducing radionuclide leaching and transport. Curtain walls have been used at Oak Ridge for groundwater diversion (see Section 3.2.1.3).

N. Waste Permeability Reduction. Reduction of waste permeability involves the injection of suitable grout materials (e.g., cement, clay, asphaltic, polymeric, or other chemical materials) into the buried wastes to fill interstitial spaces in the waste-soil matrix and reduce the permeability of the matrix. The pressurized injection also compresses and compacts soft areas in the waste. (This technique could also be used to reduce trench cap permeability.)

By reducing waste permeability, radionuclide migration caused by hydrological action is reduced. As an added benefit, compression of soft spots reduces the extent of subsidence damage.

O. Waste Leachability Reduction. This technique involves the injection of suitable materials into buried wastes to chemically and/or physically bond to the radionuclides, reducing their leachability. (This is very similar to item N above and, with proper selection of materials, both techniques can be used simultaneously.)

By decreasing the leachability of the waste, the importance of water as a transport mechanism is reduced.

P. Retention Media Injection. Retention media injection is the injection of suitable material (e.g., ion-exchange materials, adsorbents, clays, and other chemical substances) into the soil surrounding the buried wastes to filter out, adsorb, bond to, or otherwise retain radionuclides migrating through the soil. Injection methods similar to those used in preceding techniques are used here.

By surrounding the wastes with retention media, radionuclide migration from hydrological action is reduced. The long-term effectiveness of this technique is questionable, however, because of the possibilities for channeling, bypassing, and material breakdown with time.

Q. Revegetation. Revegetation is the reestablishment of a vegetative cover on a disturbed ground surface. After the surface is prepared, it is planted with selected vegetation species. Various aids to revegetation (e.g., fertilizers, soil amendments, mulches, and chemical stabilizers) are used as necessary.

Revegetation of burial grounds can be used to control wind and water erosion and, to some extent, mass wasting and the site moisture balance. However, plant roots can be disruptive, as discussed in Section 10.1.1.3, so care must be taken in the choice of vegetative species to be used. The effectiveness of vegetation increases over a period of years, until the plant community reaches maturity.

R. Vegetation Management. Vegetation management is the maintenance of a vegetated surface to ensure the continued viability of the vegetative community and to provide corrective action for incidental problems. Elements of a vegetation management program, which can be used separately or in various combinations, include replanting of damaged areas, periodic mowing of grass, use of herbicides, use of competing plant species, periodic clearing of undesirable vegetation, and use of biological (bacterial or insect) controls.

A vegetation management program in a burial ground can be used to reduce erosion damage and to restrict plant-root penetration into buried wastes.

S. Wind Breaks. Wind breaks (or shelterbelts) are barriers that reduce wind speed in an area of concern, and are an established soil conservation tool. Either vegetation or physical barriers may be used; however, the use of a vegetation barrier could result in plant- or tree-root penetration into the buried waste.

Wind breaks are used to control wind erosion at a burial ground.

10.2 SELECTION OF ALTERNATIVE STABILIZATION PLANS

By reference to Table 10.1-1, it can be seen that a relatively large number of site/waste stabilization plans involving combinations of stabilization techniques can be postulated for dealing with potential radionuclide transport mechanisms at a particular site. These postulated plans will vary widely in effectiveness, cost, useful life, ease of implementation, etc. To select a stabilization plan for implementation at a specific site, it is necessary to establish some evaluation criteria. After screening the multitude of available plans, a small number are chosen for detailed analysis. These plans are evaluated and a final selection is made.

This section describes the process used to select site/waste stabilization plans. The bases used for plan selection are described in Section 10.2.1. Procedures used for preliminary plan selection are outlined in Section 10.2.2. Final plan selection is described in Section 10.2.3.

A single plan would normally be chosen for implementation at a particular site. The plan would take into account any stabilization activities performed during the operational phase of the burial ground. In this study, three plans are chosen for evaluation at each of the two generic sites (the arid western and humid eastern sites). The plans range from very simple plans, which might be used in cases where stabilization activities have been a part of burial ground operating procedures, to complex plans, which might be required in situations where site maintenance during burial ground operation was minimal and extensive stabilization measures are required prior to site closure.

10.2.1 Bases for Selection of Stabilization Plans

Because only a small number of alternative stabilization plans are subjected to detailed analysis, it is important that these plans be selected with care. The selected plans must provide adequate protection against radionuclide migration within the limits and constraints (e.g., available financing, site conditions, performance requirements, and material availability) imposed on the site operator. Therefore, it is important that the bases used for selection of the stabilization plans also be given careful consideration.

This section discusses the criteria used to evaluate stabilization techniques and plans, and illustrates the evaluation of individual techniques with regard to these criteria. It also lists the dominant release mechanisms for each generic site, which are used to determine which techniques are appropriate in formulating the stabilization plans for these sites.

10.2.1.1 Bases for Evaluation of Stabilization Techniques and Plans

Factors used in this study to evaluate stabilization plans and techniques include:

- effectiveness against radionuclide transport mechanisms
- initial cost
- annual maintenance cost
- anticipated useful life (i.e., the period over which the technique or plan retains at least 75% of its original effectiveness)
- ease of application.

These factors are not all of equal importance. Because the primary concern in burial ground stabilization is protecting the health and safety of the public, the most important evaluation factor is effectiveness against radionuclide transport mechanisms. Cost considerations and anticipated useful life are of secondary importance. Ease of application is the least important factor. Other factors that might be employed in an evaluation of stabilization techniques and plans include availability of materials, esthetics of the technique or plan, potential for land use following plan implementation, and public acceptability of the plan.

10.2.1.2 Evaluation of Stabilization Techniques

Stabilization plans are composed of combinations of individual techniques. Therefore, the first step in the evaluation of a plan is to evaluate the techniques on which the plan is based. The results of an evaluation of the stabilization techniques discussed in Section 10.1, using the evaluation factors from Section 10.2.1.1, are presented here.

Stabilization techniques are ranked with regard to effectiveness in dealing with radionuclide transport mechanisms in Table 10.2-1. The ranking is

TABLE 10.2-1. Effectiveness Ratings of Prospective Site/Waste Stabilization Techniques Against Radionuclide Transport Mechanisms[a]

RELEASE MECHANISMS / PROSPECTIVE SITE/WASTE STABILIZATION TECHNIQUES	A. SUBSURFACE ROCK LAYER	B. SUBSURFACE HARD LAYER	C. SUBSURFACE MEMBRANE	D. SURFACE ROCK COVER	E. SURFACE HARD COVER	F. CAPPING SOIL PROPERTIES MODIFICATION	G. BACKFILL AND COMPACTION	H. SITE TOPOGRAPHY ADJUSTMENT	I. INCREASED CAPPING THICKNESS	J. IMPROVED CAPPING DRAINAGE	K. PERIPHERAL DRAINAGE AND DIVERSION	L. SUMP PUMPING WITH TREATMENT	M. CURTAIN WALL	N. WASTE PERMEABILITY REDUCTION	O. WASTE LEACHABILITY REDUCTION	P. RETENTION MEDIA INJECTION	Q. REVEGETATION	R. VEGETATION MANAGEMENT	S. WIND BREAKS
GEOMORPHOLOGICAL																			
EROSION (WATER)	S[b]	S	S	1	1	4		2									2	2	
EROSION (WIND)	S	S	S	1	1	3		4									1	1	2
SUBSIDENCE		2	4		2		1		3					1					
FROST ACTION						4		3	1	2									
MASS WASTING						3		2		3							4	4	
HYDROLOGICAL																			
GROUND WATER		4	4		M[c]	M		M		M	2	1	2	1	1	1			
PERCOLATION		1	1		1	3		3		2	3	3	4	1	1	1			
OVERFLOW		2	2		2	3		3		2	3	1		4	4				
BIOLOGICAL																			
PLANT UPTAKE	2	2	3		1	M			3									2	
ANIMAL ACTION	2	1	4	2	1				3										
HUMAN ACTIVITY																			
EXCAVATION	2	2		2	2				3										
AGRICULTURE	2	2	4	1	1				3										

[a] EFFECTIVENESS RATINGS ARE: 1-EXCELLENT, 2-GOOD, 3-FAIR, AND 4-POOR

[b] AN S INDICATES A SECONDARY CONTROL THAT BECOMES EFFECTIVE IF PRIMARY CONTROLS FAIL.

[c] AN M INDICATES A TECHNIQUE THAT IS EFFECTIVE UNDER SPECIFIC CONDITIONS AND IS THUS CONSIDERED MARGINAL.

on a scale of 1 to 4, from most effective to least effective. Due to the lack of objective data, the rankings shown in the table are subjective and are made by members of the LLW burial ground study team. Further research is needed to objectively quantify effectiveness values.

Estimates of initial and annual maintenance costs, useful life, and ease of application for the stabilization techniques considered in this study are shown in Table 10.2-2. Cost ranges are based on information from References 2 through 5; further development is found in Section F.1.2 of Volume 2. The costs are given on a per-trench basis and include materials, equipment, and labor. Per-unit costs for stabilization of larger areas (i.e., entire burial grounds) are anticipated to be somewhat less than those shown. The useful life is defined as the time period during which a stabilization technique retains at least 75% of its original effectiveness. Estimates of useful life are taken from the references, where such data are available; in some cases, these estimates are modified to provide more realistic values on the basis of engineering judgment. In cases where no values are available in the literature, the useful life is estimated by the study team. Ease of application is rated subjectively on a scale of 1 to 5, from easiest to most difficult.

Effectiveness, cost, and other factors used to rank stabilization techniques will vary from site to site, depending on a variety of conditions (e.g., geology, hydrology, climate, and burial ground operating history). Therefore, the values given in this section are general in nature, and should be carefully examined and refined as necessary when considering the application of a technique to a specific site or situation. Many of these techniques are still in the development stage, and uncertainties exist concerning technique effectiveness and cost.

The ranking of a stabilization plan with respect to a particular evaluation factor is not simply the sum of the rankings of the techniques that comprise the plan. The ranking of specific plans is discussed in Section 10.2.2.

10.2.1.3 Dominant Release Mechanisms

For a given site, the dominant release mechanisms (i.e., those radionuclide transport mechanisms with a significant potential for initiating radionuclide migration from the site) must be identified to select stabilization

TABLE 10.2-2. Estimated Costs and Related Factors for Prospective Site/Waste Stabilization Techniques

Stabilization Techniques	Initial Cost[a] ($K/trench)	Annual Maintenance[a] Costs ($K/trench year)	Useful Life[b] (years)	Ease of Application[c]	Comments
A. Subsurface Rock Layer	13 - 37	Not Maintained	80 - 200	2	
B. Subsurface Hard Layer	8.6 - 35	Not Maintained	80 - 200	3	
C. Subsurface Membrane	4.8 - 14	Not Maintained	10 - 40	3	
D. Surface Rock Cover	3.0 - 8.1	0.09 - 0.41	200+	1	
E. Surface Hard Cover	3.7 - 25	0.18 - 2.0	40 - 100	2	
F. Capping Soil Properties Modification	3.4 - 13	As Needed[d]	200+	1	
G. Backfill and Compaction	7.2 - 12	As Needed[d]	200+	1	
H. Site Topography Adjustment	1.8 - 3.8	0.05 - 0.19	200+	1	
I. Increased Capping Thickness	4.9 - 7.2	As Needed[d]	200+	1	
J. Improved Capping Drainage	1.7 - 17	0.09 - 0.85	200+	1	
K. Peripheral Drainage and Diversion	$100-500/linear meter	$5-25/linear meter	200+	2	
L. Sump Pumping with Treatment	0.55-7.7	0.11 - 0.23	30	4	Maintenance cost includes operating expenses
M. Curtain Wall	≤110	Not Maintained	25 - 100	4	
N. Waste Permeability Reduction	300 - 1500	Not Maintained	25 - 100	5	
O. Waste Leachability Reduction	300 - 1500	Not Maintained	25 - 100	5	
P. Retention Media Injection	200 - 1100	Not Maintained	10 - 40	5	
Q. Revegetation	0.20-0.46	(See R)	200+	2	
R. Vegetation Management	(See Q)	0.02 - 0.05	200+	2	
S. Wind Breaks	$300-400/km length[e]	$15-22/km length[e]	50 - 100	1	Tree shelterbelt, with no irrigation

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(a) Costs per trench based on 150-m x 15-m trench with 1.5-m border (2750 m^2 area). All costs rounded to two significant figures, and include materials, labor, and equipment. See Section F.1.2 of Volume 2 for cost information bases.

(b) Useful life defined as period over which stabilization technique retains at least 75% of original effectiveness.

(c) Ease of application rated on scale of 1 to 5, from easiest to most difficult.

(d) Maintained as indicated necessary by site surveillance, with maintenance costs not estimated.

(e) Irrigation is required in arid areas, increasing costs by one to two orders of magnitude.

plans that provide adequate protection against radionuclide migration. Where a specific release mechanism is of particular concern, the stabilization plans chosen may include several techniques effective against that release mechanism, thus providing a greater margin of protection.

The methodology for identifying critical pathways for the migration of radioactivity from an LLW burial ground is discussed in Section 8. On the basis of data presented in Section 8, dominant release mechanisms are identified for the reference burial sites of this study. In order of decreasing importance, the dominant release mechanisms for the western site are:

- human activities (excavation and agriculture)
- wind erosion.

For the eastern site, the dominant release mechanisms (in order of decreasing importance) are:

- human activities (excavation and agriculture)
- hydrological releases (percolation and overflow)
- water erosion.

10.2.2 Preliminary Selection of Stabilization Plans

Preliminary selection of stabilization plans for a particular LLW burial site involves the selection of "packages" of stabilization techniques to provide protection against the dominant release mechanisms at that site. This preliminary selection involves identification of prospective plans, semiquantitative evaluation of these plans, and elimination of the less-suitable ones. This simplifies the final selection process by limiting the number of prospective plans being considered. It also allows the remaining plans to be examined in more detail.

10.2.2.1 Identification of Prospective Stabilization Plans

A large number of prospective stabilization plans can be postulated for a given site, using the stabilization techniques presented in Section 10.1. These techniques can be used either individually or in various combinations. A semi-quantitative evaluation of the possible plans, based on the information presented in Tables 10.2-1 and 10.2-2, verifies that many plans can be quickly eliminated from detailed consideration. Some of the possible plans do not provide sufficient protection against the dominant release mechanisms and should be rejected. Other plans, while sufficiently effective, are overly complex and/or expensive (i.e., they are no more effective than less-complex, less-expensive alternatives) and can also be eliminated. In addition, it is unnecessary to include all possible variations of a plan, as minor plan modifications can be made during the subsequent detailed analysis.

On the basis of the preliminary semi-quantitative evaluation described above, many possible stabilization plans are eliminated from further consideration. Those plans retained for detailed evaluation in this study are listed in Tables 10.2-3 and 10.2-4 for the arid western and humid eastern sites, respectively. The listed plans serve to illustrate the range and general characteristics of plausible stabilization plans. Letters shown in the "Plan Code" columns of the tables identify the individual techniques that make up the plans, and refer to letters used to identify the techniques in Section 10.1 and Tables 10.1-1 and 10.2-1.

10.2.2.2 Evaluation of Prospective Stabilization Plans

The information in Tables 10.2-3 and 10.2-4 includes an evaluation of prospective stabilization plans on the bases of effectiveness in controlling the dominant release mechanisms at the two sites, estimated costs of initial application and annual maintenance, anticipated useful life, and ease of application.

The costs reported for a plan are not just the simple sum of the costs of the individual techniques included in the plan. Similar activities may be required for several techniques in a plan. Where this overlap of activities occurs, the initial cost is reduced. Furthermore, use of a particular technique may reduce or eliminate the maintenance requirement for another technique included in the same plan (e.g., applying a hard surface cover after adjusting site topography essentially eliminates the need to maintain the new site contours).

Although precise values for some of the evaluation parameters in Tables 10.2-3 and 10.2-4 are difficult to estimate, relative differences between the plans are more important than absolute values. These differences can be identified by examining the tables. This allows the stabilization

TABLE 10.2-3. Comparison of Prospective Site/Waste Stabilization Plans for the Arid Western Site

Plan No.	Plan Code[b]	Stabilization Plan Description	Effectiveness Rating for:[a] Excavation	Agriculture	Wind Erosion	Estimated Initial Cost ($K/trench)[c]	Estimated Annual Maintenance Costs ($K/trench year)[c]	Anticipated Useful Life (Years)[d]	Ease of Application (1-5)[e]
101	E	Surface hard cover	2	1	1	3.7 - 25	0.18 - 2.0	40 - 100	2
102	I,D	Increased capping thickness, surface rock cover	2	1	1	7.9 - 15	0.09 - 0.41	200+	1
103	I,Q,R	Increased capping thickness, revegetation, vegetation management	3	V	1	5.1 - 7.7	0.02 - 0.05	200+	2
104	A and/or B, I,Q,R	Subsurface rock and/or hard layer, increased capping thickness, revegetation, vegetation management	2	V	1	17 - 36	0.02 - 0.05	80 - 200	3
105	A and/or B, I,D	Subsurface rock and/or hard layer, increased capping thickness, surface rock cover	1	1	1	20 - 43	0.09 - 0.41	80 - 200	3
106	C,I,Q,R	Sursurface membrane, increased capping thickness, revegetation, vegetation management	3	V	1	5.0 - 20	0.02 - 0.05	10 - 40	3
107	C,I,D	Subsurface membrane, increased capping thickness, surface rock cover	2	1	1	7.9 - 27	0.09 - 0.41	10 - 40	3
108	P,D	Retention media injection, surface rock cover	2	1	1	220 - 1100	0.09 - 0.41	10 - 40	5
109	P,Q,R	Retention media injection, revegetation, vegetation management	NE	NE	1	220 - 1100	0.02 - 0.05	10 - 40	5
110	N and/or O,E	Waste permeability and/or leachability reduction, surface hard cover	2	1	1	300 - 1500	0.18 - 2.0	25 - 100	5
111	N and/or O,Q,R	Waste permeability and/or leachability reduction, revegetation, vegetation management	NE	NE	1	300 - 1500	0.02 - 0.05	25 - 100	5

(a) Effectiveness ratings given only for release mechanisms of concern. Ratings are: 1 - Excellent, 2 - Good, 3 - Fair, 4 - Poor, V - Variable and NE - Not Effective
(b) Code letters refer to stabilization techniques presented in Section 10.1.
(c) Costs per trench based on 150-m x 15-m trench with 1.5-m border (2750 m^2 area). Costs include materials, labor, and equipment, and are rounded to two significant figures.
(d) Useful life defined as period over which stabilization plan retains at least 75% of original effectiveness.
(e) Ease of application rated on scale of 1 to 5, from easiest to most difficult.

TABLE 10.2-4. Comparison of Prospective Site/Waste Stabilization Plans for the Humid Eastern Site

Plan Number	Plan Code[b]	Stabilization Plan Description	Effectiveness Rating for[a]					Estimated Initial Cost ($K/trench[c]	Estimated Annual Maintenance Costs ($K/trench year)[c]	Anticipated Useful Life (years)[d]	Ease of Application (1-5)[e]	Comments
			Excavation	Agriculture	Percolation	Overflow	Water Erosion					
201	H,E	Site topography adjustment, surface hard cover	2	1	1	2	1	5.5 - 27	0.18 - 2.0	40 - 100	2	
202	H,K,Q,R	Site topography adjustment, peripheral drainage and diversion, revegetation, vegetation management	NE	NE	3	3	1	3.9 - 13.6	0.16 - 0.71	200+	2	Assuming 180-trench site with 3.35 km perimeter
203	I,J,D	Increased capping thickness, improved capping drainage, surface rock cover	2	1	2	2	1	9.7 - 32	0.18 - 1.3	200+	1	
204	I,L,Q,R	Increased capping thickness, sump pumping with treatment, revegetation, vegetation management	3	V	3	1	2	5.7 - 15	0.13 - 0.28	30	3	
205	A and/or B, I,L,Q,R	Subsurface rock and/or hard layer, increased capping thickness, sump pumping with treatment, revegetation, vegetation management	2	V	V	1	2	18 - 44	0.13 - 0.28	30	4	
206	A and/or B, I,J,D	Subsurface rock and/or hard layer, increased capping thickness, improved capping drainage, surface rock cover	1	1	2	2	1	22 - 60	0.18 - 1.3	50 - 200	3	
207	C,I,Q,R	Subsurface membrane, increased capping thickness, revegetation, vegetation management	3	V	1	2	2	5.0 - 20	0.02 - 0.05	10 - 40	3	
208	C,I,D	Subsurface membrane, increased capping thickness, surface rock cover	2	1	1	2	1	7.9 - 27	0.09 - 0.41	10 - 40	3	
209	P,Q,R	Retention media injection, revegetation, vegetation management	NE	NE	1	NE	2	220 - 1100	0.02 - 0.05	10 - 40	5	
210	N and/or O, E	Waste permeability and/or leachability reduction, surface hard cover	2	1	1	2	1	300 - 1500	0.18 - 2.0	25 - 100	5	
211	N and/or O, Q,R	Waste permeability and/or leachability reduction, revegetation, vegetation management	NE	NE	1	4	2	300 - 1500	0.02 - 0.05	25 - 100	5	
212	M,B,H,D	Curtain wall, subsurface hard layer, site topography adjustment, surface rock cover	1	1	1	2	1	18 - 50	0.09 - 0.41	25 - 100	4	Assumes curtain wall at site perimeter

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(a) Effectiveness ratings given only for release mechanisms of concern. Ratings are: 1 - Excellent, 2 - Good, 3 - Fair, 4 - Poor, V - Variable, and NE - Not Effective.
(b) Code letters refer to stabilization techniques presented in Section 10.1.
(c) Costs per trench based on 150-m x 15-m trench with 1.5-m border (2750 m^2 area). Costs include materials, labor, and equipment and are rounded to two significant figures.
(d) Useful life defined as period over which stabilization plan retains at least 75% of original effectiveness.
(e) Ease of application rated on scale of 1 to 5, from easiest to most difficult.

plans to be compared with each other, and, by taking into account the relative importance of each of the factors, the relative acceptability or suitability of individual plans can be assessed.

10.2.3 Final Selection of Stabilization Plans

The final selection of a stabilization plan for a particular site is made on the basis of an evaluation of alternative plans, using information like that presented in Tables 10.2-3 and 10.2-4. Because this is a study to evaluate future decommissioning needs, sets of three alternative plans (rather than single plans) are chosen for detailed cost and safety analyses at each generic burial site. These alternative plans are listed in Table 10.2-5.

TABLE 10.2-5. Alternative Site/Waste Stabilization Plans

Arid Western Site	Stabilization Plan Description	Stabilization Techniques Used[a]
Minimal Plan	Site inspection, stabilization of final trenches and of damaged areas, vegetation management	G,R
Modest Plan	Increased capping thickness, revegetation, vegetation management	I,Q,R
Complex Plan	Subsurface rock layer with hard top, increased capping thickness, revegetation, vegetation management	A,B,I,Q,R
Humid Eastern Site		
Minimal Plan	Site inspection, stabilization of final trenches and of damaged areas, vegetation management	G,R
Modest Plan	Increased capping thickness, capping soil properties modification, improved capping drainage, revegetation, vegetation management	I,F,J,Q,R
Complex Plan	Peripheral drainage and diversion, sump pumping with treatment, subsurface hard layer, increased capping thickness, revegetation, vegetation management	K,L,B,I,Q,R

(a) Code letters refer to stabilization techniques presented in Section 10.1.

The stabilization plans listed in Table 10.2-5 include a minimal plan, a relatively modest one, and a more complex one. These plans correspond to varying levels of effort that may be required to properly stabilize a site. The minimal plan assumes that stabilization has been an integral part of normal site procedures during burial ground operation and, therefore, only a minor effort is required to prepare the site for long-term care. The modest and complex plans correspond to increasingly greater needs for site/waste stabilization before the site is turned over to the state for long-term care. The level of effort required to stabilize a site at the conclusion of burial operations depends on site-specific parameters and on the degree of stabilization performed during burial operations as individual trenches are filled.

Ordinarily, the choice of a plan for a given site is not influenced by the choice for another site. However, in this study, the minimal and the modest plans chosen for the two sites are essentially the same, differing only because of site-specific differences (e.g., dominant release mechanisms and general site characteristics). This allows a comparison of similar plans applied to different sites. The complex plans chosen for the two sites are intentionally different, to allow for detailed analysis of a wider range of stabilization alternatives.

Details of methods and procedures for implementation of the stabilization plans listed in Table 10.2-5 are given in Sections 10.3 and 10.4 for the western and eastern sites, respectively.

10.3 DESCRIPTION OF ALTERNATIVE STABILIZATION PLANS FOR THE ARID WESTERN SITE

The three site/waste stabilization plans selected for the western site are described in this section. These plans are designed to provide the required protection against the dominant release mechanisms at the site (i.e., excavation, agriculture, and wind erosion). As previously discussed, one of the plans is minimal, one relatively modest, and the other more complex. Procedures and work schedule estimates are presented for each plan. The environmental monitoring program for the site, as it pertains to stabilization, is also described here. Because support activities (i.e., planning and preparation and quality assurance) are essentially the same for all of the plans for both sites, these activities are discussed separately in Section 10.5. Long-term care activities following site stabilization are discussed in Section 10.6. Cost estimates for all of the stabilization plans are presented in Section 12.

10.3.1 Minimal Stabilization Plan for the Arid Western Site

The minimal stabilization plan for the western site assumes that trenches were satisfactorily stabilized as they were filled. Therefore, the minimal plan includes the stabilization of only those trenches that were active during the final period of site operation (e.g., the nine trenches filled during the final 18 months of operation of the reference burial ground). The minimal plan also assumes that stabilization activities involving the entire burial ground (e.g., a polymer coating over the whole site) are not required at the conclusion of waste emplacement operations.

Stabilization of the nine trenches filled during the last 18 months of operation is assumed to be accomplished by increasing the capping soil thickness over the trenches, followed by grading and revegetation of the surface. (This same stabilization technique is used for the modest plan for the entire burial site and is described in Section 10.3.2.)

The entire site is inspected to identify any remedial measures required to prepare the site for long-term care. Site repairs include backfilling and compaction of subsided areas, repair of exclusion fencing, and vegetation management (e.g., reseeding of disturbed areas, clearing the site of undesirable vegetation, use of herbicides, etc.). After these activities are completed, the site is released to the government agency responsible for long-term care.

Minimal stabilization of the western site is estimated to require 10 weeks to complete, based on the stabilization activity details and assumptions presented in Section H.2 of Volume 2.

10.3.2 Modest Stabilization Plan for the Arid Western Site

The modest stabilization plan assumes that burial trenches were not stabilized as they were filled. Therefore, stabilization of the entire burial site is necessary when waste emplacement operations cease. As shown in Table 10.2-5, the modest stabilization plan for the western site includes increased capping thickness over the buried wastes, revegetation of the resulting surface, and vegetation management. Vegetation management activities are initiated on an as-needed basis (as indicated by site observation) and continue on into the long-term care period. Recontouring of the site may take place in conjunction with the increase in capping soil thickness if it is determined that new site contours are required to improve site drainage. For this study it is assumed that the original site contours are maintained. Hence, no recontouring of the site is required for this plan except in those areas where waste-trench subsidence has created depressions; these depressions are filled to restore the site to original post-burial contours.

The increase in capping thickness results in the wastes being located further below the ground surface, reducing the chances of waste disruption by frost heaving, plant and animal action, and human activity. Revegetation of the surface provides protection against erosion and, on an arid site such as this, significantly reduces percolation, because of the consumption and evapotranspiration of soil moisture by the plants. Management of the site vegetation ensures the continued viability of the vegetative community, providing protection against erosion and against intrusion by undesirable deep-rooted plant species such as Russian thistle (tumbleweed).

10.3.2.1 Stabilization Procedures

Procedures for the modest stabilization plan for the western site include site preparation, capping thickness increase, and revegetation. Vegetation management procedures are used during both stabilization and subsequent long-term care, but only those used during stabilization are discussed here. A schematic representation of the stabilization plan is shown in Figure 10.3-1.

Site Preparation. Site preparation activities for this plan consist mainly of removing or killing site vegetation and laying out survey markers to provide instructions for subsequent activities. Site preparation also includes the filling and compacting of any soft areas that might later subside under heavy-equipment traffic. These soft areas are identified by visual inspection, by ground scans (e.g., ultrasonic) to locate subsurface voids, or by other means.

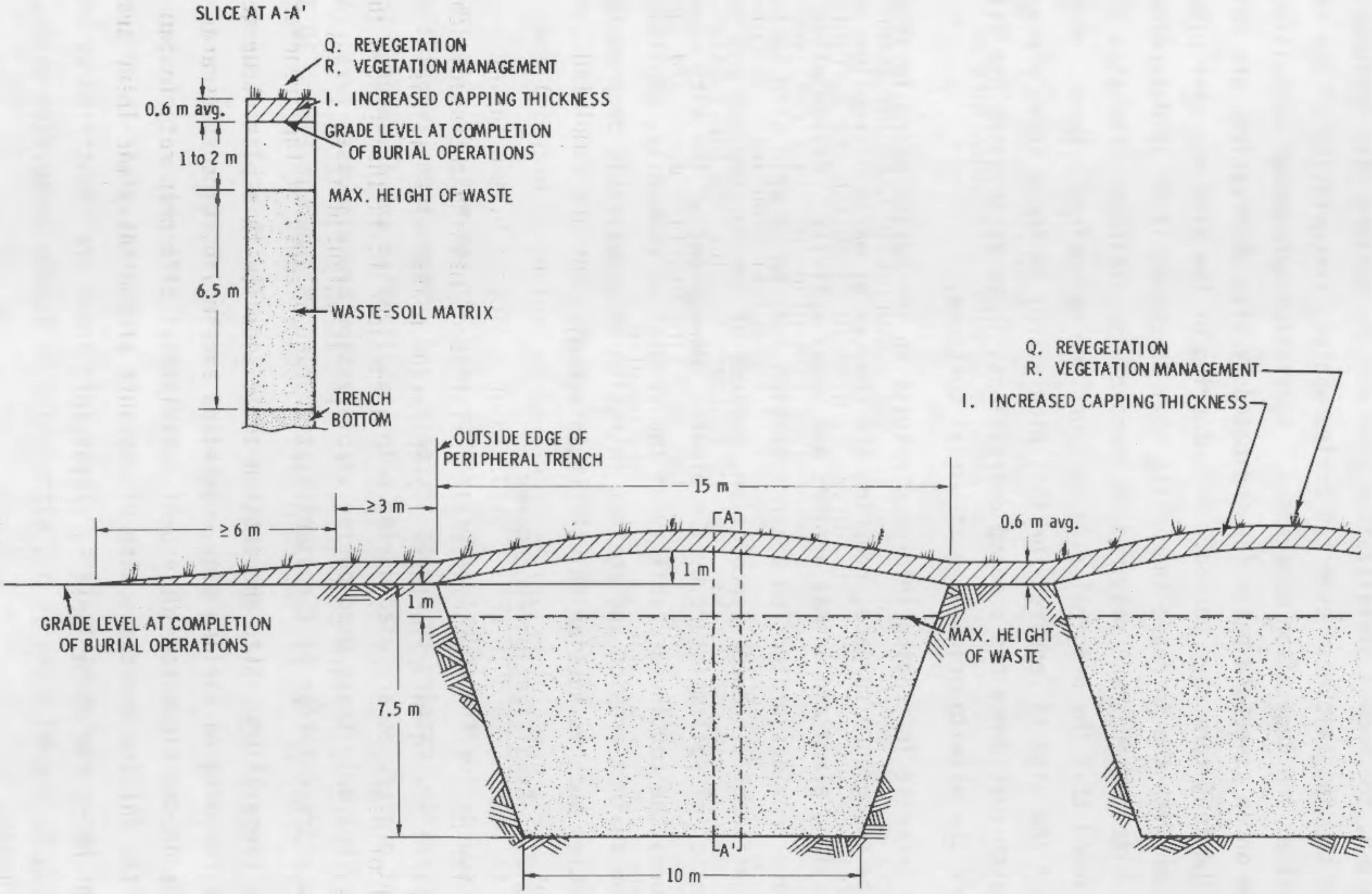

FIGURE 10.3-1. Schematic Representation of the Modest Stabilization Plan for the Arid Western Site

Site vegetation must be killed or removed to ensure that no viable plant roots remain in the soil profile in close proximity to the buried wastes. Any large plants, such as sagebrush or rabbitbrush, are destroyed using a brush-hog to chop them into small pieces. Smaller vegetation such as grasses or forbs,(a) along with any roots remaining from the large plants, are killed by applying herbicides to the site. Care is taken to avoid herbicide drift that might cause damage to vegetation in areas adjacent to the site. The total area to receive backfill is cleared using these techniques.

After the site is cleared of vegetation, small soft areas likely to subside under heavy-equipment traffic are identified. Backfill is hauled into these areas, dumped, and carefully compacted with vibratory compactors to reduce the hazard.

A civil survey of the site is carried out concurrently with the other site preparation activities. This survey is used to establish the current contours of the site, to develop the detailed plot plan for the stabilized burial ground, and to verify the locations of the burial trenches. To complete the survey, markers are laid out as instructions for the backfilling activities that follow, to ensure that the resulting backfill depth and surface contours are as specified in the detailed plan.

Capping Thickness Increase. After site preparations are completed, the capping thickness over the wastes is increased by hauling in backfill and spreading it to a uniform thickness of 0.6 m as indicated by the survey markers. The backfill is native topsoil (silty sand) meeting the specifications prepared during the planning and preparation phase. The fill is obtained from nearby, hauled to the site, and spread. It is then graded to obtain the specified surface contours. The fill is extended at full depth over all the trenches, to at least 3 m past the outer edges of the trenches at the periphery of the site, and is then sloped down (with a 10 to 1 or gentler slope) to original grade level. Standard earthmoving techniques and equipment are used for these activities. No special effort is made to compact the backfill, but some compaction occurs because of the heavy-machinery traffic during the spreading and grading activities.

(a)A forb is any herb that is not grass or grasslike.

During the backfilling, limited surveying continues to verify that the depth and contours of the fill meet the specifications for the job.

Revegetation. After the capping thickness is increased, the site is revegetated with a mixture of drought-resistant annual and perennial grasses selected during the planning and preparation phase. One possible mixture is simply cheatgrass and Siberian wheatgrass. Other desirable species such as forbs, mosses, and lichens are anticipated to move into the revegetated area naturally within several years, providing a more diverse and vigorous vegetative community and increasing erosion resistance.

Based on soil tests performed during planning and preparation, fertilizer is used to improve the nutrient balance of the soil. A chemical soil stabilizer (organic emulsion) and a mulch (straw) are used to improve the soil moisture balance and to limit erosion damage until the vegetation becomes established. A hydroseeder(a) is used to spread the seed and other materials (i.e., fertilizer, mulch, and stabilizer). The revegetation is carried out according to the specifications established during the planning and preparation phase.

Vegetation Management. Management of site vegetation is primarily used during long-term care (see Section 10.6). However, if site observations indicate that it is necessary, vegetation management is initiated during stabilization. It is assumed that, during stabilization, vegetative management is limited to the repair of small areas disturbed during the stabilization of adjacent ground.

It is anticipated that small parts of areas already revegetated are disturbed by equipment traffic during revegetation of adjacent areas. These small disturbed areas require repair (i.e., releveling and reseeding). No additional fertilizer is used, but mulch and chemical stabilizer are reapplied. Because of the small size of these disturbed areas, repairs can be made using hand methods or small-scale lawn-and-garden machinery. Any ruts in the

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(a) A hydroseeder is a machine in which the seed and other materials to be applied are mixed in a water-based slurry and sprayed on the surface. All the materials used can be applied in one pass or, as is more common, several passes can be made.

surface caused by machinery traffic are leveled either by hand-raking or by grading with a small tractor. The area is reseeded either by spreading the seed with a hand-seeder and raking it into the soil or by using a mechanical seeder drawn by a small tractor. Mulch is distributed manually, and the chemical stabilizer is applied either with a hand-sprayer or with a small tractor-mounted sprayer.

There are several reasons why the temporary use of irrigation to hasten the establishment of the vegetation is not considered in this study. When irrigation is discontinued in arid areas, shock is induced in the plants, causing subsequent damage and possible vegetative failure. Irrigation also leaches nutrients from the soil, requiring increased fertilization. Finally, excessive irrigation may lead to significant moisture percolation through the buried wastes, resulting in possible radionuclide leaching and transport.

10.3.2.2 Work Schedule Estimates

The overall schedule and sequence of events for the modest stabilization of the western site is shown in Figure 10.3-2, based on the stabilization activity details and assumptions presented in Section H.2 of Volume 2. As shown in the figure, 29 weeks of effort are required after burial ground shutdown to complete the stabilization. Planning and preparation required prior to stabilization is discussed in Section 10.5.1.

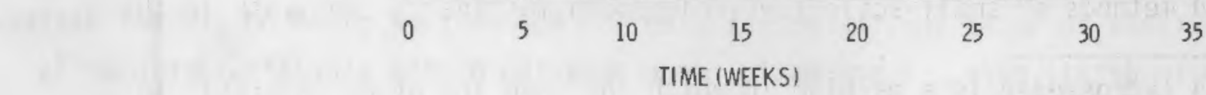


FIGURE 10.3-2. Estimated Work Schedule for the Modest Stabilization of the Arid Western Site

10.3.3 Complex Stabilization Plan for the Arid Western Site

The complex stabilization plan assumes that burial trenches were not stabilized as they were filled. Therefore, stabilization of the entire burial site is necessary when waste emplacement operations cease. As shown in Table 10.2-5, the complex stabilization plan for the western site includes a subsurface rock layer with a hard top, increased capping thickness, revegetation of the surface, and vegetation management. Vegetation management activities are initiated on an as-needed basis (as indicated by site observation) and continue into the long-term care period. The site is not recontoured; the final site contours, after addition of the subsurface layer and the backfill, approximate the original contours.

The subsurface hard-topped rock 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 if primary erosion controls fail. The subsurface layer and the backfill cover increase the capping thickness, resulting in the wastes being located further below the ground surface. This reduces the chances of waste disruption by frost heaving, plant and animal action, and human activity. Revegetation provides protection against erosion and, on an arid site, reduces percolation (as discussed earlier). Management of site vegetation ensures the continued viability of the vegetative community, providing protection against erosion and against intrusion by undesirable plant species such as Russian thistle (tumbleweed).

10.3.3.1 Stabilization Procedures

Procedures for the complex stabilization plan for the western site include site preparation, rock layer emplacement, rock layer hard-topping, capping thickness increase (backfilling), revegetation, and vegetation management during stabilization. The procedures for site preparation, capping thickness increase, revegetation, and vegetation management are essentially identical to those for the modest plan for the western site and are not discussed in detail here. A schematic representation of the stabilization plan is shown in Figure 10.3-3.

Site Preparation. Site preparation activities are identical to those presented in Section 10.3.2.1, except that the inclusion of the subsurface

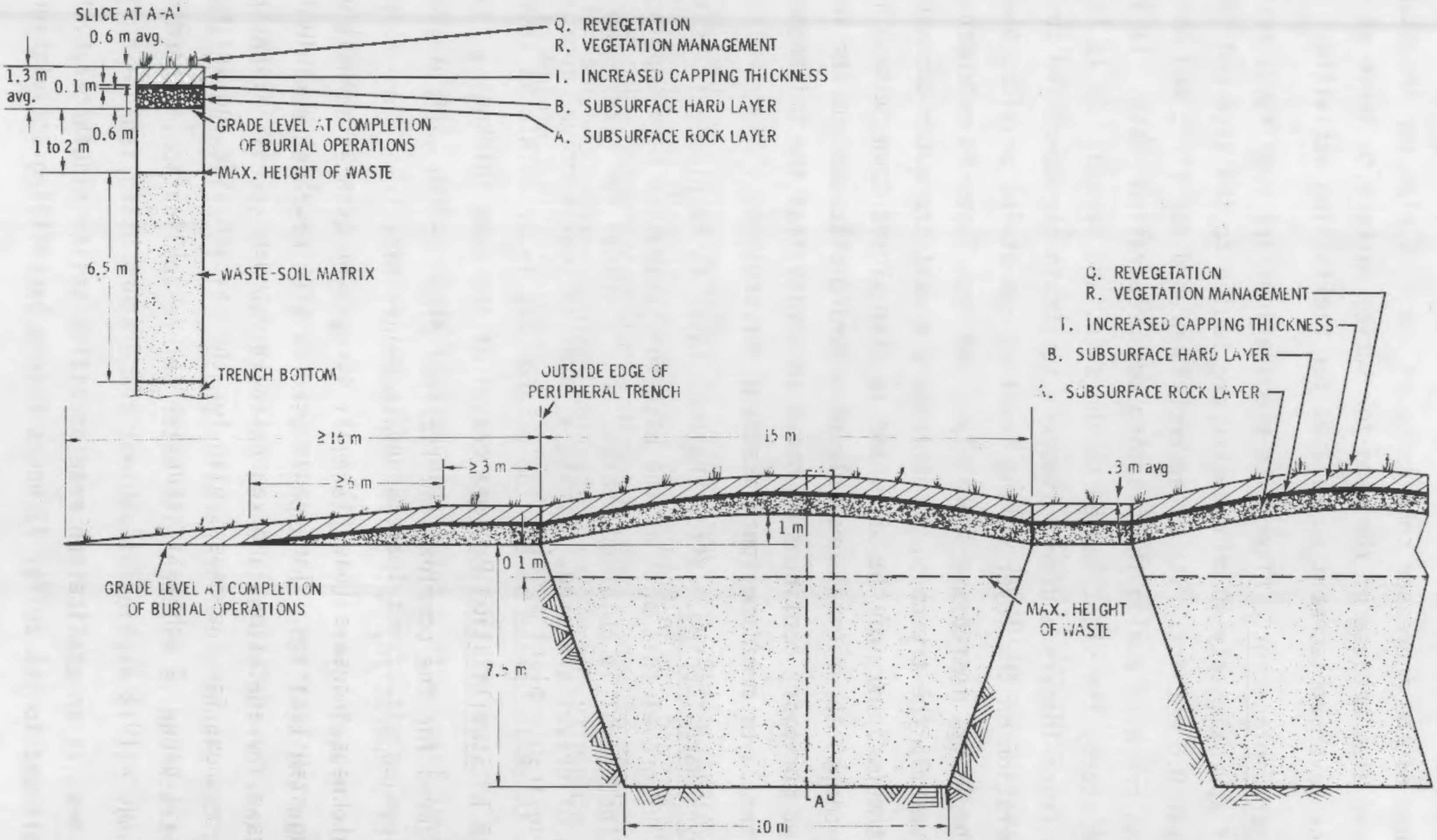


FIGURE 10.3-3. Schematic Representation of the Complex Stabilization Plan for the Arid Western Site

rock layer results in the need for a slightly more detailed civil survey. This is because of the increased complexity of the plot plan for the stabilized site, and also because of the need for survey markers to serve as instructions for rock layer emplacement as well as for backfilling activities.

Rock Layer Emplacement. After site preparations are completed, rocks (cobblestones) of approximately 40 mm diameter are hauled to the site and spread to form a layer 0.6 m thick. The clean rock is graded for size, and meets the specifications prepared during the planning and preparation phase. It is obtained from nearby the site, hauled to the site, and spread. It is then leveled with front-loaders and/or bulldozers to obtain the specified contours. Equipment operation on the layer during leveling operations provides some compaction of the layer, increasing stability. The rock layer is extended at full depth over all the trenches, to at least 3 m past the outer edges of the trenches at the periphery of the site, and is then sloped down (with a 10 to 1 or gentler slope) to original grade level. During placement of the rock layer, limited surveying continues in order to verify that the thickness and contours of the layer meet the specifications for the job.

Rock Layer Hard-Topping. After the rock layer is in place, it is topped with a layer of gravel that acts as the base for subsequent hard-topping of the layer. The gravel is obtained nearby, and is graded for size. Two different sizes of gravel are used. First, a layer of coarse gravel approximately 50 mm thick is spread on the top of the rock layer. This is covered, in turn, with a layer of (smaller) pea gravel of the same thickness, resulting in a gravel layer with a total thickness of about 0.1 m. The gravel is spread and leveled with front-loaders and/or bulldozers.

After the gravel layer is in place, it is sprayed with an asphalt emulsion to harden and seal it. The asphalt used is a water-based emulsion that is custom-mixed for the project, based on tests run and specifications prepared during the planning and preparation phase. It is delivered to the site in a tanker-truck and is diluted with water before application, according to specifications. It is applied at ambient temperature using tankers equipped with spray bars, at an application rate specified by the manufacturer. The asphalt is allowed to set up for 72 hours before backfilling activities commence.

Capping Thickness Increase. The capping thickness is increased by backfilling, as described in Section 10.3.2.1. The hard-topped rock layer is covered with 0.6 m of topsoil, with the fill beyond the rock layer sloped down to the original grade level with a 10 to 1 or gentler slope (to match the slope of the edge of the rock layer).

Revegetation. The revegetation procedure for this plan is identical to that for the modest plan for the western site, as described in Section 10.3.2.1.

Vegetation Management. Vegetation management activities during stabilization are assumed to be limited to the repair of small areas disturbed during the stabilization of adjacent ground. Procedures are described in Section 10.3.2.1. Vegetation management activities during long-term care of the site are discussed in Section 10.6.

10.3.3.2 Work Schedule Estimates

The overall schedule and sequence of events for the complex stabilization of the western site is shown in Figure 10.3-4, based on the stabilization activity details and assumptions presented in Section H.2 of Volume 2. As shown in the figure, 35 weeks of effort are required after burial ground shutdown to complete stabilization of the site. Planning and preparation required prior to stabilization is discussed in Section 10.5.1.

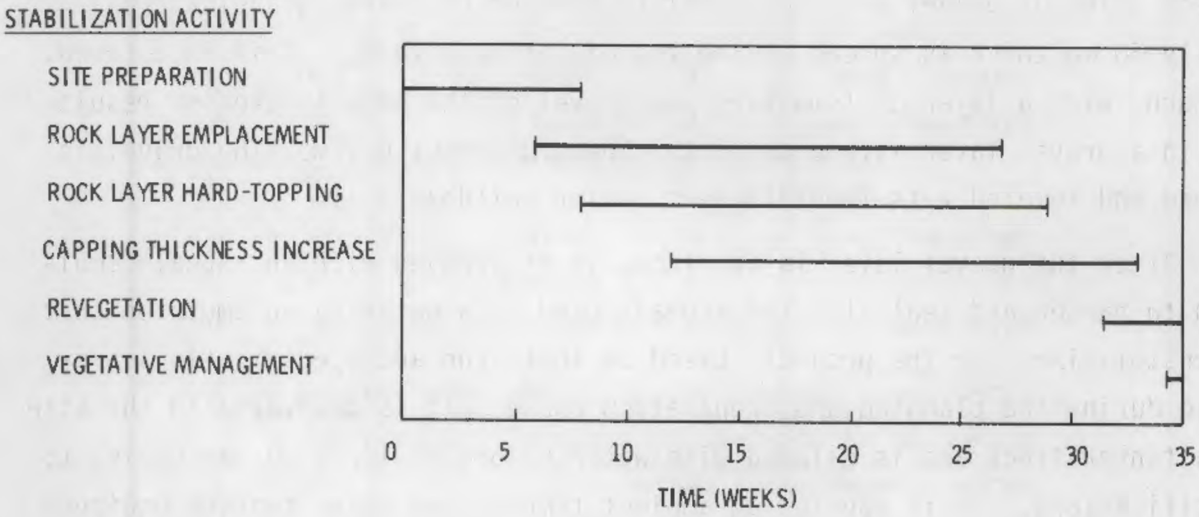


FIGURE 10.3-4. Estimated Work Schedule for the Complex Stabilization of the Arid Western Site

10.3.4 Environmental Monitoring During Stabilization of the Arid Western Site

Environmental monitoring requirements during stabilization of an LLW burial site are discussed in Section 9.2. Requirements during stabilization of the reference western site are summarized in Table 10.3-1. Sampling requirements during site decommissioning are based on the operational sampling program summarized in Table 7.2-3. The frequency of onsite soil sampling is increased during stabilization, and special sample points are designated, to detect any changes in radioactivity levels in the soil caused by stabilization procedures.

TABLE 10.3-1. Environmental Sampling Program During Stabilization of the Western Site

Sample Type	Number of Sample Locations	Sampling Frequency	Total Samples$^{(a)}$ Minimal Plan$^{(b)}$	Modest Plan	Complex Plan
Water - Onsite Wells	6	Semi-annual	2	6	12
Offsite Wells	3$^{(c)}$	Annual	1	3	3
Surface Water	2$^{(c)}$	Semi-annual	1	2	4
Total			4	11	19
Air Particulates - Onsite	1	Weekly	10	29	35
Offsite	2$^{(c)}$	Weekly	20	58	70
Total			30	87	105
Soil - Onsite	4	Bi-weekly	20	60	72
Offsite	2	Annual	0	2	2
Total			20	62	74
Vegetation - Onsite	4	Annual	1	4	4
Small Mammals - Onsite	4	Annual	1	4	4
Offsite	4	Annual	1	4	4
Total			2	8	8
Game Birds - Offsite	4	Annual	1	4	4
Fish - Offsite	1	Quarterly	1	2	3
Direct Radiation	3$^{(c,d)}$	Monthly	27	63	81

(a) Total samples computed on the basis of stabilization periods of 10, 29, and 35 weeks for the minimal, modest, and complex plans, respectively.
(b) Annual and semi-annual samples estimated on a pro rata basis.
(c) Includes one control sample location.
(d) Three dosimeters at each location.

The total number of environmental samples required during site stabilization by the modest or complex plans is based on time requirements for the completion of decommissioning activities (29 weeks for the modest plan and 35 weeks for the complex plan). The sampling program for the minimal stabilization plan is simply a continuation of the program during burial operations, shown in Table 7.2-3.

10.4 DESCRIPTION OF ALTERNATIVE STABILIZATION PLANS FOR THE HUMID EASTERN SITE

The three site/waste stabilization plans selected for the eastern site are described in this section. These plans are designed to provide the required protection against the dominant release mechanisms at the site (i.e., human activitites, hydrological action, and water erosion). As previously discussed, one of the plans is minimal, one relatively modest, and the other more complex. Procedures and work schedule estimates are presented for each plan. The environmental monitoring program for the site, as it pertains to stabilization, is also described here. Support activities (i.e., planning and preparation and quality assurance) are discussed in Section 10.5. Long-term care activities following site stabilization are discussed in Section 10.6. Cost estimates are given in Section 12.

10.4.1 Minimal Stabilization Plan for the Humid Eastern Site

The minimal stabilization plan for the eastern site is essentially the same as that for the western site, described in Section 10.3.1. The minimal plan assumes that trenches were satisfactorily stabilized as they were filled. Therefore, the plan includes the stabilization of only those trenches that were active during the final period of site operation.

The entire site is inspected to identify any remedial measures required to prepare the site for long-term care. Site repairs include backfilling and compaction of subsided areas, repair of exclusion fencing, and vegetation management. Because of the higher incidence of inclement weather and higher rainfall at the eastern site, backfilling and compaction requirements are anticipated to be about 25% greater at the eastern site than at the western site.

Minimal stabilization of the eastern site is estimated to require 11 weeks to complete, based on the stabilization activity details and assumptions presented in Section H.2 of Volume 2.

10.4.2 Modest Stabilization Plan for the humid Eastern Site

As shown in Table 10.2-5, the modest stabilization plan chosen for the eastern site is similar to the modest plan for the western site, discussed previously. The plan assumes that stabilization of the entire site takes place when waste emplacement operations cease. The plan for the eastern site includes the same techniques used for the western site, namely increased capping thickness over the buried wastes, revegetation of the resulting surface, and any necessary vegetation management. In addition, the eastern plan includes modification of capping soil properties and improved capping drainage to provide greater protection against hydrological release. Vegetation management activities continue during long-term care, as described in Section 10.6. It is assumed that the original site contours are maintained when the soil thickness over the trenches is increased, so that no major recontouring of the site is required. However, depressions created by waste-trench subsidence are filled to restore the original post-burial grade level, and minor contour adjustments are made as required for the capping drainage system.

The increase in capping thickness results in the wastes being located further below the ground surface, reducing the chances of waste disruption by frost heaving, plant and animal action, and human activity. The modification of the capping soil properties (by adding clay and compacting the capping soil) increases the erosion resistance of the soil and reduces moisture percolation. The improved capping drainage also reduces moisture percolation by channeling precipitation away from the trenches. Revegetation of the surface provides added protection against erosion, and vegetation management ensures the continued viability of the vegetative community.

10.4.2.1 Stabilization Procedures

Procedures for the modest stabilization plan for the eastern site include site preparation, capping thickness increase, capping drainage improvement, capping soil properties modification, revegetation, and vegetation management during stabilization. The procedures for site preparation, capping thickness increase, revegetation, and vegetation management are similar to those for the modest plan for the western site and are not discussed in detail here. A schematic representation of the stabilization plan is shown in Figure 10.4-1.

Site Preparation. Site preparation activities are identical to those presented in Section 10.3.2.1, except that the civil survey and the resulting plot plan for the stabilized site are slightly more complicated for this stabilization plan. This is because of the need to design the capping drainage system, and to provide adequate instructions (in the form of survey markers) for its construction.

Capping Thickness Increase. The capping thickness is increased by backfilling in a manner similar to that described in Section 10.3.2.1. The backfill used is native topsoil (loess) meeting the required specifications, and is obtained from nearby the site. For this plan, the fill is graded to the approximate surface contours, rather than the finished contours, because of the subsequent operations (i.e., digging of the drainage-ditch system and incorporation of clay into the soil).

Capping Drainage Improvement. A system of small drainage ditches is dug on the site to allow precipitation to flow easily away from the burial trenches. The basic design for the system is prepared during the planning and preparation phase, with the final design prepared after the civil survey of the site. The ditches are dug with front-loaders and/or bulldozers, and the edges are smoothed by grading. The ground surface between the ditches is contoured to ensure that all precipitation readily drains to the ditches. Limited surveying continues during this activity to verify that the system is constructed as designed. The ditches are revegetated with the rest of the site, as described below.

Capping Soil Properties Modification. After the drainage system is laid out, the properties of the capping soil over the entire surface of the burial trench area are modified by adding clay to the soil and then compacting it. The type and amount of clay added is determined by soil testing performed during the planning and preparation phase. The clay is spread on the surface in

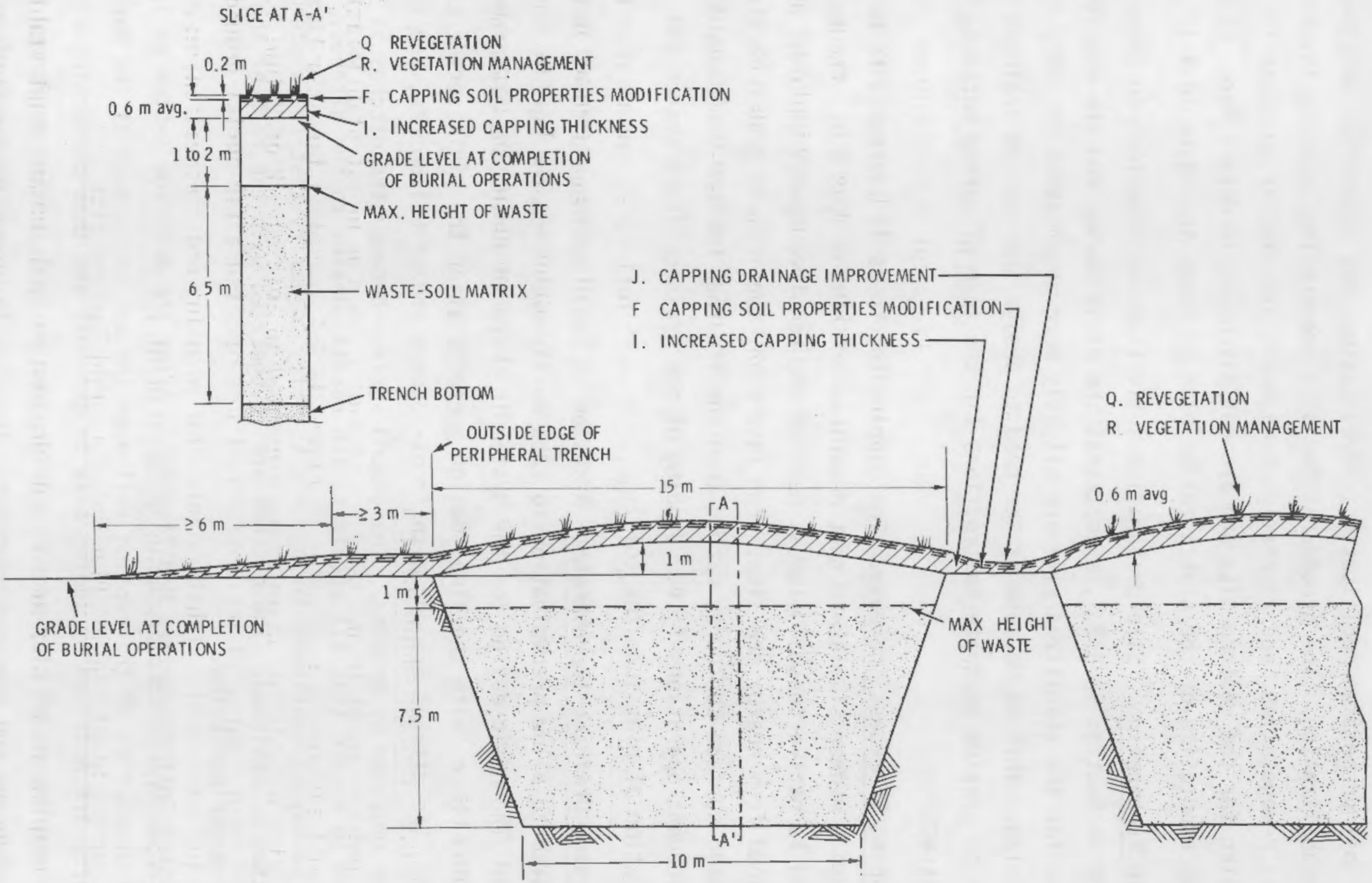


FIGURE 10.4-1. Schematic Representation of the Modest Stabilization Plan for the Humid Eastern Site

the specified amount, after which it is disced into the soil. Several passes are made with the disc to incorporate the clay uniformly into the top 0.15 to 0.2 m of soil. The soil is then compacted using a sheepsfoot roller or other appropriate compactor. (Reference 6 describes variables affecting compaction and applicability of compaction techniques to specific situations.) Several passes of the roller are required (two passes are assumed) to achieve the degree of compaction specified during planning and preparation, and soil tests are carried out to verify the compaction. Finally, the site is graded to obtain the specified site contours.

Revegetation. The revegetation procedure is similar to that described for the modest western plan (see Section 10.3.2.1) except that different plant species are used. The site is revegetated with a mixture of annual and perennial grasses suited to the soil and climate conditions at the site, as specified during planning and preparation. One possible mixture is simply fescue and ryegrass. A legume such as alfalfa, birdsfoot trefoil, or sweetclover may be added to the mixture. The final selection of plant species is based on tests performed during planning and preparation.

Vegetation Management. Vegetation management activities during stabilization are assumed to be limited to the repair of small areas disturbed during revegetation of adjacent ground, as described in Section 10.3.1.1. The temporary use of irrigation is not considered to be either necessary or desirable at an eastern site.

10.4.2.2 Work Schedule Estimates

The overall schedule and sequence of events for the modest stabilization of the humid eastern site is shown in Figure 10.4-2, based on the stabilization activity details and assumptions presented in Section H.2 of Volume 2. As shown in the figure, 34 weeks of effort are required after burial ground shutdown to complete the stabilization. The planning and preparation required prior to stabilization is discussed in Section 10.5.1.

10.4.3 Complex Stabilization Plan for the Humid Eastern Site

The complex stabilization plan for the eastern site assumes that stabilization of the entire site takes places when waste emplacement operations cease.

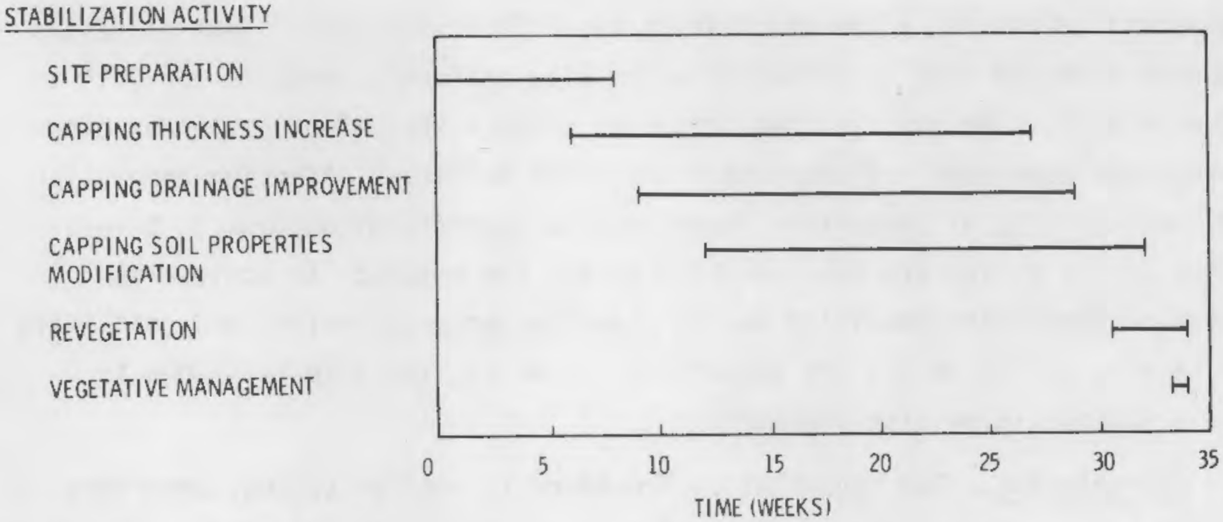


FIGURE 10.4-2. Estimated Work Schedule for the Modest Stabilization of the Humid Eastern Site

As shown in Table 10.2-5, the complex plan includes peripheral drainage and diversion, a subsurface hard layer, increased capping thickness, revegetation, sump pumping with treatment and vegetation management. The capability for handling trench water is ensured during stabilization, but sump pumping (with water treatment) is initiated during long-term care only if needed. Some recontouring of the site may also be necessary to ensure that moisture percolating down to the subsurface hard layer drains from the site, rather than building up on top of the layer (and to ensure adequate surface drainage of the entire trench area).

The peripheral drainage/diversion ditches provide protection against hydrological transport mechanisms by intercepting moisture migrating toward the site and by providing drainage for moisture that builds up above the subsurface hard layer. The subsurface hard 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 if primary erosion controls fail. The increased capping thickness results in the wastes being located further below the ground surface, reducing the chances of waste disruption by frost heaving, plant and animal action, and human activity. Revegetation of the surface provides protection against erosion, and vegetation management ensures the continued viability of the vegetative community. Capability for pumping and treatment of trench water provides further protection against radionuclide migration by hydrological action.

10.4.3.1 Stabilization Procedures

Procedures for the complex stabilization plan for the eastern site include site preparation, hard layer emplacement, capping thickness increase, revegetation, vegetation management during stabilization, and peripheral drainage/diversion system construction. Preparations for sump pumping and treatment of trench water are also completed. The procedures for site preparation, capping thickness increase, revegetation, and vegetation management are similar to those presented previously and are not discussed in detail here. A schematic representation of the stabilization plan is shown in Figure 10.4-3.

Site Preparation. Site preparation activities are similar to those presented for the other plans. However, the civil survey of the site is expanded to take into account the peripheral drainage/diversion system and the subsurface hard layer. In addition, minor recontouring of the site is required to ensure the proper drainage of moisture percolating down to the hard layer, to prevent moisture build-up on top of the layer. In general, the site slopes gently to one side, so only a small amount of grading is expected to be required to eliminate uneven areas and depressions. This grading takes place after the filling and compacting of any areas judged as likely spots for subsidence.

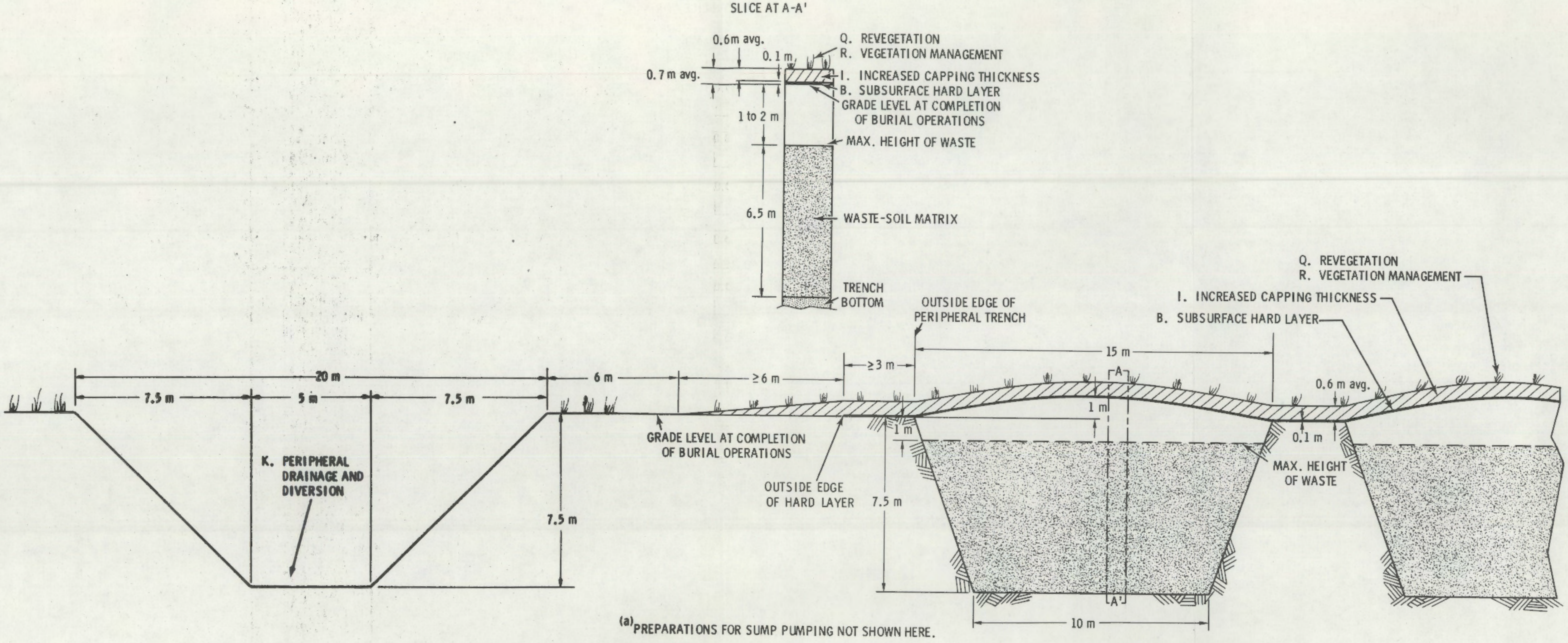
Hard Layer Emplacement. After site preparations are completed, an asphalt-soil layer about 0.1 m thick is laid over the entire trench area of the site, and extended at least 3 m past the outer edges of the peripheral trenches. The area to be covered by the layer is first compacted using a drum-type road roller. Following this, a soil stabilizer machine is used to mix asphalt emulsion into the surface soil in compliance with specifications prepared during planning and preparation. The machine works by pulverizing the surface soil with a rotating horizontal-drum cutter, spraying the asphalt emulsion into the soil in a mixing chamber, and then laying the asphalt-soil mixture on the surface. The product of this step is a loose mixture of asphalt-coated soil particles. This mixture is then compacted, using a road roller, to form the hard management ensures the continued viability of the vegetative community. Capability for pumping and treatment of trench water provides further protection against radionuclide migration by hydrological action.

10.4.3.1 Stabilization Procedures

Procedures for the complex stabilization plan for the eastern site include site preparation, hard layer emplacement, capping thickness increase, revegetation, vegetation management during stabilization, and peripheral drainage/diversion system construction. Preparations for sump pumping and treatment of trench water are also completed. The procedures for site preparation, capping thickness increase, revegetation, and vegetation management are similar to those presented previously and are not discussed in detail here. A schematic representation of the stabilization plan is shown in Figure 10.4-3.

Site Preparation. Site preparation activities are similar to those presented for the other plans. However, the civil survey of the site is expanded to take into account the peripheral drainage/diversion system and the subsurface hard layer. In addition, minor recontouring of the site is required to ensure the proper drainage of moisture percolating down to the hard layer, to prevent moisture build-up on top of the layer. In general, the site slopes gently to one side, so only a small amount of grading is expected to be required to eliminate uneven areas and depressions. This grading takes place after the filling and compacting of any areas judged as likely spots for subsidence.

Hard Layer Emplacement. After site preparations are completed, an asphalt-soil layer about 0.1 m thick is laid over the entire trench area of the site, and extended at least 3 m past the outer edges of the peripheral trenches. The area to be covered by the layer is first compacted using a drum-type road roller. Following this, a soil stabilizer machine is used to mix asphalt emulsion into the surface soil in compliance with specifications prepared during planning and preparation. The machine works by pulverizing the surface soil with a rotating horizontal-drum cutter, spraying the asphalt emulsion into the soil in a mixing chamber, and then laying the asphalt-soil mixture on the surface. The product of this step is a loose mixture of asphalt-coated soil particles. This mixture is then compacted, using a road roller, to form the hard



[(a)] PREPARATIONS FOR SUMP PUMPING NOT SHOWN HERE.

FIGURE 10.4-3. Schematic Representation of the Complex Stabilization Plan for the Humid Eastern Site[(a)]

layer. Tests of the mixture are made to verify proper compaction, as specified by QA procedures. The layer is allowed to set up for 72 hours before subsequent backfilling activities commence.

Capping Thickness Increase. The capping thickness is increased by backfilling, using procedures discussed previously. The backfill is native topsoil (loess). Some of the backfill is obtained from the area where the peripheral drainage/diversion system is constructed. The remainder is hauled in from offsite. The backfill is extended at full depth to cover the entire hard layer, and is sloped down (with a 10 to 1 or gentler slope) to original grade level at the edges. Some contouring of the site is necessary to properly mate the site drainage system with the peripheral drainage/diversion system.

Peripheral Drainage/Diversion System Construction. Concurrently with the other stabilization activities, drainage/diversion ditches are dug in the 50-m-wide exclusion area around the site perimeter. The ditches completely encircle the site and are about 7.5 m deep, 20 m wide at the top, and 5 m wide at the bottom. The ditches are designed to intercept both runoff approaching the site and ground water that might intrude into the buried wastes, and also to provide drainage for excess moisture above the subsurface hard layer. They are dug using standard earth-moving equipment and techniques. The topsoil removed is used as part of the backfill over the trenches (see Capping Thickness Increase above), and the subsoil is used to construct ditch berms or is removed from the site. The ditches are surveyed to verify that they are constructed as specified in the detailed plot plan. The ditches are revegetated along with the site, but the plant species used for the ditches are chosen for tolerance to high soil-moisture content. An impermeable liner is not used in the ditches, to allow ground water to seep into the ditches and drain away from the burial trenches.

Revegetation. The revegetation procedure for this plan is identical to that for the modest plan for the eastern site, as described in Section 10.4.2.1.

Vegetation Management. Vegetation management activities during stabilization are assumed to be limited to the repair of small areas disturbed during revegetation of adjacent ground, as described in Section 10.3.2.1.

Preparations for Sump Pumping and Treatment. The wells installed in the burial trenches during operations (see Section 7.2.2) are checked to verify that the screened ends extending into the trench drains are clear and that the wells themselves are not damaged in such a way that pumps cannot be installed if needed. It is anticipated that only a small number of the wells will require repair. The water treatment system located in the decontamination area of the maintenance building is checked out, serviced as necessary, and then placed on standby. It is anticipated that only minor servicing of the system is required. Sump pumps and transfer lines are not installed at this time; they are installed during the long-term care period when and if they are required (see Section 10.6).

10.4.3.2 Work Schedule Estimates

The overall schedule and sequence of events for the complex stabilization of the eastern site is shown in Figure 10.4-4, based on the stabilization activity details and assumptions presented in Section H.2 of Volume 2. As shown in the figure, 36 weeks of effort are required after burial ground shutdown to complete the stabilization. The planning and preparation required prior to stabilization is discussed in Section 10.5.1.

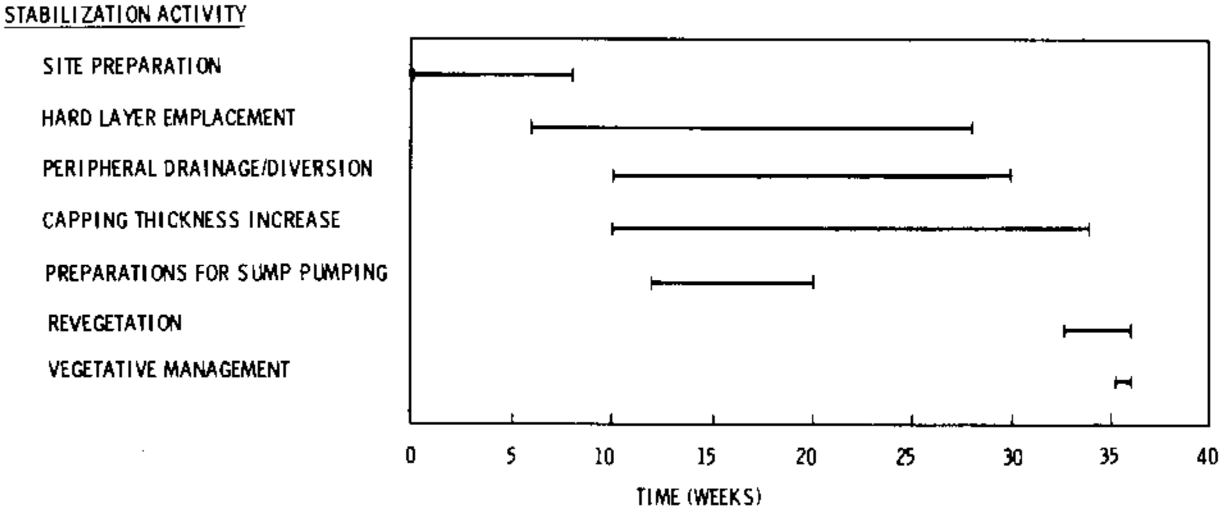


FIGURE 10.4-4. Estimated Work Schedule for the Complex Stabilization of the Humid Eastern Site

10.4.4 Environmental Monitoring During Stabilization of the Humid Eastern Site

Environmental monitoring requirements during stabilization of an LLW burial site are discussed in Section 9.2. Requirements during stabilization of the reference eastern site are summarized in Table 10.4-1. Sampling requirements during site decommissioning are based on the operational sampling

TABLE 10.4-1. Environmental Sampling Program During Stabilization of the Eastern Site

Sample Type	Number of Sample Locations	Sampling Frequency	Total Samples[a]		
			Minimal Plan[b]	Modest Plan	Complex Plan
Water - Onsite Wells	12	Quarterly	12	36	36
Offsite Wells	5[c]	Semi-annual	2	5	10
Surface Water	4[c]	Quarterly	4	12	12
Total			18	53	58
Air particulates - Onsite	1	Weekly	11	34	36
Offsite	2[c]	Weekly	22	68	72
Total			33	102	108
Soil - Onsite	4	Bi-weekly	24	68	72
Offsite	2	Annual	1	2	2
Total			25	70	74
Vegetation - Onsite	4	Annual	1	4	4
Small Mammals - Onsite	4	Annual	1	4	4
Offsite	4	Annual	1	4	4
Total			2	8	8
Game Birds - Offsite	4	Annual	1	4	4
Milk - Offsite	3	Quarterly	3	9	9
Fish - Offsite	4	Quarterly	4	12	12
Farm Crops - Offsite	3	Annual	1	3	3
Direct Radiation	3[c,d]	Monthly	36	72	81

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[a] Total samples computed on the basis of stabilization periods of 11, 34, and 36 weeks for the minimal, modest, and complex plans, respectively.
[b] Annual and semi-annual samples estimated on a pro rata basis.
[c] Includes one control sample location.
[d] Three dosimeters at each location.

program summarized in Table 7.2-3. The frequency of onsite soil sampling is increased during stabilization, and special sample points are designated, to detect any changes in radioactivity levels in the soil caused by stabilization procedures.

The total number of environmental samples required during site stabilization by the modest or complex plans is based on time requirements for the completion of decommissioning activities (34 weeks for the modest plan and 36 weeks for the complex plan). The sampling program for the minimal stabilization plan is simply a continuation of the program during burial operations, shown in Table 7.2-3.

10.5 STABILIZATION SUPPORT ACTIVITIES

Several support activities are necessary to ensure the successful and efficient completion of LLW burial ground decommissioning by site/waste stabilization. A planning and preparation phase, which includes all activities necessary to prepare for decommissioning, is completed during the final months of burial ground operations before the actual stabilization begins. The activities described below apply particularly to site stabilization by the modest and complex plans. For sites where trench stabilization has been a part of operating procedures and only minimal stabilization is required prior to site release, a much reduced planning effort would be necessary. For example, a Master Decommissioning Plan would already have been prepared, but some form of environmental assessment would probably be required prior to termination of the operating license.

A quality assurance program is carried on throughout the decommissioning effort, beginning with the planning and preparation phase and continuing on through the actual stabilization period. Additional quality assurance details are provided in Section F.2 of Volume 2.

10.5.1 Planning and Preparation for Burial Ground Stabilization

Planning and preparation activities for burial ground stabilization are carried out concurrently with the final 18 months of burial ground operation.

At the beginning of this period, the site operator assembles a staff to perform planning and preparation functions and to oversee the decommissioning activities. The members of this staff draw on their own experience, as well as the experience of others, in carrying out their assignments.

Planning and preparation activities include:

- preparation of a Master Decommissioning Plan
- preparation of an Environmental Impact Statement
- preparation of new and revised technical specifications
- preparation of detailed work plans and procedures
- selection of contractors and training of decommissioning workers
- procurement and testing of special equipment and materials.

Figure 10.5-1 shows the time sequence for the work associated with the planning and preparation phase, which includes all activities required to prepare for the stabilization of the burial ground.

A major activity during the planning and preparation phase is the preparation and submittal of a Master Decommissioning Plan for review and approval by the appropriate state or federal regulatory agency. The plan includes a description of the documentation required for decommissioning as well as a general description of decommissioning activities. It is based on appropriate

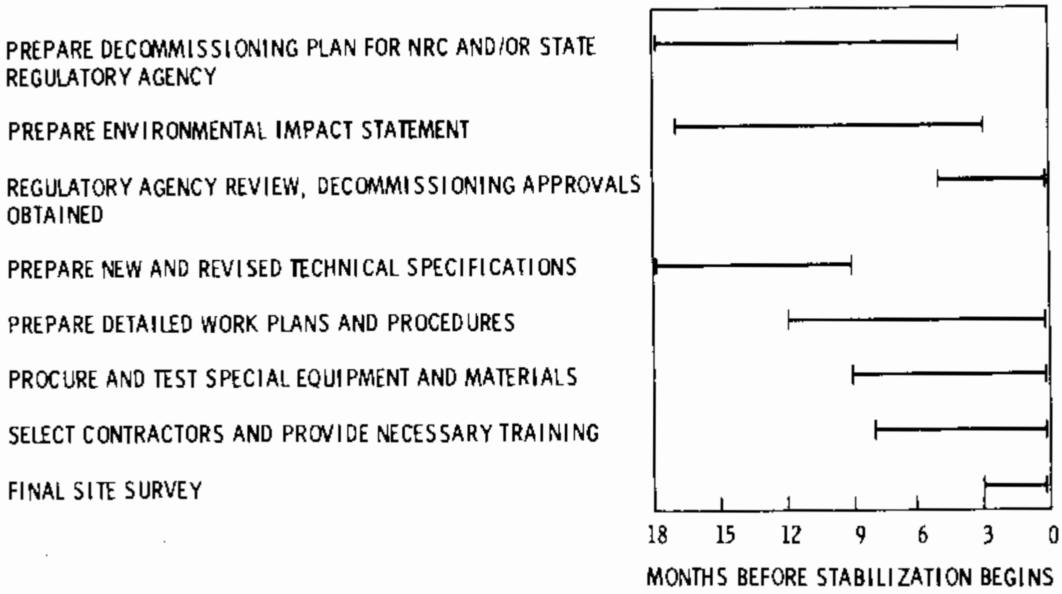

FIGURE 10.5-1. Sequence and Schedule of the Planning and Preparation Phase of Site/Waste Stabilization

decommissioning criteria and on regulations and guides applicable to decommissioning. (Decommissioning criteria are discussed in Section 8. A review of the current status of regulations applicable to decommissioning an LLW burial ground is given in Section 5.) The plan addresses the following items:

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

In conjunction with the preparation of the Master Decommissioning Plan, data are developed to assess the environmental impact of decommissioning activities. Environmental records are reviewed, areas with inconsistent or incomplete data are identified, and additional measurements are made to provide a complete and accurate environmental picture. This information is then used to provide a basis for the final selection of decommissioning plans and methods. It also provides baseline data for future environmental surveillance activities (i.e., during long-term care).

Government regulations(7,8) require the preparation of an Environmental Impact Statement for activities, such as decommissioning an LLW burial ground, that could significantly affect the quality of the human environment. Topics covered in the statement include:

- the environmental impact of the proposed action
- any adverse environmental effects that cannot be avoided if the proposal is implemented
- alternatives to the proposed action
- the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity
- any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented.

Although not currently required, another important component that should be included in the planning and preparation phase is the preparation of new and revised technical specifications. New specifications are required for equipment and materials that are used or installed during the stabilization and the subsequent long-term care activities, including such items as new environmental monitoring systems, stabilization equipment (e.g., compactors, hydroseeders, etc.), and materials (e.g., topsoil, plant seed, fertilizer, chemical stabilizers, mulches, etc.). These new items are chosen to meet the requirements of the specific stabilization plan in the most efficient and economical manner. Revised specifications are needed for equipment that remains and is used after burial ground operations cease (e.g., existing monitoring systems, wells, sumps, etc.). Specifications for items related solely to burial ground operations, with no use during or following decommissioning, are deleted.

Detailed work plans and procedures are prepared for the decommissioning activities. The Master Decommissioning Plan is divided into manageable tasks, and available decommissioning techniques are carefully reviewed. Decisions are then made on the general techniques to be used to accomplish each task. Detailed procedures are developed, along with related safety requirements, for each of the decommissioning tasks and also for any necessary predecommissioning activities. Equipment and material requirements, manpower requirements, schedules, and costs are estimated. The plan is documented in detail, necessary safety analysis reports are prepared, and all appropriate documents are submitted to the proper governmental agencies for approval.

It is assumed that decommissioning planning is performed by the site operator but that the actual decommissioning activities associated with the modest and complex plans are performed by contractors hired specifically for this work. These contractors are selected during the final 8 months of burial ground operation, and their personnel are provided with any necessary training for their work.

Any materials or special equipment needed for decommissioning are procured and tested during the planning and preparation phase. This ensures that all items meet the specifications imposed on them, and that the decommissioning activities can proceed without undue delay after shutdown of the burial ground operations.

The final step in the planning and preparation phase is a comprehensive radiation survey of the site, to verify that the site is free of surface contamination and to provide baseline radiation dose-rate information. This survey is made in the last three months of burial ground operation.

10.5.2 Quality Assurance Program

An appropriate quality assurance (QA) program is carried on throughout the decommissioning effort to assure that all applicable regulations are met, that the work is performed according to plan, that the work does not endanger public safety, and that work procedures assure the safety of the decommissioning staff.

During the 12-month period prior to shutdown, the QA engineer is active in the following areas:

- reviewing decommissioning plans for quality assurance involvement
- preparing inspection/test procedures as work plans are developed
- reviewing designs of test equipment for quality assurance input
- ordering any inspection/test equipment required to perform quality assurance/quality control functions
- receiving procured equipment and verifying acceptance
- preparing inspection/test procedures to be imposed on contractors and subcontractors
- finalizing and documenting the formal Quality Assurance Plan.

The QA efforts during the actual stabilization period include:

- performing QA functions for procurements
- qualifying suppliers
- auditing all program activities

- monitoring the performance of Foremen, Equipment Operators, Laborers, Truck Drivers and Health Physics Technicians for compliance with work procedures
- verifying compliance of radioactive handling activities with appropriate procedures and regulations
- performing necessary inspection services to assure compliance with work plans
- maintaining auditable files on the QA audits
- preparing a final report on overall performance of the decommissioning program with regard to the QA function.

Additional details on the Quality Assurance Program are given in Section F.2 of Volume 2. A nominal level of effort, consisting of audit functions and records checks, is required on an annual basis during the long-term care period following burial ground decommissioning.

10.6 LONG-TERM CARE OF STABILIZED BURIAL GROUNDS

Long-term care of an LLW burial site includes all activities required to maintain and verify the capability of the site to adequately confine the radionuclides to the immediate vicinity of the burial trenches. These activities are, in general, a continuation of maintenance and surveillance activities established during the site operation and stabilization periods. The long-term care period commences at the completion of site stabilization activities, and continues until it is determined that the waste materials buried at the site no longer pose a potential radiological hazard. For this study it is assumed that this period will be approximately 200 years.

The activities and procedures discussed in this section pertain primarily to those tasks required to provide administrative control of the site, and to maintain site stabilization provisions and engineered surveillance systems. The estimated costs of long-term care activities are given in Section 12.2.

10.6.1 Administrative Control of the Site

Administrative control of an LLW burial site during long-term care generally includes all those activities necessary to provide proper maintenance and surveillance of the site. The specific elements of site administrative control described in this section pertain to these requirements and to site access limitation.

A responsible public agency serves as site manager during this period. In this function, the responsible agency integrates and coordinates all site-access authorizations for routine inspection, maintenance, and surveillance activities. The agency can perform these activities with its own personnel or can contract with qualified service organizations for site maintenance and surveillance activities. The agency maintains records of inspection and maintenance activities. It also supervises the environmental surveillance program, maintains a file of the resulting data, and supervises the analysis of the data.

Evaluation of environmental surveillance data should be performed periodically (annually, or more often as required) to verify the adequacy of site maintenance activities and to detect any unusual radionuclide migration. To insure the availability of environmental data for evaluation it is important to store the data in a form that enhances retrievability. Storage in a form that makes the data available for computer analysis is desirable.

With only periodic surveillance, continuous control of access into the exclusion area of the site is difficult to ensure. Permanent site markers and exclusion fencing provide the primary deterrent to unauthorized access. However, if incidents of unauthorized entry, theft, or vandalism are frequent, the agency can install and monitor electronic intrusion-detection systems until more permanent deterrents are provided (e.g., hardened trench caps, added exclusion fencing, etc.).

The responsible agency also administers and controls land use and property development activities in areas adjacent to the burial ground site. In this capacity, the agency must remain cognizant of all planned operations or activities near the site that may alter projected behavior or accessibility of the radionuclides contained in the burial site. The agency should inform developers or entrepreneurs of the potential radiological considerations near the site, and should maintain pertinent demographic data for the area surrounding the site.

10.6.2 Environmental Surveillance During Long-Term Care

Environmental surveillance tasks are primarily concerned with sampling and laboratory analysis requirements. It is assumed that technical personnel from the responsible agency obtain environmental surveillance samples, consisting mainly of groundwater specimens, onsite soil and vegetation, small mammals, and ambient-radiation dosimeters. Analytical laboratory services are assumed to be provided by a nonagency contractor. Data evaluation may be performed by the responsible agency or by an outside contractor.

Environmental surveillance during long-term care is discussed in Section 9.2.3 and summarized in Table 9.2-1. For the first 25 years after site stabilization, sampling frequencies and the number of sample locations are maintained at the level required during the operational period of the site. After the initial 25 years of long-term care, the environmental sampling requirements are assumed to be reduced, on an overall basis, to about one-quarter of the operational support level. Because of differences in physical site characteristics, sampling and analytical requirements for the humid eastern site are somewhat greater than those for the arid western site.

10.6.3 Site Maintenance During Long-Term Care

Requirements for site maintenance during long-term care are expected to vary somewhat with the specific burial site. Although generic tasks such as erosion control, trench cap repair, water infiltration control, and vegetation management are basic maintenance elements at all burial sites, the methods of implementation reflect the variations in the site characteristics, particularly climatology. The maintenance requirements for the two reference sites are discussed in the following sections.

10.6.3.1 Arid Western Site

Requirements for site maintenance following stabilization of the western site by the minimal or modest plans are postulated to be identical. Requirements for site maintenance following stabilization by the complex plan are somewhat greater because of the need to maintain the subsurface rock layer and hard cover. The minimal, modest, and complex plans for site stabilization of the western site are described in Section 10.3. Long-term site maintenance requirements are described below.

Site Maintenance Following Stabilization by the Minimal or Modest Plan. The burial ground surface is inspected in several ways. Personnel entering the site for environmental sampling are assumed to give the site a quick visual inspection to detect any obvious damage or deterioration. In addition, major (detailed) site inspections are scheduled periodically (monthly to yearly). For this study, it is assumed that major inspections normally occur twice each year--once in the late spring following the peak windy period and once in the late fall following the normal growing season. (More frequent inspections may be necessary during periods of unusual surface activity, such as extremely high winds or extended periods of heavy rainfall.) Of primary concern during the spring inspection is the possibility of wind erosion damage to the trench cap. The late fall inspection is primarily to assess the condition of site vegetation. The status of site access control structures (e.g., permanent boundary markers and/or exclusion fencing) and surveillance/monitoring systems is also determined during each inspection.

Serious wind (or water) erosion to the trench cap is readily discernible; however, gradual attrition of the trench cap soil is not readily apparent by visual inspection. At each inspection, the current condition and thickness of the trench cap is compared to previous inspection data and to the original surface contour established during site stabilization.

If erosion or other damage has occurred to the trench cover material, prompt action is required to prevent further damage and to ensure the safe confinement of the buried radionuclides.

Soil or trench cover material is replaced in the eroded areas, compacted, and graded to the original contour. In areas where repeated wind erosion has occurred, the composition of the cover materials can be altered to reduce or preclude further erosion damage. For example, the replacement cover material may contain crushed rock or gravel or added clay to enhance the adhesion and stability of materials vulnerable to erosion. (See item F in Section 10.1.2.)

Vegetation management is also a major long-term site maintenance activity. As stated in Section 10.3.2, site revegetation with shallow-rooted grasses is a key component of site stabilization, since root systems of such vegetation enhance the erosion resistance of the trench cap and evapotranspiration reduces the percolation of water through the soil. The condition of burial ground vegetation must be carefully examined at each site inspection. Fertilizers, mulches, and/or pesticides are applied to site vegetation as needed to maintain a healthy vegetative community. Areas of trench cap repair, or areas in which erosion or prairie fire has destroyed the vegetation, must be reseeded and fertilized to reestablish a healthy grass cover; the optimum period for these revegetation activities is the fall season. The presence of undesirable vegetation must also be noted during site inspection. Deep-rooted vegetation, such as tumbleweed and sagebrush, must be cleared from the site and destroyed (by burning or chemical treatment) to deter natural reseeding or reestablishment of undesirable species.

During each site inspection, the integrity of exclusion fences and the condition of boundary markers (or location monuments) are determined. Evidence of unauthorized site entry by humans or site entry by burrowing or foraging animals is noted, and measures are taken to prevent or deter recurrence. Such measures include repairs to and upgrading of exclusion fencing, boundary markers, warning signs, or other site control structures. These measures commence immediately after completion of the site inspection. All site maintenance and repair activities are coordinated with the site environmental surveillance procedures described in Section 10.6.2. Repairs and upgrading of environmental surveillance systems are expected periodically; such tasks are normally performed with other site maintenance activities to minimize and control the impact of equipment traffic on the site.

Records of all site inspections and repairs are needed to facilitate the continuation of maintenance activities. Accurate records of site condition details and required maintenance activities provide succeeding site caretakers with essential data for planning continued surveillance and maintenance activities.

Site Maintenance Following Stabilization by the Complex Plan. Site inspection requirements for the complex stabilization plan are generally reduced because of the greater thickness of the trench cap and the greater resistance of the trench cover (subsurface rock layer with hard top) to environmental effects. Therefore, it is postulated that major site inspections are needed only on an annual basis. (As before, more frequent inspections may be necessary during periods of unusual surface activity, such as extremely high winds or extended periods of heavy rainfall.) The annual inspection is supplemented by the quick visual checks made during environmental sampling.

The condition of the trench cap and vegetation cover is of primary importance at each annual inspection. All areas are examined for evidence of erosion damage, and corrective repairs are made as needed. Trench cap materials are added to the eroded areas to restore the original site contours. The repaired areas are seeded with shallow-rooted arid-land grasses, and fertilizers, mulches, and pesticides are applied as needed to promote rapid recovery of the vegetation.

Because of the added weight resulting from the increased overburden and the subsurface rock layer, some subsidence of the stabilization profile can be expected over the 200-year period postulated for long-term care. During each annual inspection, surface contours of the trench caps are compared (in detail) with those of the previous annual inspection and with the original site contours established during stabilization. Minor subsidence of the surface profile (which may be visually apparent but does not cause significant cracking or disruption of the surface) is not of great concern, since some minor slumping and densification of the capping material is considered a normal occurrence during the 2- to 3-year period immediately following site stabilization. Serious subsidence of the surface profile (causing noticeable surface damage) is of considerable concern, since such an occurrence can compromise the integrity of the hard cover over the subsurface rock layer. Serious subsidence can also create a depression in the trench cap that acts as a collection basin for runoff or that is vulnerable to accelerated wind or water erosion. Areas of serious subsidence are repaired to restore the confinement capability of the trench cover and subsurface structures. The repair procedure requires removal of the capping material in the affected area, to expose the hard cover for detailed inspection. This allows for verification of the subsidence mechanism and for appropriate remedial measures (e.g., compaction). After this is completed, the depression in the hard cover is filled with rock or gravel to the original elevation profile of the subsurface rock layer, and the hard cover over the entire fill/repair area is patched. Care must be exercised in patching the hard cover to ensure that the edges of the patch form an effective seal with the original hard cover, thus restoring the integrity of the hard cover over the entire surface of the trench area. After completing the patch, the trench cap materials are replaced over the repaired area. Capping materials are supplemented as needed to restore the original contour and profile of the surface. Revegetation of the surface completes the repair procedure.

Other long-term care activities for the complex plan include general vegetation management tasks, inspection and repair of site access control structures, upgrading and repair of environmental surveillance systems, and documentation of maintenance and surveillance activities. The intent and implementation of these activities are essentially identical to the comparable requirements of the minimal and modest stabilization plans, described previously.

10.6.3.2 Humid Eastern Site

Requirements for site maintenance following stabilization of the eastern site by the minimal or modest plans are postulated to be identical. Requirements for site maintenance following stabilization by the complex plan are somewhat greater because of the need to maintain the subsurface hard layer and the peripheral drainage system. The minimal, modest, and complex plans for site stabilization of the eastern site are described in Section 10.4. Long-term site maintenance requirements are described below.

Site Maintenance Following Stabilization by the Minimal or Modest Plan. Major inspections at the humid eastern site are assumed to be conducted four times a year, on a quarterly basis. The increase in inspection frequency at the eastern site over that required for the western site is necessitated by the greater precipitation at the eastern site. (Additional inspections may be required after periods of severe weather.) The primary concern at each inspection is the effect of precipitation and resulting runoff on the site stabilization measures. The condition of trench caps, vegetation, drainage ditches, and site surveillance and access control structures is determined during each inspection. Planning for any required maintenance and repair immediately follows the inspection.

Trench cap areas damaged by water erosion or subsidence are restored to the original capping thickness and reseeded with shallow-rooted vegetation, with attendant applications of fertilizers, mulches, and pesticides. Undesired deep-rooted vegetation is cleared from the site and the grass cover is mowed, as required. Drainage ditches are cleared of debris to restore the desired flow channels. Site contours are adjusted or restored to control surface runoff, and vegetation is restored in all areas damaged by equipment traffic during site contouring. Repairs to site boundary markers, exclusion fencing, and any surveillance/monitoring systems (e.g., air samplers) are performed as needed to maintain their functional status. Detailed records of the inspection and maintenance activities are prepared and placed in site documentation files.

Complex Stabilization Plan Maintenance. Maintenance requirements for the complex stabilization plan include all the activities described above for the modest plan, together with maintenance of the subsurface asphalt-soil hard layer, trench-sump wells, and the peripheral drainage and diversion systems.

The subsurface asphalt-soil hard layer must be repaired in areas where serious subsidence has occurred. This procedure is similar to subsidence repair for the western site. Trench capping material in the affected area is removed to expose the hard layer. Fill (gravel or clay) is added and compacted into the depression to restore the original elevation profile of the hard layer.

The fill area is then covered with an asphalt-soil mixture and compacted, and the perimeter of the patched area is joined to the original hard layer to restore the integrity of the layer. The trench cap material is then replaced and contoured to the original profile. Reseeding of the area with shallow-rooted vegetation completes the maintenance procedure.

All trench-sump wells are checked during each site inspection. Silt or other debris in the well casing is removed to restore the functional capability of the sump wells. In the event the well casing has collapsed or seriously shifted, or has become otherwise inserviceable because of corrosion or cracking, a new well is installed immediately adjacent to the original one. Engineering drawings and other technical documents from the original stabilization are consulted prior to well replacement to ensure safe and successful completion of the project.

The peripheral drainage and diversion system is expected to require little maintenance (other than vegetation control) during the long-term care period, because of the durability of the earthwork construction. However, it is possible that extreme climatic changes or changes in hydrologic characteristics at the site may dictate major modifications to the original system. In that event, the original construction plans and procedures are consulted, and improvements are made as needed to restore or increase the system's effectiveness.

10.6.4 Possible Remedial Measures

Site maintenance activities similar to those discussed above are expected to adequately preserve the confinement capabilities of the stabilized LLW burial site. However, unanticipated site variables may increase maintenance requirements and/or the incidence of repeated damage to a given stabilization measure (e.g., chronic wind or water erosion at the same location of a given trench). In addition, some stabilization measures may not provide the anticipated degree of confinement, as indicated by environmental surveillance data and site inspections. Such occurrences may indicate that additional remedial measures are needed to ensure the continued viability of the confinement systems at the site. Remedial measures can involve application of established (or modified) stabilization techniques, or the development and application of new techniques specifically tailored to the needs of the particular site or trench. Examples of possible remedial measures for both the western and eastern sites are summarized here, and are described in Section 10.1 and Appendix F.

10.6.4.1 Arid Western Site

At the arid western site, persistent high winds or drought conditions may accelerate trench cap erosion and interfere with surface repairs such as trench cover backfilling and contouring or reseeding of shallow-rooted vegetation. Remedial action can consist of the establishment of a surface rock layer or the construction of a surface hard layer of asphalt or concrete. Hardening of the surface also provides added protection against human excavation, damage by foraging or burrowing animals, and establishment of deep-rooted vegetation.

Construction of wind breaks can also be used to reduce wind erosion damage. Wind break structures may be "sand fences," concrete walls, or berms of built-up rock or gravel. The wind breaks are generally placed at right angles to the prevailing wind. Strategic placement of a wind break can actually result in the buildup of the trench cover, through accumulation or mounding of wind-blown soil on the downwind side of the wind break.

10.6.4.2 Humid Eastern Site

Extended periods of heavy precipitation at the humid eastern site may result in accelerated water erosion of the trench cap (due to heavy surface runoff), increased infiltration of water into the trenches, and significant changes in groundwater elevations and flow paths. Possible remedial measures include the construction of interceptor/diversion ditches in the vicinity of the trench cap to redirect surface runoff away from the trench, and trench cap sealing with bentonite-shale layers or subsurface membranes (of plastic, rubber, or synthetic composites) to reduce infiltration into the trench. Curtain walls or subsurface trench dams may be installed to divert groundwater flows or reduce groundwater elevations in the vicinity of the trenches. Trench-sump pumps may be installed in sump wells at the lower end of trenches to remove or control water in the trench, or to eliminate surface seepage at the perimeter of the trench. Facilities for treating water pumped from the trenches are provided to contain and package the radionuclides present in the trench water. Water treatment systems include pumps, piping, surge tanks, evaporators, offgas de-entrainers, and sludge concentrate solidification and packaging units.

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11.0 WASTE RELOCATION ACTIVITIES

Waste relocation from a low-level waste (LLW) burial ground involves exhumation of the buried waste, repackaging the waste if necessary, and reburial of the waste at a deep geologic disposal site, a federally operated or other commercial shallow-land burial ground, or in another trench on the same site. The rationale for waste relocation is discussed in Section 4. Because of the potential for significant radiation exposure to decommissioning workers and the high dollar costs, waste relocation would likely be considered only in situations where site/waste stabilization and long-term care are not sufficient to ensure the continued capability of the site to provide adequate containment of the buried waste. In this study, partial waste relocation is investigated in detail for the following cases:

- relocation of high beta-gamma radioactivity waste from a slit trench
- relocation of transuranic (TRU) waste from a section of a burial trench
- relocation of all of the waste from a single burial trench.

In addition, an estimate is made of the manpower, time and cost of relocating the waste from the entire reference burial ground.

This section describes methods and procedures for relocating radioactive waste for the three special cases listed above. Waste relocation program considerations are discussed in Section 11.1. The exhumation of high beta-gamma activity wastes (e.g., non-fuel-bearing reactor components) from a slit trench is described in Section 11.2. Removal of a TRU waste package from a section of a burial trench is described in Section 11.3. After selective exhumation of the more hazardous wastes has been accomplished, relatively simple excavation techniques can usually be used to safely exhume the balance of the waste from a burial trench. These techniques are described in Section 11.4.

Manpower estimates and costs for the waste relocation options described in this section and for relocation of the waste from the entire reference burial ground are summarized in Section 12. Details of waste relocation activities are presented in Appendix G, and cost details are presented in Appendix H of Volume 2.

11.1 WASTE RELOCATION PROGRAM CONSIDERATIONS

This section provides a general discussion of some factors that must be considered in developing a waste relocation plan for a particular site, and of the steps required to develop the plan.

11.1.1 Selection of Decommissioning Techniques

Several factors can influence the selection of the techniques and procedures used for waste relocation at a particular site. Some obvious factors are manpower requirements, time, and costs. Additional factors can be categorized as follows:

- decommissioning criteria
- site considerations
- waste considerations.

11.1.1.1 Decommissioning Criteria

Formal criteria for the decommissioning of LLW burial grounds have not yet been established by government regulatory agencies.(1) Residual radioactivity levels permitted by such criteria will determine the magnitude of the decommissioning task in terms of the quantity of waste to be exhumed as well as the amount of associated contaminated soil requiring removal and packaging.

11.1.1.2 Site Considerations

Site-related factors influencing the selection of waste exhumation and handling techniques include climate, hydrology, and the physical and chemical properties of soil.

The frequency and severity of adverse weather conditions determine weather protection requirements for excavation and waste handling activities. Temperature extremes may require either the suspension of decommissioning activities or the use of enclosures equipped with HVAC (heating, ventilation and air conditioning). Heavy rain or snow require sheltering the working areas and providing for drainage and runoff. Protection from high winds is necessary to prevent resuspension and subsequent dispersion of contamination and contaminated soils at the work site and offsite, with attendant potential for occupational and public exposure.

The physical and chemical properties of the soil affect the choice of equipment used for soil removal. Sheet piling is necessary to prevent cave-ins while excavating in sandy soil, but may be unnecessary in more cohesive soils (e.g., soils with a high clay content). Dry soil conditions involving severe dusting require the use of procedures to wet the soil or to maintain an air sweep at the excavation face. Severe dusting might also dictate the use of protective clothing, including respirators, by decommissioning workers.

11.1.1.3 Waste Considerations

Waste package integrity, waste forms, and radionuclide inventories determine the relative ease of waste exhumation and repackaging.

The fraction of associated contaminated soil requiring removal with the waste depends on the degree of package deterioration and consequent radionuclide migration into the soil around the package. For the oldest trenches, it is assumed that almost all of the waste packages (plywood boxes, 208-ℓ steel drums and fiberboard containers) are badly deteriorated.(2,3) For these trenches, all of the soil plus a layer from the bottom of the trench would need to be exhumed with the waste. The most recently buried waste packages can be assumed to be physically intact and, consequently, the amount of associated soil removed and packaged is solely a function of the ease of physical segregation.

Removal of large cement caissons and of items of contaminated equipment requires the use of cranes and, in some cases, special grappling tools.

The radionuclides present in the exhumed waste and specific radioactivity levels (i.e., radionuclide inventories) determine the radiological safety measures necessary to prevent significant exposure of decommissioning personnel to high radiation fields, as well as to prevent airborne radionuclide dispersion in excess of guideline concentrations. Extremes of containment requirements are illustrated by the use of a portable metal building inside an air-support weather shield for excavation of badly deteriorated packages of TRU waste at Idaho National Engineering Laboratory (INEL), and the open-air excavation of a section of an LLW burial trench at the Savannah River Laboratory (SRL) (see Section 3.2).

Shielding requirements for the protection of personnel during decommissioning operations depend on the specific radioactivity of the waste and on the shielding afforded by the packages used for burial. Much of the buried waste (approximately 50% by volume) is estimated to have a specific radioactivity less than 0.1 Ci/m^3 (see Table 7.3-2). However, high specific radioactivity wastes, such as demineralizer resins and ^{60}Co sources, are also buried at commercial sites.

11.1.2 Development of a Decommissioning Program Plan

Waste relocation activities are assumed to be performed by a private contractor. This contractor is hired by the site operator who has responsibility to decommission the site in preparation for termination of his operating license.

The actual decommissioning of the site is preceded by a period of planning and preparation that includes activities to insure that the decommissioning effort is performed in a safe and cost-effective manner in accordance with all applicable federal, state and local regulations. In the performance of these planning and preparation activities, the decommissioning contractor works closely with the site operator. These activities can be grouped in the following categories:

- site characterization
- documentation for regulatory agencies
- development of a detailed work plan.

11.1.2.1 Site Characterization

Site characterization involves verification of the location and the radionuclide content of packages of buried waste and assessment of the condition of these packages and the extent of radionuclide migration. Techniques for site characterization include:

- review of burial ground operating procedures
- examination of waste burial records
- examination of environmental surveillance records
- physical survey of the site
- core sampling.

Burial ground operations are reviewed to evaluate the impact of waste burial procedures, trench capping procedures, and site maintenance activities on decommissioning requirements.

Waste burial records are examined to determine the wastes buried in a particular trench, the types of packaging, and the curie content of the packages. As indicated in Section 7, burial records for older trenches are incomplete and, in some instances, inaccurate. However, recent improvements in records maintenance procedures may make it possible to characterize the radionuclide content of newer trenches in some detail, and to verify the location of a waste package to within about 5 to 10 m. The buried waste can then be more precisely located by core sampling.

A review of environmental monitoring records provides background information on the extent and type of radionuclide migration that may have occurred at a site. It also provides a data baseline for use in determining whether decommissioning activities are effective in limiting the release of radioactivity to acceptable levels. Additional environmental monitoring during the planning and preparation phase may be necessary to provide a data base that is adequate for comparison with post-decommissioning monitoring data.

The physical survey of the site serves to define the boundaries of individual burial trenches. Where waste exhumation is to be performed, the site survey also identifies the approximate locations of particular waste packages whose burial locations are shown on trench grid maps.

Core sampling is used to precisely locate the position of a particular waste package. It is also used to determine the extent of radionuclide migration within a trench and from a trench into the surrounding soil. In most instances, the objective of core sampling is simply to drill a hole for insertion of the probe from a monitoring instrument. In addition, analysis of the soil sample removed by drilling can give an indication of package integrity and waste migration. The core sampling program is in three phases:

- random sampling of a trench
- planned sampling to more precisely define identified regions of high radioactivity and abnormal or unusual waste forms (i.e., toxic or pathologic chemicals)
- repeat sampling to resolve differences between initial sample results and trench burial records.

The core sampling program provides an operations control function throughout the decommissioning project. Details of core sampling procedures are given in Appendix G of Volume 2.

11.1.2.2 Documentation for Regulatory Agencies

A major activity during the planning and preparation phase is the preparation and submittal for review by regulatory agencies of documentation that describes the proposed decommissioning operations and their impact on man and the environment. Documents prepared for review include an Environmental Impact Statement and the Master Decommissioning Plan. For proposed waste relocation operations, the Environmental Impact Statement is a major decision tool that examines the risks of exhuming the waste versus the risks of leaving the waste in place. Both the Environmental Impact Statement and the Master Decommissioning Plan are described in Section 10.5.1.

In conjunction with the preparation of these documents, data are developed to assess the environmental impact of decommissioning activities. Environmental records are reviewed, areas with inconsistent or incomplete data are identified, and additional measurements are made to provide a complete and accurate environmental picture. This information is then used to assess the impact of waste relocation activities and to provide baseline data for future environmental surveillance activities.

11.1.2.3 Development of Detailed Work Plans

Detailed work plans are prepared, based on the Master Decommissioning Plan. For waste relocation, the detailed work plans address the following items:

- enclosure requirements
- excavation procedures
- waste packaging and transportation requirements
- personnel protection
- environmental monitoring and records maintenance.

Enclosure Requirements. The primary considerations in enclosing an excavation area are weather protection and radionuclide containment. It is technically feasible to safely excavate the bulk of the waste from an LLW burial ground without either provision. Commercially available excavating equipment is designed to operate under a wide range of weather conditions. Operations can be suspended in extremely adverse weather. Airborne contamination in an open pit can be controlled with a fine spray of water over the pit area to prevent dust suspension. Detergents may be added to the water as a wetting agent to aid in soil penetration.(2) Fixation agents to enhance soil agglomeration are commercially available.

During prolonged periods of adverse weather, or when excavating trench volumes containing large quantities of transuranics, potentially toxic or pathogenic wastes, or high concentrations of radionuclides in easily dispersed forms (volatile liquids), work enclosures may be required. Structures that meet a range of potential enclosure requirements are listed in Table 11.1-1. Wind protection can be accomplished with simple wind breaks, shields, or baffle arrangements to redirect the air flow away from the working area. Protection from heavy precipitation can be achieved through the use of simple covers such as free-span pole-type sheds, plastic "greenhouses," or with air-support-type tents such as the all-weather support shield used at INEL.(2) All structures would require provision for the collection and disposal of runoff. The all-weather shield used at INEL has several drawbacks. It has high capital and operating costs, is fragile, and is limited to only a few relocation cycles before severe fabric deterioration occurs.

Portable sheet-metal buildings with provisions for inlet air and ventilation exhaust treatment and with airlock type entry and exit are used where a containment/confinement structure is required.(2,4) Severe limitations are imposed on equipment used inside the containment structure. The constricted

TABLE 11.1-1. Enclosure Candidates for Use During Waste Exhumation

Function	Type	Description	Feasibility	Cost	Comment
Weather Protection	Wind break	Portable barriers that redirect air flow away from pit	Demonstrated	Low	Useful only at low wind speeds.
	Pole Shed	Physically supported roof over pit to protect excavation from excessive precipitation	Demonstrated	Low	Useful only at low wind speeds. Provisions for runoff collection and disposal required.
	Air Supported Envelope	Fabric or plastic structure supported by air pressure	Demonstrated	High	Usable year around; fabric deterioration limits number of relocations. HVAC capability provided.
Weather Protection and Containment	Plastic Greenhouse	Plastic sheet supported on framework with HVAC and airlock	Demonstrated	Low	Useful only under moderate weather conditions. Severe limits on equipment used inside.
	Metal Building	Portable sheet metal shed with HVAC and airlock	Demonstrated	Moderate	Useable year around. Severe limits on equipment used inside.

work space restricts equipment options and equipment size to primarily small backhoes and front-end loaders. The excavation rate is reduced by a factor of 2 or more over what could be achieved with an open-air excavation.

Excavation Procedures. Excavation can be accomplished with conventional, commercially available equipment.

A bottom-loading scraper earthmover is a good choice for removal of overburden. A bulldozer, while satisfactory for clearing small areas, would require additional support for transport of the overburden from the site. The scraper performs both functions. Overburden can be deposited between adjacent trenches or at a central backfill accumulation point.

Trench backfilling and site restoration can also be accomplished with bulldozers and scraper-earthmovers.

Once the overburden is removed, the choice of equipment for performing the bulk of the excavation is dependent upon the particular waste packages being recovered and upon enclosure requirements as discussed in the previous subsection. Large-capacity excavating equipment can be used if operating enclosures are not required. For work inside small sheet-metal enclosures, a small backhoe or a front-end loader can be used. The backhoe has the advantage of allowing the operator to be out of the pit. Equipment for performing the bulk of the excavation for the three waste relocation cases discussed in this report is described in Sections 11.2 through 11.4.

Some hand excavation work is performed, primarily in two different situations:

- final trench area cleanup for removal of spots of low-level contamination in trench bottom and sidewalls
- dislodging large, intact waste packages having low associated dose rates.

In the former case, hand excavation in conjunction with field surveys is the only practical method. In the latter case, the tradeoff is a drop in efficiency of total volume removal versus enhanced selectivity (i.e., soil segregation), ease of package removal, and reduced risk of package damage.

Waste Packaging and Transportation Requirements. A number of options are available for waste materials handling, in view of the variety of waste packages encountered as well as the variation in exhumed container integrity. When an intimate waste-soil mix is encountered with high radionuclide activity, field sorting is impractical and direct transfer from the excavation pit to the final package for transport is most satisfactory. When small intact waste packages exist with little or no smearable exterior contamination, simple transfer to a shipping container is the easiest and most efficient means of handling. Highly radioactive materials (especially breached packages and highly contaminated soil associated with such packages) are best repackaged within the excavation pit and immediately placed in a special, shielded shipping cask. Unusual or abnormal materials such as toxic/pathogenic chemicals must be handled on a special (case-by-case) basis, requiring definitive characterization of the material and its condition within the trench section.

Trucking companies that specialize in nuclear materials shipments are contracted to ship packaged contaminated materials from the burial ground to a deep geologic disposal site or a federal or other commercial shallow-land burial site. The types of containers used, the number of shipments, and the costs of these shipments are summarized in Section 12 for the waste relocation cases considered in this study. All waste shipments are made in compliance with federal, state, and local regulations as described in Section G.4 of Volume 2.

Personnel Protection. Protection of decommissioning personnel from excessive exposure to radiation during waste relocation is of prime importance when planning and scheduling decommissioning operations. Waste exhumation, repackaging and shipping activities all conform to the principle of keeping occupational radiation doses As Low As is Reasonably Achievable (ALARA).

Limitation of the dose rates received by decommissioning workers is achieved by:

- restricting access to the excavation pit
- utilization of portable and temporary shielding where necessary
- utilization of physical barriers around areas where containers are stored prior to offsite shipment
- administrative controls and careful pre-job planning.

Worker protection from inhalation and ingestion of airborne radioactivity is achieved by:

- minimizing open-pit excavation surface areas to control the total amount of material available for resuspension
- use of soil stabilization techniques to minimize the lofting of contaminated dust. (These techniques include spraying of the working face with water or oil.)
- use of weather protection structures to minimize wind resuspension and dispersion and, where necessary, suspension of operations during periods of increased risk of dispersion due to high winds

- availability of respiratory protection (both canister and portable air supplied) with conditions administratively defined for mandatory use
- use of continuous air monitoring equipment.

In addition, wherever extreme contitions are encountered such that a risk of exceeding 10 CFR 20 limits at the site boundary exists, excavations are conducted within containment structures.

Environmental Monitoring and Records Maintenance. An increase in airborne contamination during excavation of buried waste is a particular concern in planning for waste relocation activities. To monitor for airborne contamination during waste exhumation, it is assumed in this study that two or more particulate air-sampling stations are located at the site boundary in the most probable downwind direction from digging operations. A station is also located upwind from the site to serve as a control. Filters from these sampling stations are changed periodically (i.e., weekly) and counted for gross alpha and gross beta activity. In addition, each filter receives a gamma scan for any trace of gamma-emitting activation or fission products that may have become airborne.

Constant air monitors are installed in the vicinity of an excavation to monitor contamination levels in areas where decommissioning activities are being performed. Thermoluminescent dosimeters are used for readout of ambient gamma dose.

The presumed objective of waste relocation activities is to place the site in a condition that allows public use of the premises on either an unrestricted or a restricted basis. Environmental monitoring activities (e.g., monitoring of ground and surface water and counting of samples of soil and vegetation) are performed for a period of several years following the completion of exhumation activities, to verify that levels of radioactivity in the environment are low enough to permit public use of the site. Records that indicate clearly the scope and extent of waste relocation activities and the condition of the site at the conclusion of these activities are maintained at a location that permits easy public accessibility (see Section 9.3).

11.1.3 Quality Assurance Program

An extensive quality assurance (QA) program is carried on throughout the decommissioning effort to assure that all applicable regulations are met, that the work is performed according to plan, that the work does not endanger public safety, and that the work procedures assure the safety of the decommissioning staff.

During the planning and preparation period that precedes the actual waste relocation effort, QA personnel are active in the following areas:

- reviewing decommissioning plans for quality assurance involvement
- preparing inspection/test procedures as work plans are developed
- reviewing designs of test equipment for quality input
- ordering any inspection/test equipment required to perform quality assurance/quality control functions
- receiving procured equipment and verifying acceptance
- preparing inspection/test procedures to be imposed on contractors and subcontractors
- finalizing and documenting a formal Quality Assurance Plan.

The QA efforts during the actual waste relocation period include:

- performing QA functions for procurements
- qualifying suppliers
- auditing all program activities
- monitoring performance of Foremen, Equipment Operators, Laborers, and Health Physics Technicians for compliance with work procedures
- verifying compliance of radioactive packaging and shipping activities with appropriate procedures and regulations
- performing necessary inspection services to assure compliance with work plans

- maintaining auditable files on the QA audits
- preparing a final report on overall performance of the decommissioning program with regard to the QA function.

Additional details of the Quality Assurance Program are given in Section F.2 of Volume 2.

11.2 RELOCATION OF HIGH BETA-GAMMA ACTIVITY WASTE FROM A SLIT TRENCH

At some commercial sites, high beta-gamma radioactivity waste is buried separately from other radioactive waste in specially designed dry wells, pits, or slit trenches. To evaluate cost and safety requirements for the relocation of high-activity waste, this study describes procedures for the exhumation of canisters of non-fuel-bearing reactor components from a slit trench. The trench and its contents are described in Sections 7.2.3 and 7.3.2.

The procedures outlined in this section are based on the following assumptions.

- There is negligible smearable contamination on the surfaces of the canisters.
- No soluble radionuclides are present in a slit trench.
- There is minimal contamination associated with soil in the slit trenches.
- Burial records are available that give information about package contents, date of burial and approximate location of each waste package in a trench.
- Because of the greater potential for adverse weather conditions, waste relocation activities at the eastern site require a 20% longer time period for completion than at the western site.

Waste relocation from a slit trench includes several distinct operations. These are:

- core drilling and sampling
- overburden removal
- sheet piling installation
- trench excavation and waste exhumation

- packaging and shipping of retrieved canisters
- sheet piling removal
- trench backfilling and site restoration.

Figure 11.2-1 shows the sequence of operations associated with waste relocation from a slit trench.

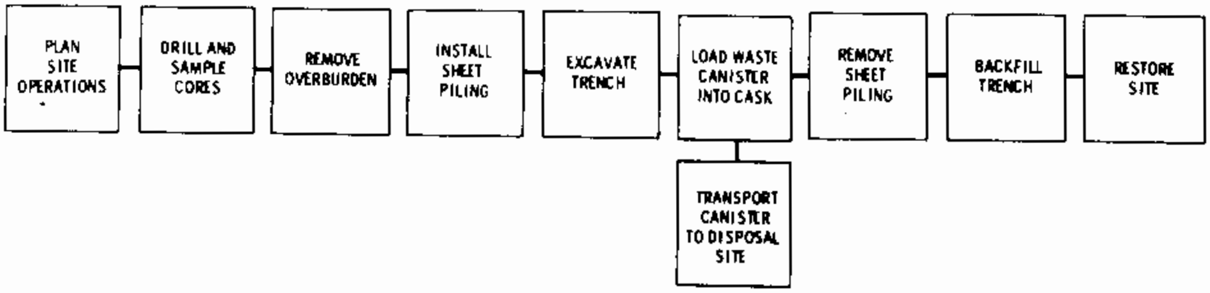

FIGURE 11.2-1. Sequence of Operations for Waste Relocation from a Slit Trench

Several alternatives exist for trench excavation and waste exhumation. These alternatives can have a major impact on decommissioning costs and schedules. Five alternative excavation methods evaluated in this study are:

- hydraulic excavation
- pneumatic excavation
- polar crane
- mobile gantry crane
- mobile gantry crane in enclosed structure.

These alternatives are briefly discussed in this section and are described in detail in Section G.1 of Volume 2.

All of the alternatives assume the installation of sheet piling along the two sides of a trench to limit the width of excavation. While sheet piling increases both the time and cost of excavation, it has the following advantages:

- It avoids excessive slopes that might be encountered in unconfined excavation. This allows work close to the edge of a trench.
- It acts to reduce the probability of cave-in during excavation and provides extra support for heavy equipment operating close to the edge of the trench.

- The earth provides an efficient barrier to protect workers from the high radiation fields associated with waste buried in a slit trench. By allowing the sides of the trench to be vertical rather than sloping, sheet piling provides shielding benefits.

To assess the impact of sheet piling on decommissioning schedules and costs, a non-piled exhumation is examined in connection with the least expensive excavation alternative, use of a polar crane.

11.2.1 Core Drilling and Sampling

It is assumed that the location of waste canisters in a slit trench can be approximately defined by examining existing burial records. To more precisely characterize the positions of these waste packages, a program of core drilling and sampling is carried out. Core drilling can either precede or follow overburden removal. In most instances the objective of core drilling is simply to provide a hole for insertion of the probe from a monitoring instrument. Some core samples are analyzed to identify contaminated soil and define the probable extent of radionuclide migration.

It is estimated that approximately 50 100-mm-diameter drill cores must be made to locate the waste in a slit trench. Each core is 7 m deep, in order to extend below the bottom of the trench. At a drilling rate of about 20 linear meters per day,(5) approximately 20 working days are required to complete the core drilling and sampling program.

11.2.2 Overburden Removal

When a slit trench is filled with waste it is capped with a covering of earth that extends above adjacent grade and is mounded over the trench to encourage water runoff. The initial decommissioning step is the removal of this upper layer, including vegetation. If the overburden is not contaminated, its removal can be handled effectively by several types of equipment. A bottom-loading scraper hauler is one of the most efficient and this method is assumed for the study. Since this excavation step is obviously more economic than the techniques described in Section 11.2.4, in practice it would be extended to the maximum depth that could be tolerated by radiation limits. For this study, it is assumed that 1 m of overburden is removed by a bottom-loading scraper hauler.

11.2.3 Sheet Piling Installation

Sheet piling is installed along the sides of a trench before excavation operations begin. The piling is steel of intermediate thickness (130 kg/m^2), with interlocking geometry. It is set back about 1.2 m on either side of the original trench walls and is driven to a depth of about 7.2 m, or about 1.2 m below the slit-trench bottom, to provide a foundation support for the piling. Horizontal reinforcements (wales) are installed between lines of piling at ground level to prevent the piling from collapsing inward as the trench is excavated.

Driving of the piling is accomplished by a steam- or air-driven "hammer" within a structural skeleton suspended from a crane. Support equipment required for driving the piling includes pile caps, an air compressor, pile guides, and air and cable leads. For piling removal the equipment is similar, except that an "extractor" is used in place of a driver.

For a 150-m-long trench, about 2,200 m^2 of piling is required. At a driving rate of 90 m^2 per day, 25 working days are needed for piling installation. Most of the piling can be salvaged for re-use.

11.2.4 Trench Excavation and Waste Exhumation

Trench excavation and retrieval of radioactive waste requires personnel protection from radioactive contamination and high radiation dose rates. The work area is controlled by health physics personnel, and anti-contamination clothing is required. Because of the high dose rate, most operations are performed remotely and entrance to the pit is generally prohibited.

Several equipment options exist for remote excavation of a slit trench after overburden removal and sheet piling installation. These options are summarized in Table 11.2-1. The table provides numerical data on excavation rates and costs for each option, and a qualitative evaluation of four factors that should be considered in making a decision about the best equipment to use for a particular excavation requirement. The decision criteria factors in Table 11.2-1 are qualitatively ranked on a scale of low, medium, and high. The factors include the reliability of the equipment, the probability that

TABLE 11.2-1. Equipment Options for Slit Trench Excavation

Option	Description	Excavation Rate (m^3/hr)	Unit Cost[a] ($\$/m^3$)	Reliability	Probability of Container Damage	Potential for Spread of Contamination	Worker Exposure
Hydraulic Excavation	Uses high-velocity steam of water to sluice out soil from burial trench.	5	121.60	Low	Low	High	Low
Pneumatic Excavation	Combines mechanical digging of trench soil with pneumatic transport of soil out of trenches.	10	92.80	Medium	Low	Low	Low
Polar Crane with Sheet Piling	Uses remotely operated clamshell-type digger suspended from polar crane	20	63.10	High	Medium	Medium	Low
Polar Crane without Sheet Piling	Polar crane option but without sheet piling. Requires removal of greater volume of soil.	30	75.60	High	Medium	Medium	High
Mobile Gantry Crane	Uses remotely operated clamshell-type digger suspended from gantry crane.	16	72.40	High	Medium	Medium	Low
Structure Enclosed Mobile Gantry Crane	Gantry crane option, but enclosed in lightweight sheet metal building for weather protection.	8.5	124.40	High	Medium	Medium	Low

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[a] Includes direct worker labor and equipment costs for trench excavation and sheet piling installation and removal.

use of the equipment might result in damage to a buried canister, the potential for a spread of contamination (especially the dispersal of contaminated soil), and the potential for worker exposure.

The equipment options listed in Table 11.2-1 are briefly described on the following pages. Details are found in Section G.1 of Volume 2.

11.2.4.1 Hydraulic Excavation

Hydraulic excavation involves the use of a high-velocity stream of water to sluice out soil from the burial trench. The loosened soil is removed from the work area in the form of a mud or slurry. The mud or slurry is dewatered and recovered water is reused. The dewatered soil is stored for later use as backfill.

The sluicing head used with this equipment contains both sluicing nozzles and a slurry pickup pipe. It is positioned over the trench, using a boom crane. A television camera is used for remote monitoring of the sluicing operation. Ten-cm-diameter flexible hoses supply the sluice stream and retrieve the resultant slurry.

The excavation rate is lower and the unit cost is higher for this option than for any other excavation option considered.

11.2.4.2 Pneumatic Excavation

Pneumatic excavation combines mechanical digging of trench soil with pneumatic transport of the soil out of the trench. Soil is loosened remotely, using an excavation device (such as a spud fork) suspended from a long boom crane. A fluidizing stream of air is used to transport the freshly dug soil from the burial trench.

If necessary or desirable for the separation of contaminated from noncontaminated soil, two alternate fluidized stream paths can be provided downstream, equipped with valves that are controlled by signals from a radiation monitor.

The excavation rate is higher and the unit cost lower for this option than for the hydraulic excavation option; but costs for this option are not as favorable as for the more conventional excavation methods considered.

11.2.4.3 Polar Crane

For this option a remotely operated clamshell-type digger suspended from the arm of a jib (polar) crane provides both mechanical digging and soil transport capability. The jib crane is motorized for travel and has a shielded cab for the operator. A remote television camera is used to visually monitor the digging and retrieving operations.

This method is simple, low in cost, and has a high production rate. For purposes of cost comparisons, this excavation method is evaluated with and without sheet piling. Without sheet piling the excavation rate is postulated to be greater and the unit cost of excavation lower than it is with sheet piling. However, in order not to exceed the angle of repose of the soil at a burial site (i.e., to ensure the stability of the pit slopes), more soil must be excavated if sheet piling is not used. For an assumed angle of repose of 1:1, approximately twice as much soil is removed during excavation of a slit trench without sheet piling as is removed if sheet piling is used. As discussed in Section 11.2, sheet piling provides an extra margin of both industrial accident-type safety and radiation shielding.

11.2.4.4 Mobile Gantry Crane

The equipment and operation for this option is essentially the same as for the polar crane option (Section 11.2.4.3), except that the jib crane is replaced by a gantry crane. The crane is mounted on wheels that ride on tracks placed on either side of the excavation. The gantry crane articulated-arm clamshell is more convenient to move and operate than the clamshell attached to the arm of a jib crane. However, the capital cost of the equipment is somewhat higher. Excavation rates are comparable for the two cases.

11.2.4.5 Mobile Gantry Crane in Enclosed Structure

In this option, the gantry crane is enclosed in a lightweight sheet-metal building that provides both weather protection and some confinement of contamination, should this be necessary. The building and bridge crane are both attached to a 7.5-m-wide by 15-m-long chassis mounted on wheeled carriages. The crane is remotely operated. The building is equipped with lighting, television cameras, water-spraying capability, and radiation detection instrumentation. The wheels on which the building chassis are mounted ride on tracks on either side of the excavation.

A trap door in the roof of the building permits movement of casks into and out of the enclosure. The lower edges of the building are sealed with metal and rubber strips, or with inflatable rubber bumpers.

The limited movement of equipment within the enclosure slows operations and, together with increased equipment requirements, increases the unit cost of operations.

11.2.5 Packaging and Shipping of Retrieved Canisters

As a canister is exposed during the excavation process, digging temporarily stops and the canister is disinterred and placed in a cask for shipment to a deep geologic disposal site or other shallow-land burial site. Retrieval of an exposed waste canister involves the following steps:

1) moving an empty cask on its trailer to a position near the trench

2) removal of the cask lid and transfer of the empty cask into the trench, using a supplementary crane equipped with a hook

3) remotely positioning the waste canister in the cask, using the supplementary crane

4) remotely replacing the lid on the cask

5) manually fastening the cask lid, since personnel exposure is minimal with the cask closed

6) lifting the cask from the trench and securing it on the tractor-drawn trailer used to transfer it to deep geologic disposal.

During transfer of a waste canister from its position in the slit trench to a shipping cask, the canister must be reoriented from a horizontal to a vertical position and raised for insertion into the cask. This operation is accomplished at the excavated end of the slit trench, where a cement block radiation shield is constructed. The shield affords protection to decommissioning workers while the canister is being raised in position for insertion into the shipping cask.

Packaging and shipping of canisters exhumed from a slit trench is accomplished in accordance with DOT regulations published in 49 CFR, Parts 173 through 178, NRC regulations published in 10 CFR, Part 71, and Regulatory Guide 7.1. Shipments are made in massive lead and steel casks that provide protection from high gamma dose rates. Transport of the casks to a deep geologic disposal site or to a commercial or federally operated shallow-land burial site is accomplished using trucking companies that specialize in transporting radioactive materials. The distance from the LLW burial ground to the repository is assumed to be 2,400 km. A total of 5 days is assumed for the round trip, including a half day at each end to load and unload the cask. Details of waste shipment requirements and costs are found in Section 12.3.

Cask requirements are determined by the speed of excavation and the time required to seal a canister inside a cask and remove it from the burial trench. This latter time requirement is estimated at 2 hours per canister. Assuming 6 hours of trench work during an 8-hour shift, the total time required to exhume the 90 canisters from a slit trench is estimated at 57 work days for the polar crane option and 64 work days for the gantry crane option. (A 20%

increase in the time requirement is assumed for the eastern site to allow for inclement weather.) This represents an average canister packaging rate of about 1.5 canisters per day. Thus, a minimum of eight casks would be required on a continuous basis to expeditiously relocate the waste from a slit trench.

It is postulated that the volume of contaminated soil requiring packaging and reburial or shipment to deep geologic disposal or to another shallow-land burial site is minimal. Contaminated soil is packaged in 1.2-m by 1.2-m by 1.8-m steel boxes and shipped in exclusive-use vans.

11.2.6 Trench Backfilling and Site Restoration

After all of the canisters of high beta-gamma radioactivity waste are removed from a slit trench, the sheet piling is removed with a vibratory pile extractor. Extraction and salvage of the piling is assumed to proceed at the rate of 60 m^2 per day.

As the sheet piling is removed, the trench is backfilled with soil removed from the trench supplemented by trucked borrow materials to fill the trench area to adjacent grade levels. For onsite soil, this can be a bulldozing operation.

Compaction of the backfill is accomplished with a roller. The trench area is then graded and seeded to conform with surface conditions for the entire burial ground. Site maintenance activities are described in Section 10.6.3.

11.2.7 Work Schedule Estimates

Work schedules for the completion of decommissioning activities related to relocation of high beta-gamma radioactivity waste from a slit trench are shown in Figure 11.2-2 for the western site and in Figure 11.2-3 for the eastern site. These work schedules are based on time requirements for waste relocation operations shown in Table 11.2-2, with appropriate consideration for overlap of operations that can be performed simultaneously. Time requirements for waste relocation operations are determined from operating crew requirements shown in Table 11.2-3.

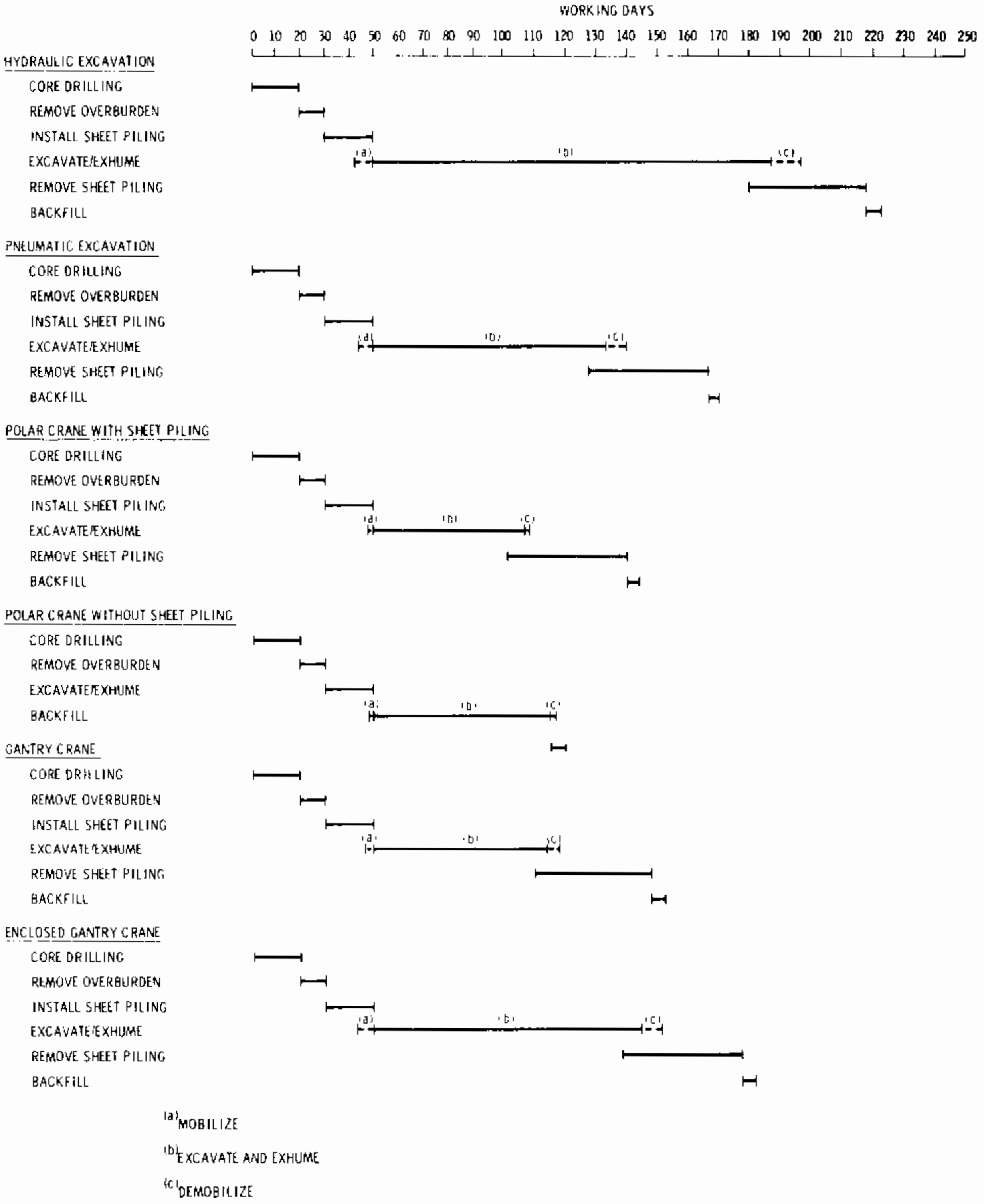

FIGURE 11.2-2. Schedule for Waste Relocation from a Slit Trench - Western Site

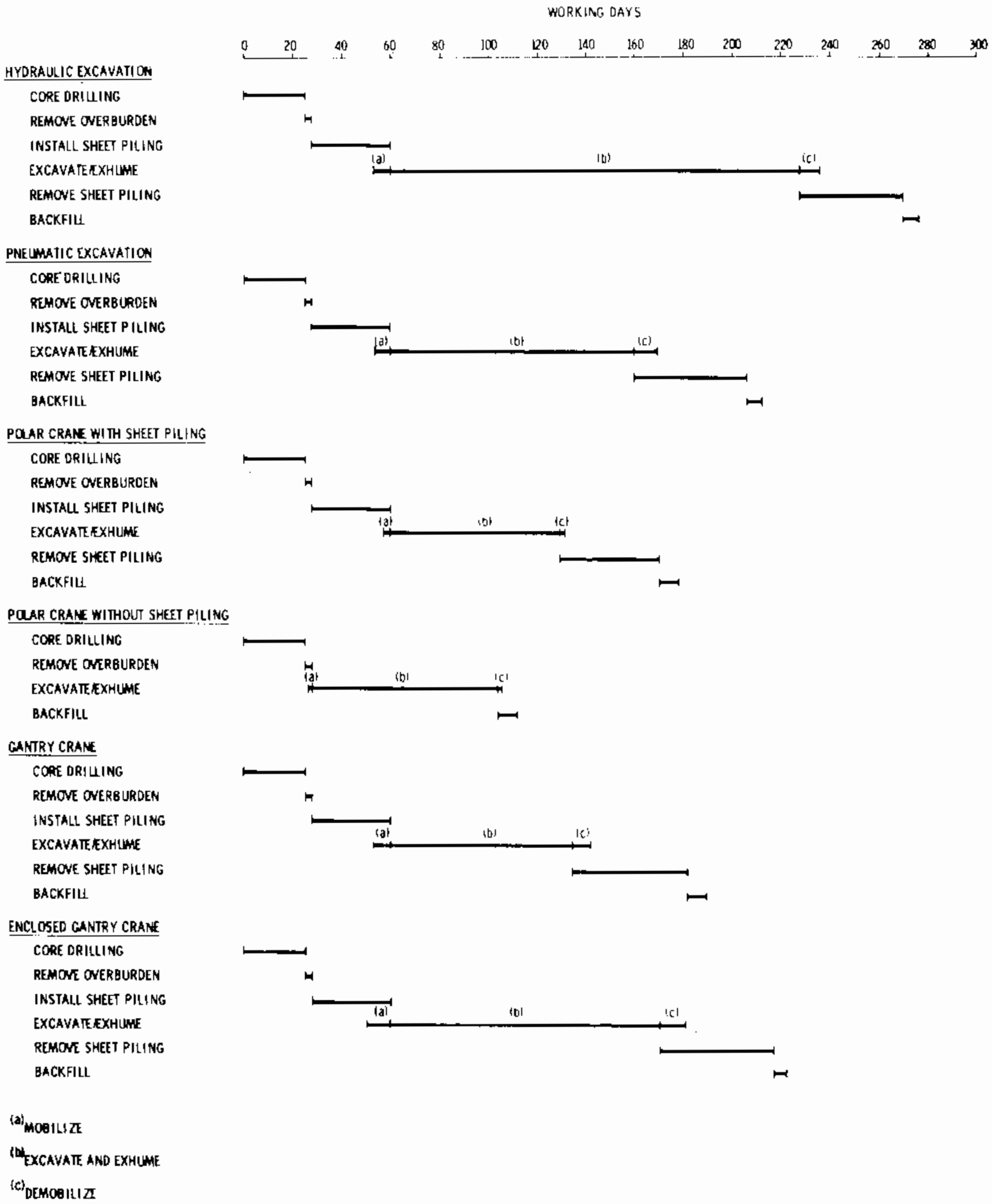

FIGURE 11.2-3. Schedule for Waste Relocation from a Slit Trench - Eastern Site

TABLE 11.2-2. Time Requirements for Waste Relocation from a Slit Trench

	Time Requirements in Working Days											
	Hydraulic Excavation		Pneumatic Excavation		Polar Crane with Sheet Piling		Polar Crane without Sheet Piling		Gantry Crane		Enclosed Gantry Crane	
Operation	Western Site	Eastern Site	Western Site	Eastern Site	Western Site	Eastern Site	Western Site	Eastern Site	Western Site	Eastern Site	Western Site	Eastern Site
Drill and Sample Cores[a]	20	24	20	24	20	24	20	24	20	24	20	24
Remove Overburden	3	3	3	3	3	3	3	3	3	3	3	3
Install Sheet Piling[a]	27	33	27	33	27	33	---	---	27	33	27	33
Excavate Trench and Exhume Waste												
Mobilization/Demobilization[b]	16	19	12	14	2	2	2	2	8	10	14	17
Excavate	108	130	54	65	27	33	36	43	34	41	64	77
Exhume	30	36	30	36	30	36	30	36	30	36	30	36
Subtotal	154	185	96	115	59	71	68	81	72	87	108	130
Remove Sheet Piling[a]	38	45	38	45	38	45	---	---	38	45	38	45
Backfill Trench	4	5	4	5	4	5	4	5	4	5	4	5
Total	246	295	188	225	151	181	95	113	164	197	200	240
Total with Overlaps[c]	222	276	170	207	144	179	93	111	152	187	181	223

(a)Time requirements include one day each for mobilization and demobilization.

(b)Mobilization/Demobilization includes all activities required to install the equipment prior to the start of operations and to decontaminate and remove the equipment after operations are completed.

(c)See Figures 11.2-2 and 11.2-3.

TABLE 11.2-3. Operating Crew Requirements for Waste Relocation from a Slit Trench

Operation	Operating Crew
Drill and Sample Cores	Drilling Foreman Laborer - 2 Health Physics Technician
Remove Overburden	Equipment Operator Health Physics Technician
Install Sheet Piling	Foreman Equipment Operator - 2 Laborer Health Physics Technician
Excavation/Exhumation	Foreman Equipment Operator - 2 Laborer - 2 Health Physics Technician
Remove Sheet Piling	Foreman Equipment Operator - 2 Laborer Health Physics Technician
Backfill Trench	Equipment Operator - 2 Truck Driver Health Physics Technician

The number of people in each operating crew shown in Table 11.2-3 is based solely on personnel requirements for efficient performance of the work. No allowance is made for an increase in crew size to limit worker exposure to radiation. Occupational exposure calculations summarized in Section 13.3 indicate that there is a high potential for worker exposure to radiation during some waste relocation operations. Using work requirements as the sole criterion for determining crew size results in an underestimate of the number of workers required, if individual occupational doses are kept within the limits defined by regulations. To limit occupational exposure, crew sizes would need to be increased, or an individual whose dose limit has been reached would need to be reassigned to a job that does not involve exposure to radiation. Thus, several individuals might perform a task that in Table 11.2-3 is shown as requiring the services of a single worker.

Work schedules are shown for each of the excavation alternatives considered in the study. For each alternative, the times required for all waste relocation operations at a given site (other than trench excavation) are the same. Sheet piling installation, trench excavation, sheet piling removal, and trench backfilling are all estimated to require about 20% more time for completion at the eastern site than at the western site, to allow for adverse weather conditions at the eastern site.

Considering only those options in which sheet piling is used, total times for waste relocation from a slit trench at the western site are estimated to range from 29 weeks for excavation using a polar crane to 45 weeks for excavation using hydraulic removal and transport of the soil. At the eastern site, waste relocation times are estimated to range from 36 weeks for excavation using a polar crane to 55 weeks for hydraulic excavation. Waste relocation, using a polar crane without sheet piling, is estimated to require 19 weeks for completion at the western site and 23 weeks for completion at the eastern site.

11.3 RELOCATION OF TRANSURANIC WASTE FROM A SECTION OF A BURIAL TRENCH

This section describes methods and procedures for exhumation of a package of TRU waste from a section of a burial trench. The waste package is assumed to have a volume of less than 1 m^3 and to contain 40 g of plutonium. The burial trench is described in Section 7.2.2.

The procedures outlined in this section are based on the following assumptions:

- Records are available that give the date of burial, package contents, type of package, and the approximate location in the trench (to within 5 to 10 m) of the TRU waste package.
- The package is a wood or fiberboard container or 208-ℓ steel drum that has experienced significant deterioration.
- Non-TRU waste that is exhumed to get to the TRU waste is returned to the excavation as part of the fill after the TRU package has been retrieved.

TRU package removal from a conventional burial trench includes several distinct operations. These are:

- core drilling and sampling
- overburden removal
- sheet piling installation
- TRU package excavation
- repackaging and shipping of the TRU waste
- sheet piling removal
- backfilling and site restoration.

Figure 11.3-1 shows the sequence of operations associated with TRU package removal.

Retrieval of TRU waste takes place inside an enclosure that is constructed over the site of the excavation. Because of this, there is no difference in time required for excavation between the eastern and western sites. For other operations (e.g., pre/post excavation operations) a 20% greater time requirement is assumed for the eastern site.

Sheet piling is used for this excavation to limit the size of the excavation and to provide additional safety, as outlined in Section 11.2.

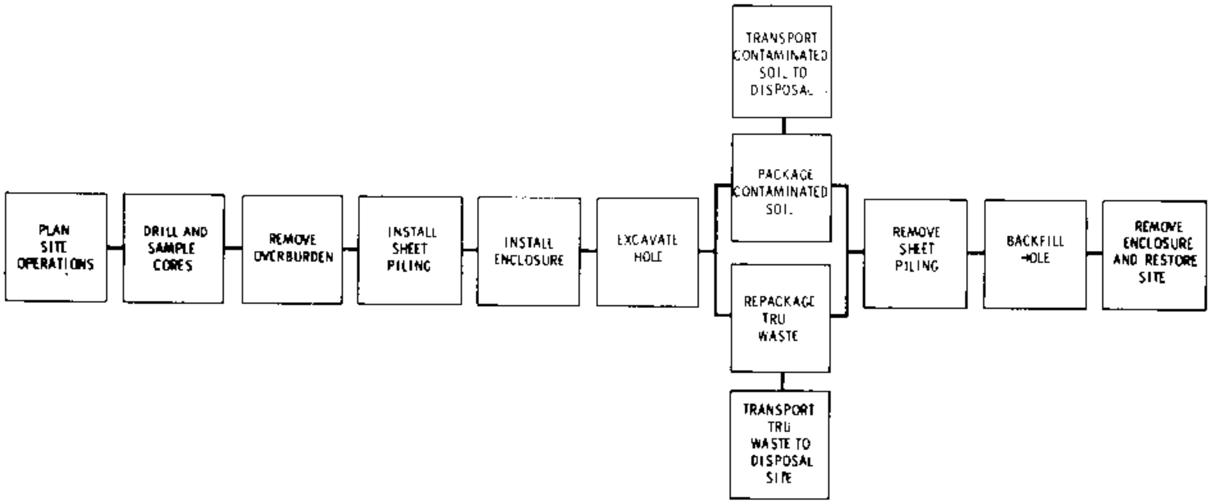

FIGURE 11.3-1. Sequence of Operations for Removal of TRU Waste from a Section of a Burial Trench

Excavation of TRU waste has been demonstrated at INEL(2,5) and at Rocky Flats.(4) However, at these sites the TRU waste was not mixed with beta-gamma waste. Excavation of a TRU waste package at a commercial burial ground would likely be performed under work conditions that included a significant background of beta and gamma radiation. This could result in a substantial beta-gamma radiation dose to decommissioning workers as well as the potential for exposure to transuranics. Occupational radiation doses for this activity are summarized in Section 13.3.

Several different excavation procedures have been employed in the demonstration programs at INEL and Rocky Flats. Four excavation options for TRU package removal are considered in this study:

1) single enclosure with manual excavation techniques
2) single enclosure with remote excavation techniques
3) double enclosure with manual excavation techniques
4) double enclosure with remote excavation techniques.

These options are briefly discussed below and are described in detail in Section G.2 of Volume 2.

11.3.1 Pre-Excavation Operations

Pre-excavation operations include core drilling and sampling, overburden removal, and sheet piling installation.

It is assumed that existing burial records permit the location of the TRU waste package to be determined to within 5 to 10 m. Core drilling involves an initial step wherein 10 cores are obtained from strategic locations around the work area to identify and confirm the planned location of the sheet piling. Following this, needed detail is obtained with 10 follow-up cores to precisely identify the position of the TRU package and the probable extent of any radionuclide migration. In total, 20 cores are drilled to an average depth of 8 m, totaling about 160 linear meters of core. A light drilling rig is adequate to drive these cores. Recognizing that the cores may be contaminated, special methods are used for radiation protection. The drill is encircled by an accordioned-plastic sleeve that is enclosed around a core as it is removed from the earth. The plastic is then sealed at both ends. This provides protection while the core is transferred to a laboratory for analysis. Because of the need to enclose the cores as they are removed, the drilling rate is assumed to be reduced by 25% to 15 linear meters/day.

Overburden is assumed to be removed from a 30-m-square area to a depth of 1 m. A bulldozer or bottom-loading scraper is used, with a soil removal rate of about 160 m^3/hr. Thus, 1 day is required for removal of the approximately 900 m^3 of overburden.

Sheet piling is driven to provide a 10-m-square caisson to enclose the TRU waste package and permit easy access for excavation. The piling is steel of intermediate thickness (130 kg/m^2), with interlocking geometry. It is driven to a depth of about 8.7 m, or about 1.2 m below the trench bottom, to provide a foundation support for the piling. At a rate of 90 m^2 per day, 4 days are required to install the 350 m^2 of piling. (Installation time is assumed to be 20% greater at the eastern site.) One day each for mobilization and demobilization of equipment is also required.

Equipment used for sheet piling installation includes a crane, pile-driving equipment, a power source, and an air compressor, as described previously in Section 11.2.3.

11.3.2 Trench Excavation and Waste Exhumation

The TRU waste package is assumed to be buried at a depth of about 6 m below grade. Thus, a significant quantity of soil and non-TRU waste must be removed from the excavation area to reach the TRU package. The non-TRU waste is assumed to be returned to the pit as part of the backfill after the TRU waste is recovered.

The package in which the TRU waste is buried is postulated to have deteriorated significantly, and some migration of waste into the soil surrounding the package is expected. Soil in the vicinity of the TRU package is surveyed and TRU-contaminated soil is packaged along with the waste for re-burial offsite.

Four options are considered in this study for enclosure of the work area and exhumation of the waste. These options are summarized in Table 11.3-1 and described briefly below. Details are found in Section G.2 of Volume 2.

TABLE 11.3-1. Excavation Options for Removal of TRU Waste from a Conventional Burial Trench

Option	Enclosure	Excavation of Non-TRU Waste	TRU Package Disinterment
Single enclosure with manual excavation	Lightweight metal building	Backhoe	Backhoe and men with shovels
Single enclosure with remote excavation	Lightweight metal building	Gantry crane with clamshell	Gantry crane and mobile remotely controlled manipulator
Double enclosure with manual excavation	Lightweight metal building inside air support weather shield	Backhoe	Backhoe and men with shovels
Double enclosure with remote excavation	Lightweight metal building inside air support weather shield	Gantry crane with clamshell	Gantry crane and mobile remotely controlled manipulator

Two of the options involve men working in the pit area. All personnel operating within the confines of the steel building over the excavation are dressed in launderable anti-contamination clothing (coveralls, shoecovers and gloves) and utilize plastic bubble suits similar to those used at INEL for the Early Waste Retrieval (EWR) program.(2,6) Breathing air is supplied to the suits from an air compressor specially designed to furnish clean air. The compressor has an electrical primary motor and a gasoline backup motor that can be used in the event of a power failure.

Airborne contamination within the pit area is controlled by using a fine spray of water over the working face of the pit to prevent dust. Detergent is added to the water as a wetting agent to aid in soil penetration.

11.3.2.1 Single Enclosure with Manual Excavation

For this option, the work enclosure is a lightweight metal building approximately 12 m by 18 m and 6 m high. The building is constructed of lightweight metal panels reinforced with steel beams and diagonal struts. It can be divided into two 6-m bays for ease of relocation from one site to another. Personnel access to the building is through a three-cell change booth. A large door is also provided for the movement of equipment and waste containers into and out of the building. This door is sealed during actual digging operations. A slightly negative air pressure is maintained inside the building, so that the flow of air is always inward. Exhaust air is filtered through roughing and HEPA filters. All interior surfaces of the building are painted with a strippable coating that can be removed (if necessary) to strip off contamination.

Initial excavation within the pit area (defined by the sheet piling) is performed with a backhoe assisted, as necessary, by manual work crews. Exhumation of the TRU waste package is a cooperative effort involving manual work with shovels and assistance from the backhoe. Soil in the vicinity of the package is surveyed for TRU contamination. All TRU waste and TRU-contaminated soil is packaged in 1.2-m by 1.2-m by 1.8-m steel boxes lined with plastic. The boxes are lowered into and removed from the pit area using a small (10-MT capacity) boom crane. For this study, it is estimated that two steel boxes are required to contain the volume of TRU waste and contaminated soil removed from the pit.

After the TRU waste is removed from the excavation, a small bulldozer is used to push the soil and waste mixture back into the pit and to generally clean up inside the work area.

11.3.2.2 Single Enclosure with Remote Excavation

Conditions within the excavation pit (i.e., a high radiation field or the possibility of a release of volatile radioactive material) may make it necessary to restrict the use of personnel inside the operating enclosure. Remote excavation of the TRU waste package may be required. Procedures for remote excavation are described in this section.

In this option, the containment structure described in the previous section is used.

Excavation and exhumation is performed using a clamshell attached to a gantry crane. The frame on which the gantry crane is mounted is attached to a base with wheels to facilitate movement. A mobile remotely controlled manipulator (robot) equipped with tongs for handling a variety of small tools provides mechanized assistance to the gantry crane and is utilized to clean up spills and close the metal boxes in which the waste is packaged. The mobile robot is described in Section G.2. All operations are monitored visually through windows in the containment building and remotely via television monitors.

11.3.2.3 Double Enclosure with Manual Excavation

This option is based on the method used at INEL to retrieve waste contaminated with transuranic elements from below-ground burial.(2,7) It involves the same procedures as described in Section 11.3.2.1 for the single enclosure with manual excavation option, except that double containment is provided during the excavation and repackaging of the waste by enclosing the lightweight metal building inside an Air-Support Weather Shield (ASWS).

The ASWS is a reinforced fabric structure 20 m by 40 m by 12 m high. It is supported by air pressure from inside. The structure provides effective weather protection for the lightweight steel confinement building and associated equipment and also provides a second level of confinement for radioactive particles dispersed in the air. It is designed to withstand winds up to 160 km/hr and snow loading to 140 kg/m^2. Personnel working inside the ASWS wear anti-contamination clothing and carry respirators, but do not wear the bubble suits that are required for work inside the lightweight metal building. Details of the ASWS are given in Section G.2 of Volume 2.

11.3.2.4 Double Enclosure with Remote Excavation

This option involves the same procedures as described in Section 11.3.2.2 for the single enclosure with remote excavation. Double containment is provided by enclosing the metal building inside the ASWS described in Section 11.3.2.3.

11.3.3 Packaging and Shipping of Retrieved Waste

Packaging and shipping of retrieved TRU waste is accomplished in accordance with DOT regulations published in 49 CFR, Parts 173 through 178, NRC regulations published in 10 CFR, Part 71, and Regulatory Guide 7.1. For reburial at a federal repository, the waste is assumed to be packaged in 1.2-m by 1.2-m by 1.8-m steel boxes. It is assumed that two boxes are required to contain the waste and associated contaminated soil from a single exhumation operation. The boxes are shipped to deep geologic disposal inside a Type B container,[a] such as a Super Tiger,(8) that can be transported by truck.

The distance from the LLW burial ground to a deep geologic disposal site is assumed to be 2,400 km. A total of 5 days is assumed for the round trip, including a half day at each end to load and unload the Type B overpack.

11.3.4 Post-Excavation Operations

After the pit has been filled by replacing the non-TRU contaminated waste and soil that was removed in order to uncover the TRU-contaminated waste, the containment structures (the lightweight metal building and the ASWS, if used) are decontaminated, dismantled, and removed from the site.

The final post-excavation operations include sheet piling removal and backfilling the trench area. The sheet piling removal step involves placing an extractor on the piling, decontaminating the pile after removing it from the earth, and storing the piling on the site. In the removal step, an extractor is used with the same type of support equipment (crane, power, etc.) used

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[a] Type B container is designed to survive a series of hypothetical accident test conditions with essentially no loss of containment and limited loss of shielding capability. The test sequence for Type B packages is designed to simulate the damage that might be expected in a severe accident situation. See 10 CFR 71.36.

for driving the piling. Once extracted from the earth, only a minimal type of decontamination (such as washing with water) is considered necessary, with the possible addition of wire brushing. At an extraction rate of 60 m^2 per day, 6 days are required to remove the piling from the ground and decontaminate it.

Backfilling involves the replacement of the overburden that was originally removed and stockpiled (see Section 11.3.1). The overburden is mounded and compacted to restore the original trench grade. A bulldozer and a roller are used for this operation. Allowing for mobilization/demobilization of equipment, two days are required to complete this step.

11.3.5 Work Schedule Estimates

Work schedules for the completion of decommissioning activities for the relocation of TRU-contaminated waste from a conventional burial trench are shown in Figure 11.3-2 for the western site and in Figure 11.3-3 for the eastern site. These work schedules are based on time requirements for waste relocation operations shown in Table 11.3-2. Time requirements for waste relocation operations are based on operating crew requirements shown in Table 11.3-3.

As in the case of relocation of high beta-gamma radioactivity waste from a slit trench, operating crews for relocation of TRU waste are based on the number of personnel required for efficient performance of the work. No allowance is made for increases in crew sizes to limit worker exposure to radiation. Occupational exposure calculations summarized in Section 13.3 indicate that the number of workers required for waste relocation may need to be increased to keep individual occupational doses within the limits defined by regulations.

Work schedules are shown for each of the four enclosure and excavation alternatives considered in this study. For each alternative, the times required for all waste relocation operations at a given site (other than installation of the work enclosure and exhumation of the waste) are the same. Sheet piling installation, overburden removal, work enclosure installation, sheet piling removal, and trench backfilling are all estimated to require about 20% more time for completion at the eastern site than at the western site, to

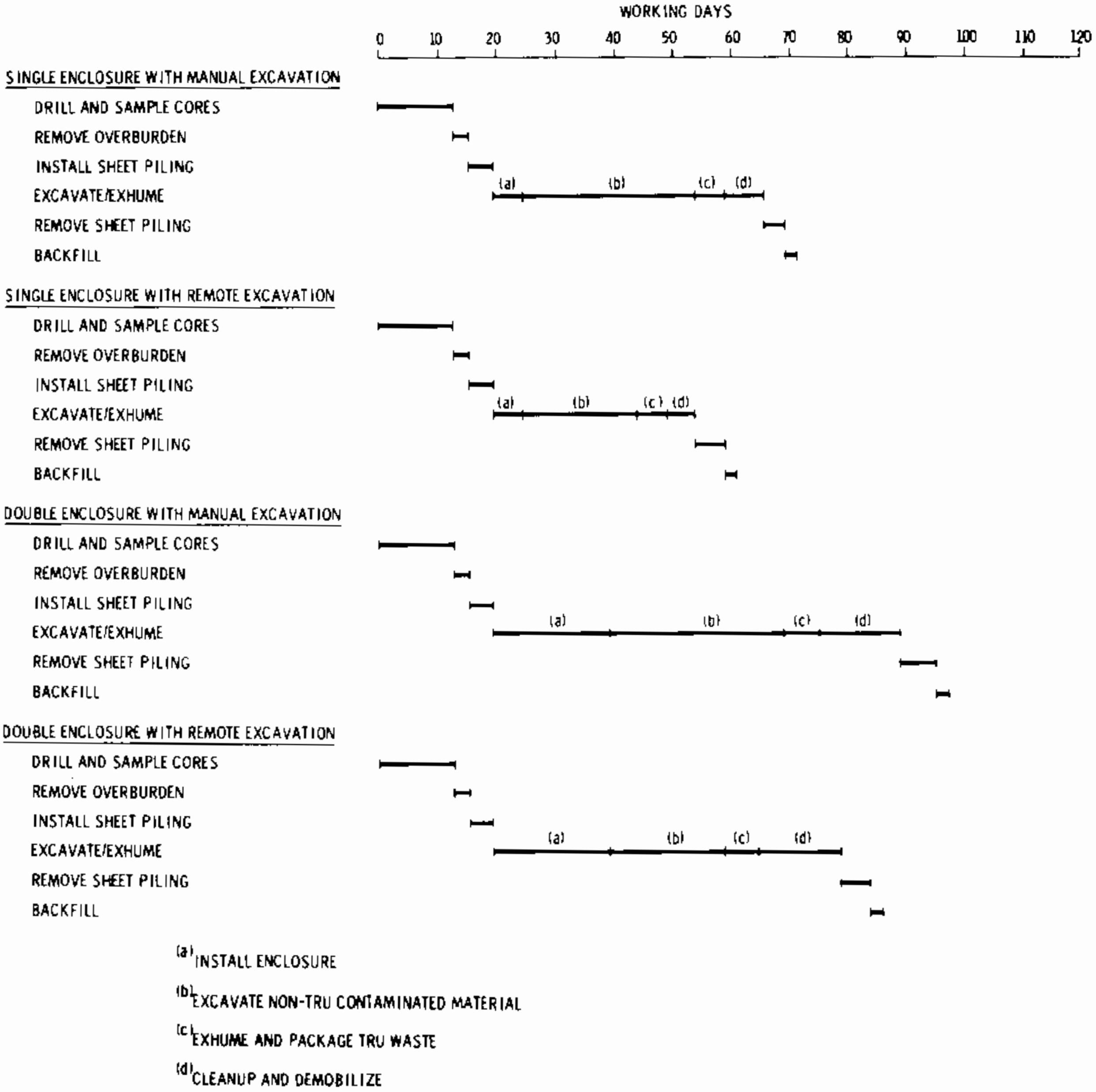

FIGURE 11.3-2. Schedule for Removal of TRU Waste from a Section of a Burial Trench - Western Site

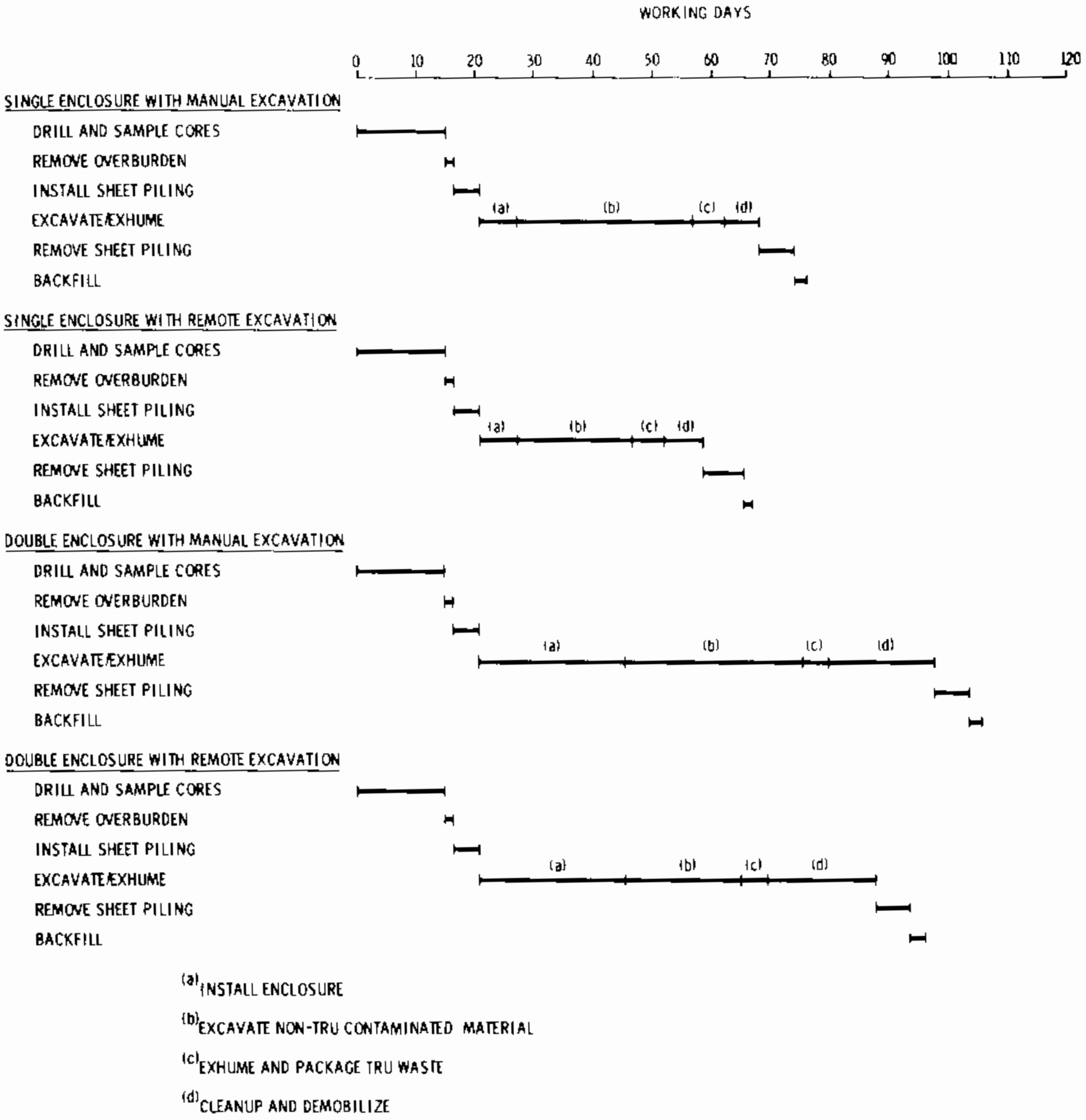

FIGURE 11.3-3. Schedule for Removal of TRU Waste from a Section of a Burial Trench - Eastern Site

TABLE 11.3-2. Time Requirements for Removal of TRU Waste from a Section of a Burial Trench

	Time Requirement in Working Days							
	Single Enclosure with Manual Excavation		Single Enclosure with Remote Excavation		Double Enclosure with Manual Excavation		Double Enclosure with Remote Excavation	
Operation	Western Site	Eastern Site	Western Site	Eastern Site	Western Site	Eastern Site	Western Site	Eastern Site
Drill and Sample Cores(a)	13	15	13	15	13	15	13	15
Remove Overburden	1	1	1	1	1	1	1	1
Install Sheet Piling(a)	6	7	6	7	6	7	6	7
Excavate Trench and Exhume Waste								
Install Enclosures	5	6	5	6	20	24	20	24
Excavate Non-TRU	30	30	20	20	30	30	20	20
Exhume TRU	5	5	5	5	5	5	5	5
Clean Up & Remove Enclosures	5	6	5	6	15	18	15	18
Subtotal	45	47	35	37	70	77	60	67
Remove Sheet Piling(a)	8	10	8	10	8	10	8	10
Backfill Trench	2	2	2	2	2	2	2	2
Total	75	82	65	72	100	112	90	102

(a)Time requirements include one day each for mobilization and demobilization.

TABLE 11.3-3. Operating Crew Requirements for Removal of TRU Waste from a Section of a Burial Trench

Operation	Operating Crew
Drill and Sample Cores	Drilling Foreman Laborer - 2 Health Physics Technician
Remove Overburden	Equipment Operator Health Physics Technician
Install Sheet Piling	Foreman Equipment Operator - 2 Laborer Health Physics Technician
Excavate Trench and Exhume Waste	Foreman Equipment Operator - 2 Laborer - 2 Health Physics Technician
Remove Sheet Piling	Foreman Equipment Operator - 2 Laborer Health Physics Technician
Backfill and Restore Site	Equipment Operator - 2 Health Physics Technician

allow for adverse weather conditions at the eastern site. Because waste exhumation takes place within an enclosure, excavation times are assumed to be the same at the two sites.

Approximately 600 m^3 of waste and soil must be removed from the upper 6 m of the pit area in order to reach the TRU-contaminated waste. To determine the time required to excavate this material, a rate of 5 m^3/hr is assumed for both the manual and remote excavation options. For manual operations it is postulated that men wearing bubble suits spend only 4 hours per working day in actual excavation activities. For remote operations, 6 hours of excavation per working day is assumed. A rate of 1 m^3/day is assumed for excavation of the TRU-contaminated waste for both the manual and remote operations.

For waste exhumation operations at INEL, the transfer of the ASWS from one site to another required more than 2 months time, and the relocation of the metal building within the weather shield required 2 weeks to complete.(7) Assuming that future mobilization/demobilization activities would benefit from past experience, it is estimated that the ASWS could be put in place in 3 weeks and removed in 2 weeks. The lightweight metal building is estimated to require 1 week for erection at the site and 1 week for removal. Construction times are based on the western site, with the eastern site requiring about 20% greater times.

Total time requirements for exhumation of a package of TRU-contaminated waste from a conventional burial trench are relatively insensitive to whether the actual excavation is performed manually or remotely. Time requirements are estimated to range from 13 weeks for the single enclosure option to 20 weeks for the double enclosure option at the western site, and from 15 weeks for the single enclosure option to 23 weeks for the double enclosure option at the eastern site.

11.4 RELOCATION OF ALL THE WASTE FROM A BURIAL TRENCH

This section describes methods and procedures for the complete exhumation and relocation of the waste from one burial trench. The reference trench is described in Section 7.2, and the reference waste inventory is described in

Section 7.3. It is assumed that high beta-gamma dose-rate waste and TRU-contaminated waste is selectively removed from the burial trench, using the techniques described in Sections 11.2 and 11.3. After selective exhumation of the more hazardous wastes is accomplished, rapid excavation techniques may be safely used to empty the trench of the remaining waste. These techniques are described in this section.

The simplified approach described here for relocation of all the waste from a burial trench may not always be possible. As discussed in the following paragraphs, various factors may make it necessary to use the techniques given in Sections 11.2 and 11.3.

Two important factors in the choice of waste relocation techniques are the radionuclide content and the specific activity of the buried waste. As shown in Section 7.3 (see Table 7.3-3), the average byproduct activity of the waste in a typical trench at the time the waste is postulated to be exhumed is about 4.3 Ci/m^3. The average TRU activity is less than 0.01 Ci/m^3. However, in an actual trench, the waste is not distributed uniformly. Some trenches will contain waste packages with byproduct or TRU activity 2 or 3 orders of magnitude greater than the average. For example, about 4% of the total volume of waste in the reference burial ground consists of solidified demineralizer resin with an average specific activity in the range of 70 to 160 Ci/m^3 (see Table 7.3-2). Some of this waste is buried in cement caissons that provide shielding from high dose rates, but not all of it is buried in shielded containers.

Another factor that could complicate waste relocation operations is the inability to determine exact locations of packages of TRU-contaminated or high beta-gamma dose-rate waste. This is particularly true for waste buried in older trenches for which inaccurate or incomplete records exist.

The presence of water in a burial trench could complicate waste relocation operations. This is more likely to occur at the eastern site than at the western site because of the higher average rainfall and shallower depth to ground water at the eastern site. Waste buried at the eastern site may be damp or it may be partially immersed in water. In this case, it would be necessary to pump the trench before starting to excavate (see stabilization procedure L of Section 10.1.2) and to provide additional capability for water removal during waste-relocation operations. Because of inclement weather at the eastern site, it may be necessary to perform the entire excavation operation inside an ASWS (see Section 11.3.2.3).

Operational interruptions for inclement weather may clearly be expected at the eastern site. Thus, freezing winter weather (impairing work and road access), rainy periods (that can make a quagmire of the burial area), and high winds (increasing the danger of contaminated dust distribution) are periods when operations may be temporarily halted. To make allowance for inclement weather at the eastern site, excavation operations are assumed to require about 20% more time for completion at this site than at the western site.

Relocation of the waste remaining in a trench after selective removal of the high-dose-rate and TRU-contaminated wastes involves the following steps:

- core drilling and sampling
- overburden removal
- waste exhumation
- repackaging and shipment of the waste
- backfilling and site restoration.

For this excavation, sheet piling is not used. The trench must be excavated to expose the original trench walls to insure removal of all of the waste. Since the trench walls were originally sloped to accommodate the angle of repose of the soil at the burial site, sheet piling is not deemed necessary. Figure 11.4-1 shows the sequence of operations associated with relocation of all the waste from a burial trench.

11.4.1 Pre-Excavation Operations

Pre-excavation operations include core drilling and sampling and overburden removal.

The feasibility of bulk excavation in the open air is greatly affected by the accuracy with which significantly hazardous wastes are located, using

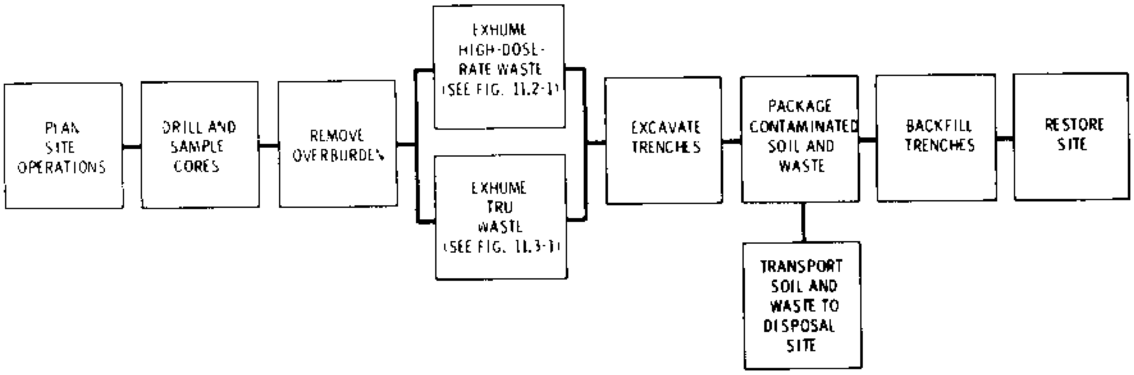

FIGURE 11.4-1. Sequence of Operations for Complete Waste Relocation from a Burial Trench

site records augmented by core drilling, so that such wastes can be selectively exhumed beforehand. Core sampling also permits determination of the degree of radionuclide migration within the trenches and from a trench into the surrounding soil. Finally, some indication of waste-package integrity may be gained from core sampling.

An initial series of borings on approximately 5-m spacings, in 3 rows, is made over the length of the trench, resulting in about 90 cores. These cores are surveyed with field instrumentation and, in some cases, subjected to more specific laboratory analyses. The resulting information is used to identify specific areas that warrant further core drilling. In addition, certain areas in a trench may appear to warrant more precise characterization, due to ambiguity in burial records. Allowing an additional 25 holes, a total of 115 cores are assumed for characterization of a trench. Cores are drilled to a depth of 8 m. Because the cores may be contaminated, they are sealed in plastic sleeves as they are removed from the earth. (See Section 11.3.1.) At a drilling rate of 15 linear meters per day, the core drilling program is assumed to require 62 days for completion, including 1 day each for mobilization and demobilization.

The overburden (down to 1 m below grade) is essentially clean material and is removed and stockpiled for later use in backfilling the trench. To provide ample working space, the area removed must exceed the dimensions of a trench. It is assumed that an area 30 m wide and 170 m long is cleared. Bottom-loading scrapers are used to accomplish this step, which is completed in 3 days.

11.4.2 Trench Excavation and Waste Exhumation

Wastes are exhumed by bulk excavation of the trench, using conventional commercially available equipment. Two exhumation cases are considered. One case utilizes a backhoe operating from above the trench. This permits most of the operating crew to be relatively remote from the exposed waste. The second case involves the use of a front-end loader operating from the floor of the trench, with the assistance of laborers who facilitate the grappling and excavation of large containers and loose waste.

The type of waste handling required depends on the original packaging and on the length of time that the waste has been buried. Some waste is buried in large cement caissons or steel liners, or in large plywood boxes. If these large containers have remained intact, and have negligible surface contamination, they are removed from the trench with the aid of a crane and grappling hooks, wrapped in plastic, and placed on a flatbed truck for shipment. The bulk of the waste is assumed to be packaged in 208-ℓ steel drums. The condition of these drums depends mostly on the length of time that has elapsed since burial of the waste. If the drums are intact and in good physical condition, they are placed directly in an overpack for shipment. Waste in damaged drums and in plywood or fiberboard boxes, loose waste, and contaminated soil is packaged as described in the following paragraph.

Loose waste and contaminated soil is fed into a large metal bin. The shipping container (a 1.2-m by 1.2-m by 1.8-m steel box for waste transported to deep geologic disposal or a comparably sized plywood box for waste destined for offsite shallow-land burial) is located below the bin and is filled from a vibrating hopper. As the shipping container is filled, it is physically vibrated to compact the waste. It is then removed from under the bin and the box lid is secured in place.

The amount of contaminated soil present in the burial trench is a function of climate and soil conditions at the site, of procedures employed during waste burial, and of the length of time that the waste has been buried. Because of the added time and cost of sorting the soil, it is assumed that all of the soil in the bottom 6.5 m of a trench is exhumed and packaged with the waste. The total volume of waste and soil packaged per trench is 12,200 m^3. The savings in exhumation costs achieved by not sorting the uncontaminated soil is partially offset by an increase in packaging and shipping costs.

A water spray is used during excavation operations to minimize the amount of dust in the air. Detergent is added to the water as a wetting agent to aid in soil penetration. All personnel operating within the trench area are dressed in launderable anti-contamination clothing (coveralls, shoecovers and gloves) and carry respirators. The use of respirators may be required during excavation operations to reduce the inhalation dose to workers from airborne radioactivity.

Brief summaries of the two exhumation options are given below. Details are given in Section G.3 of Volume 2.

11.4.2.1 Excavation from Above the Trench

In this option, most of the material removal and packaging operations are performed by personnel stationed above the trench at the level at which overburden has been removed. Some support operations are performed by personnel stationed in the excavation area.

Excavation is done by a large-capacity (2-m^3) backhoe operated from above the excavation face. The backhoe is provided with a shielded, ventilated cab for operator protection. An auxiliary crane with hook, a lift truck, and an oxyacetylene welder are also operated at ground level above the trench. Two loading bins are located in the trench. Support operations in the trench are performed by an equipment operator and a laborer using a bulldozer.

11.4.2.2 Excavation from Within the Trench

In this option, all of the material removal and packaging operations are performed by personnel working in the excavation pit. The potential for personnel exposure is greater for this option than it is for the previously discussed option.

Excavation is done by a large-capacity (2-m^3) front-end loader. Two laborers suitably protected for radiation-zone work provide manual assistance in dislodging waste forms and in grappling onto waste packages. A bulldozer is used for support operations. An auxiliary crane with hook, a lift truck, and a welder are operated at ground level above the excavation to lift loaded waste containers from the pit, secure the lids on the containers, and place the containers on a tractor-trailer for shipment.

11.4.3 Packaging and Shipping of Retrieved Waste

Packaging and shipping requirements for relocation of waste exhumed from a burial trench depend on the disposal option chosen. Three possible options are:

- disposal offsite at a deep geologic disposal site
- disposal offsite at a federal or other commercial shallow-land burial ground
- disposal onsite in another burial trench.

Locations for offsite disposal are assumed to be 2,400 km from the LLW burial ground.

For deep geologic disposal the waste is assumed to be packaged in 1.2-m by 1.2-m by 1.8-m steel boxes and transported by exclusive-use van. Type B containers such as the Super Tiger are not required because of the relatively low specific-activity of the waste. However, in some cases, shielding is required for the shipment of high-dose-rate waste. It is postulated that about 2% of the waste will require transport in shielded Type B containers.

For offsite shallow-land burial, the waste is assumed to be packaged in 1.2-m by 1.2-m by 1.8-m reinforced plywood boxes and transported by exclusive-use van. Special provision is made for packaging wastes requiring shielding.

To compute the packaging and shipping costs detailed in Section 12, all of the waste is assumed to be packaged in 1.2-m by 1.2-m by 1.8-m boxes, even though some of it is shipped directly in the container in which it is buried. This results in an overestimate of packaging and shipping costs.

All shipments offsite are made in accordance with DOT regulations published in 49 CFR, Parts 173 through 178, NRC regulations published in 10 CFR, Part 71, and Regulatory Guide 7.1.

For burial in another trench onsite, the waste is transported in 10 m^3 dump trucks. The bed of the dump truck is lined with nylon-reinforced plastic before the waste is loaded, and the plastic is folded over the top of the waste and sealed when the truck is full. The waste is then transported to the new trench and dumped, still wrapped in plastic. Water sprays are used to limit the amount of airborne contamination during truck loading and unloading operations.

11.4.4 Post-Excavation Operations

The backfilling operation is similar to that discussed in Sections 11.2.7 and 11.3.4. Approximately 12,000 m^3 of borrow material are required, in addition to the stockpiled overburden. It is assumed that such a quantity of borrow material is available within 8 km of the site. The borrow material is brought in by dump truck and dropped onto the floor of the trench, or physically run in by truck with a turnaround on the trench floor. Material delivered to the trench, plus the previously stockpiled overburden, is bulldozed into place and compacted with a roller.

11.4.5 Work Schedule Estimates

Work schedules for the completion of decommissioning activities related to the relocation of all the waste from a burial trench are shown in Figure 11.4-2 for the western site and Figure 11.4-3 for the eastern site. These work schedules are based on time requirements for waste relocation operations shown in Table 11.4-1. Time requirements for waste relocation operations are based on operating crew requirements shown in Table 11.4-2.

As in the case of other partial waste relocation operations, operating crews for relocation of all the waste from a burial trench are based on the number of personnel required for efficient performance of the work. No allowance is made for increases in crew sizes to limit worker exposure to radiation. Occupational exposure calculations summarized in Section 13.3 indicate that

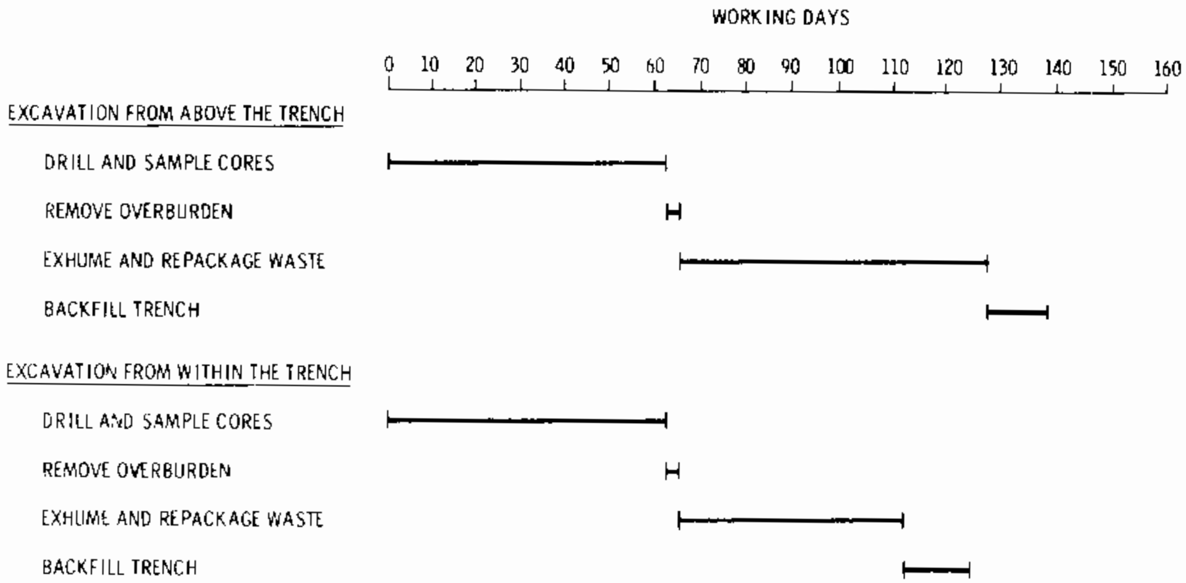

FIGURE 11.4-2. Schedule for Relocation of all the Waste from a Burial Trench - Western Site

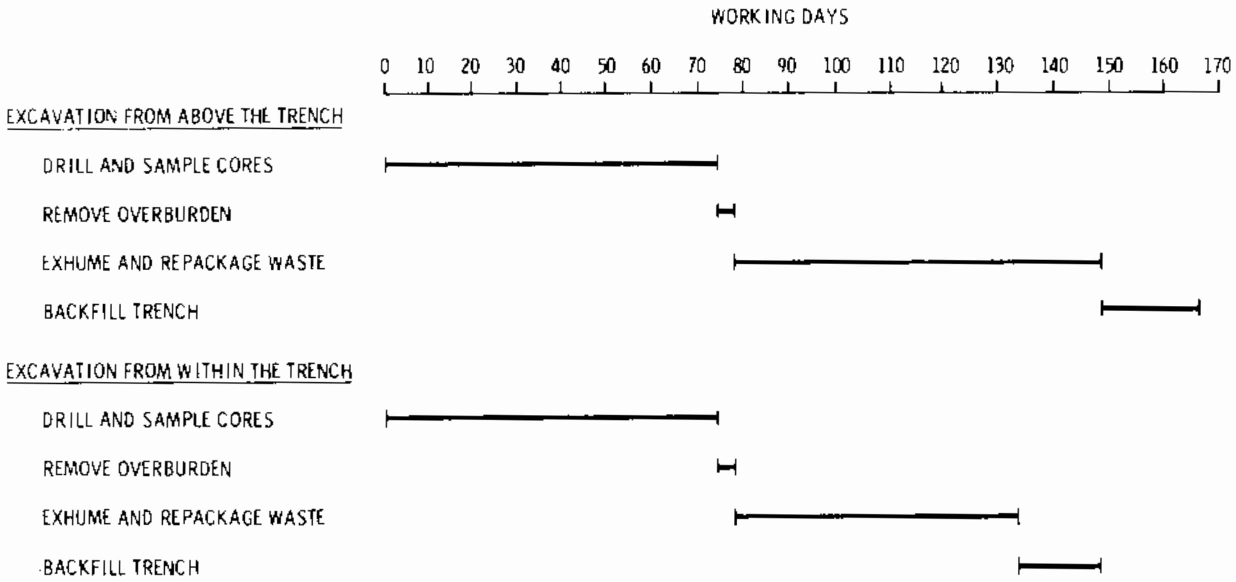

FIGURE 11.4-3. Schedule for Relocation of all the Waste from a Burial Trench - Eastern Site

TABLE 11.4-1. Time Requirements for Relocation of all the Waste from a Burial Trench

Operation	Time Requirement in Working Days			
	Excavation from Above the Trench		Excavation from Within the Trench	
	Western Site	Eastern Site	Western Site	Eastern Site
Drill and Sample Cores[(a)]	62	74	62	74
Remove Overburden	3	4	3	4
Exhume & Package Waste				
Mobilize/Demobilize[(b)]	5	6	5	6
Excavate	57	69	42	50
Backfill Trench	12	14	12	14
Totals	139	167	124	148

(a) Time requirements include one day each for mobilization and demobilization.

(b) Mobilization/Demobilization includes all activities required to install the equipment prior to the start of operations and to decontaminate and remove the equipment after operations are completed.

TABLE 11.4-2. Operating Crew Requirements for Relocation of all the Waste from a Burial Trench

Operation	Operating Crew
Drill and Sample Cores	Drilling Foreman Laborer - 2 Health Physics Technician
Remove Overburden	Equipment Operator - 2 Health Physics Technician
Exhume and Repackage Waste (2 crews)	Foreman - 2 Equipment Operator - 8 Truck Driver - 2 Laborer - 8 Health Physics Technician - 2
Backfill Trench	Foreman Equipment Operator - 4 Truck Driver - 4 Laborer - 2 Health Physics Technician

the number of workers required for waste relocation may need to be increased to keep individual occupational doses within the limits defined by regulations.

Work schedules are shown for both the excavation option in which the bulk of the work is performed by personnel stationed above the trench and for the option in which all of the work is performed by personnel working in the excavation pit. Schedules are based on the assumption that waste exhumation operations are performed by two crews working simultaneously. The crews start at either end of the trench and excavate toward the center. Excavation times are about 20% greater at the eastern site than they are at the western site, because of the greater possibility of inclement weather at the eastern site.

Time requirements for excavation of a trench are calculated on the basis of excavation rates of 18 m^3/hr per crew for excavation from above the trench and 24 m^3/hr per crew for excavation from within the trench. Six hours of actual excavation are assumed to be performed during a normal working day.

The time required to backfill an excavated trench is calculated on the basis of a fill rate of 1,350 m^3/day. Some of the fill is the overburden originally removed from the trench. Bottom-loading scrapers are used to return this material to the excavation site. Most of the fill consists of borrow that must be brought in by truck from an offsite location.

Time requirements for the complete waste relocation operation at the western site are estimated at 28 weeks for excavation from above the trench and 25 weeks for excavation from within the trench. At the eastern site, the time requirements are 34 weeks and 30 weeks for the two options.

11.5 BURIAL GROUND STABILIZATION AND LONG-TERM CARE FOLLOWING PARTIAL WASTE RELOCATION

In this study, methods and procedures for partial waste relocation are described for three specific cases:

- relocation of high beta-gamma radioactivity waste from a slit trench
- relocation of TRU-contaminated waste from a section of a burial trench
- relocation of all of the waste from a burial trench.

In most instances of burial ground decommissioning, it is assumed that selective exhumation of the waste from particular trenches is accompanied by measures designed to stabilize the entire burial ground. These activities are followed by a period of long-term care of the site. Procedures for site stabilization and long-term care are discussed in Section 10.

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8. Directory of Packagings for Transportation of Radioactive Materials, WASH-1279, p. 251, USAEC Division of Waste Management and Transportation, Washington DC, October 1973.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, and the National Technical Information Service, Springfield, Virginia 22161.

12.0 DECOMMISSIONING COSTS

This section presents estimates of manpower requirements, equipment and material requirements, waste disposal requirements, and costs for decommissioning the reference low-level waste (LLW) burial grounds. Cost estimates are made for stabilization, long-term care, and waste relocation. The costs are based on decommissioning procedures summarized in Sections 10 and 11 and developed in detail in Appendices F and G of Volume 2. Costs are included for support staff and decommissioning worker labor, equipment and materials, contaminated waste management (packaging, transportation, and disposal), contractor fees, utilities and other miscellaneous owner expenses, and specialty contractors. All costs are in 1978 dollars.

The basic cost estimates presented in this section assume relatively efficient performance of the decommissioning activities. A 25% contingency is added to the cost estimate totals as an allowance for unforeseen problems or scheduling delays that may arise during decommissioning. The total costs presented are therefore believed to be representative of actual expenses that would be incurred to decommission the reference LLW burial grounds, using the methods described in this report.

12.1 COST ESTIMATES FOR SITE/WASTE STABILIZATION ACTIVITIES

The estimated costs for the six burial ground stabilization plans considered in this study are summarized in Table 12.1-1. Stabilization is estimated to require from 10 to 36 weeks (plus an additional period for planning and preparation), and to cost from $0.5 million to $7.7 million, depending on the site and the stabilization plan chosen.

The minimal plans assume that burial trenches are satisfactorily stabilized during site operations as they are filled. Therefore, cost estimates for the minimal plans include the costs of stabilization of trenches that were active during the final years of site operation plus the costs of remedial measures required to prepare an entire site for long-term care. Minimal plan stabilization procedures are performed by the site operator.

TABLE 12.1-1. Summary of Estimated Stabilization Costs

	Minimal Plan		Modest Plan		Complex Plan	
	Cost in Millions of 1978 Dollars[a]	Percent of Total	Cost in Millions of 1978 Dollars[a]	Percent of Total	Cost in Millions of 1978 Dollars[a]	Percent of Total
Western Site						
Manpower-						
Support Staff	0.238	62.5	0.563	27.3	0.616	10.0
Decommissioning Workers	0.044	11.6	0.288	14.0	0.687	11.2
Contractor's Equipment	0.028	7.4	0.299	14.5	0.696	11.3
Materials and Supplies	0.057	15.0	0.724	35.1	3.646	59.3
Contractor's Fee[b,c]	---	---	0.150	7.3	0.452	7.4
Environmental Monitoring Services	0.006	1.6	0.018	0.9	0.022	0.4
Records Maintenance	0.001	0.3	0.005	0.2	0.005	0.1
Miscellaneous Owner Expenses[d]	0.006	1.6	0.014	0.7	0.016	0.3
Subtotals	0.380	100.0	2.061	100.0	6.140	100.0
25 Contingency	0.095		0.515		1.535	
Total Stabilization Costs	0.5		2.6		7.7	
Eastern Site						
Manpower-						
Support Staff	0.247	59.7	0.606	19.6	0.625	14.3
Decommissioning workers	0.056	13.5	0.509	16.5	0.609	13.9
Contractor's Equipment	0.033	8.0	0.454	14.7	0.562	12.9
Materials and Supplies	0.061	14.7	1.250	40.3	2.206	50.4
Contractor's Fees[b,c]	---	---	0.226	7.3	0.320	7.3
Environmental Monitoring Services	0.010	2.4	0.028	0.9	0.030	0.7
Records Maintenance	0.001	0.3	0.005	0.2	0.005	0.1
Miscellaneous Owner Expenses[d]	0.006	1.4	0.015	0.5	0.016	0.4
Subtotals	0.414	100.0	3.093	100.0	4.373	100.0
25 Contingency	0.104		0.773		1.093	
Total Stabilization Costs	0.5		3.9		5.5	

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[a] Number of figures shown is for computational accuracy only.
[b] Contractor's fee calculated on the basis of 8 of the sum of manpower, equipment and materials cost.
[c] Activities for minimal plan performed by site operator; hence no contractor's fee.
[d] Miscellaneous expenses include utilities, taxes, and insurance costs.

The modest and complex plans assume that stabilization of the entire site takes place when burial operations cease. Cost estimates for these plans assume that the site operator hires a contractor to decommission a site.

Support staff manpower costs include planning and preparation costs. For the minimal plan, much of the documentation required for site decommissioning (e.g., the Master Decommissioning Plan) is completed at an early time during site operations. Therefore, staff requirements for planning and preparation are smaller for the minimal plan than they are for the modest or complex plans.

Support staff requirements for the modest or complex plans are relatively inflexible to changes in project complexity, largely because of the planning and preparation requirements. Thus, support staff costs do not increase at the same rate as overall project costs. Decommissioning worker labor, equipment, and materials requirements are more closely related to project complexity, and their costs generally increase at a rate similar to that of the overall costs. As a result, the percentage of overall cost attributable to manpower generally decreases (and the percentage attributable to equipment and materials increases) as project complexity increases.

The complex plan for the eastern site is estimated to cost less than the complex plan for the western site. Two major factors influence the relative magnitudes of complex-plan cost estimates. First, both complex plans include an increase in the capping soil thickness over the trenches. For the western site, all of the backfill is assumed to be transported to the burial ground from an offsite location. For the eastern site, more than half of the required backfill is available onsite as a result of the construction of the peripheral drainage/diversion system. Thus, manpower and material requirements and costs for the capping thickness increase are calculated to be smaller for the eastern site than they are for the western site. Second, both plans include installation of a layer of asphalt over the burial trenches. For the complex plan at the western site, the asphalt is used to seal the subsurface rock layer. For the complex plan at the eastern site, the asphalt provides the subsurface hard layer. There are large uncertainties in the thicknesses of asphalt needed for these stabilization activities. Therefore, an asphalt layer thickness of 100 mm is assumed for both stabilization activities. If only half as much asphalt (i.e., 50 mm) were required to seal the rock layer at the western site, material costs for the complex plan at this site would decrease by about \$1 million. Conversely, if an additional 50 mm (for a total thickness of 150 mm) were required for the subsurface hard layer at the eastern site, material costs for the complex plan at this site would increase by about \$1 million.

12.1.1 Manpower Requirements and Costs for Stabilization

Estimates are made of the work force required to plan and execute the stabilization activities described in Sections 10.3 and 10.4. These work force estimates are used, together with the unit manpower costs given in Section H.1 of Volume 2, to estimate stabilization manpower costs. The bases for these manpower costs are described in this section, and further details are provided in Section H.2 of Volume 2.

12.1.1.1 Manpower Requirements

The decommissioning work force organizational chart for stabilization is shown in Figure 12.1-1. The work force is described in two parts: 1) the decommissioning support staff that plans, supervises, and provides support services for the stabilization activities, and 2) the decommissioning workers who perform the actual stabilization activities. The six general types of functions performed during stabilization are described briefly below:

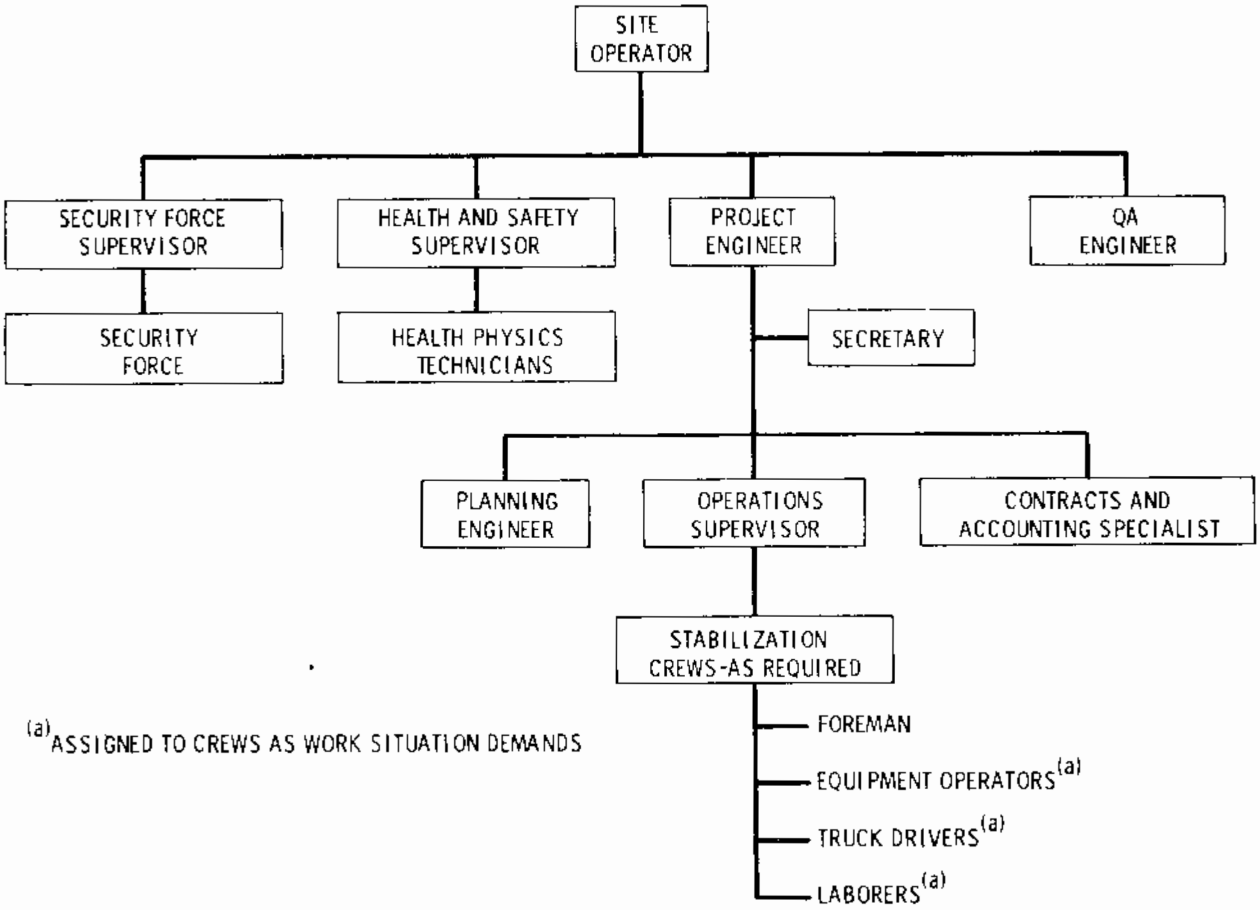

FIGURE 12.1-1. Postulated Organizational Chart for Burial Ground Stabilization

Project Management. Their function is to prepare and implement the decommissioning plan in a safe and cost-effective manner.

Quality Assurance (QA). Their function is to develop the QA plan and monitor the safety and performance of the decommissioning activities.

Decommissioning Operations. Their function is to develop detailed decommissioning plans, and carry out the actual decommissioning activities.

Health and Safety Protection. Their function is to develop and implement methods to ensure the protection of the health and safety of the public and the decommissioning workers.

Security. Their function is to provide protection of the facility and the equipment from unauthorized access or use.

Support Services. Their function is to provide accounting, procurement and stores, and secretarial and clerical services in support of the decommissioning activities.

Job description details for key individuals in the stabilization staff organization are given in Section H.2 of Volume 2, and are summarized briefly below.

Project Engineer. This person is responsible for planning, coordinating, and carrying out the stabilization activities in a safe and cost-effective manner.

Health and Safety Supervisor. This person is responsible for developing and implementing the industrial and radiation safety program.

Security Force Supervisor. This person is responsible for site security.

Contracts and Accounting Specialist. This person is responsible for procurements and disbursement of funds.

Quality Assurance Engineer. This person develops and implements the QA plan to assure that decommissioning is performed in accordance with the decommissioning plan and QA requirements.

Planning Engineer. This person is responsible for planning and scheduling of activities.

Operations Supervisor. This person develops detailed activity procedures and specifications and, through the foremen, supervises the performance of the project.

The actual stabilization activities are carried out by stabilization crews. These crews consist of a foreman, together with equipment operators, truck drivers, and laborers who are assigned to crews as the work situation demands. The duties and experience of the members of the basic stabilization crew are outlined below.

Foreman. This person supervises the performance of all decommissioning activities. He coordinates with the engineering staff, through the operations supervisor, to plan and execute each day's activities. He assembles the crew and equipment required to perform these activities and instructs the crew on the procedures and safety precautions to be followed. In some cases, the foreman is assumed to perform some decommissioning activities as well as supervise other members of his crew (e.g., surveying). It is anticipated that the foreman has been employed in a similar position in previous projects comparable to stabilization, so that he has detailed knowledge and experience related to the work required.

Equipment Operators, Truck Drivers, and Laborers. These people perform the bulk of the stabilization activities. They are assumed to possess the necessary skills for stabilization--either through past experience on similar projects or through specialized training prior to or during stabilization.

Health Physics Technician. This person is added to the basic work crew as the work situation demands. He provides instruction in industrial and radiation safety precautions to be followed for each task and monitors compliance with written radiation work procedures. He performs on-the-job radiation measurements and has the authority to stop work if any potentially unsafe situations arise.

The decommissioning support staff is assembled during the planning and preparation phase, prior to the start of actual stabilization activities. Initial management staff consists of the project engineer and the planning engineer. Other staff personnel are added as their services are required during the planning and preparation phase. Planning and preparation activities take place during the final 18 months of burial ground operations. Therefore, support activities such as site security are available during planning and preparation as part of normal operations, and are not charged to decommissioning.

The decommissioning staff is generally sized and structured on a one-shift, 5-day week. Site security is carried out on a four-shift, 7-day week. To take into account inefficiencies inherent in the work tasks performed, manpower requirements are developed on the basis of reasonable worker time-efficiencies.

Manpower requirements are generally greatest during the middle of stabilization, during the largest-scale operations. Staff size is estimated to be smaller during the preparatory activities and again during the final stabilization tasks.

12.1.1.2 Manpower Costs

Estimated manpower requirements and associated costs are shown in Tables H.2-1 and H.2-2 of Volume 2, and are summarized in Table 12.1-2. A total of from 6.2 to 17.0 man-years is estimated to be required for the support staff, depending on the stabilization plan considered, at an estimated labor cost of from $238,000 to $625,000. A total of from 1.5 to 23.1 man-years is estimated to be required for the decommissioning workers to perform the actual stabilization activities, at a labor cost of from $43,000 to $687,000. The total labor costs for stabilization are therefore estimated to range from about $281,000 to $1.3 million without contingencies, depending on the stabilization plan considered.

It should be recognized that the completion of such activities occasionally takes longer than anticipated. Increased costs can often be offset by savings made through the rapid reduction of decommissioning personnel as soon as it is recognized that they can no longer be effectively utilized. The final stages of many activities, for example, can be accomplished by relatively small groups.

TABLE 12.1-2. Summary of Manpower Utilization and Costs for Stabilization

Stabilization Plan	Manpower Category	Man-Years[a]	Cost ($ thousands)[a,b]
Minimal Plan for Western Site	Support Staff	6.16	237.7
	Decommissioning Workers	1.52	43.5
	Totals	7.68	281.2
Modest Plan for Western Site	Support Staff	15.12	562.8
	Decommissioning Workers	9.40	288.1
	Totals	24.52	850.9
Complex Plan for Western Site	Support Staff	16.75	615.9
	Decommissioning Workers	23.06	686.7
	Totals	39.81	1 302.6
Minimal Plan for Eastern Site	Support Staff	6.44	247.1
	Decommissioning Workers	1.98	56.3
	Totals	8.42	303.4
Modest Plan for Eastern Site	Support Staff	16.43	605.9
	Decommissioning Workers	16.75	508.6
	Totals	33.18	1 114.5
Complex Plan for Eastern Site	Support Staff	17.01	624.7
	Decommissioning Workers	20.10	609.2
	Totals	37.11	1 233.9

(a)Number of figures shown is for computational accuracy only.
(b)Contingency of 25% not included in these costs.

12.1.2 Material and Equipment Requirements and Costs for Stabilization

Estimates of material and equipment costs for the six stabilization plans considered in this study are shown in Table 12.1-3. Material and equipment requirements are based on stabilization procedures described in Sections 10.3 and 10.4 and details and assumptions given in Section H.2.2 of Volume 2. The costs are calculated on the basis of unit costs given in Section H.1. The total estimated cost for contractor equipment ranges from

TABLE 12.1-3. Estimated Material and Equipment Costs for Stabilization

Stabilization Plan	Stabilization Activity	Equipment Costs ($ thousands)[a,b]	Material Costs ($ thousands)[a,b]
Minimal Plan for Western Site	Trench Stabilization	16.8	30.0
	Repair Damaged Areas	7.8	12.0
	Revegetation/Vegetation Management	3.8	15.3
	Totals	28.4	57.3
Modest Plan for Western Site	Site Preparation	9.5	27.9
	Capping Thickness Increase	277.8	622.0
	Revegetation/Vegetation Management	11.4	73.6
	Totals	298.7	723.5
Complex Plan for Western Site	Site Preparation	9.5	30.8
	Rock Layer Emplacement	288.2	933.0
	Rock Layer Hard Topping	108.8	1 982.0
	Capping Thickness Increase	277.8	622.0
	Revegetation/Vegetation Management	11.4	78.6
	Totals	695.7	3 646.4
Minimal Plan for Eastern Site	Trench Stabilization	16.8	30.0
	Repair Damaged Areas	12.3	15.0
	Revegetation/Vegetation Management	3.8	16.3
	Totals	32.9	61.3
Modest Plan for Eastern Site	Site Preparation	14.0	33.8
	Capping Thickness Increase	277.8	622.0
	Capping Drainage Improvement	32.0	0.0
	Capping Soil Properties Modification	118.6	520.0
	Revegetation/Vegetation Management	11.4	74.6
	Totals	453.8	1 250.4
Complex Plan for Eastern Site	Site Preparation	55.4	33.8
	Hard Layer Emplacement	124.5	1 800.0
	Peripheral Drainage/Diversion	203.8	13.3
	Capping Thickness Increase	161.8	276.0
	Preparations for Sump Pumping	5.0	2.0
	Revegetation/Vegetation Management	11.4	80.6
	Totals	561.9	2 205.7

(a)Number of figures shown is for computational accuracy only.
(b)Contingency of 25% not included in these costs.

about $28,000 to $696,000, depending on the stabilization plan considered. The total cost for materials and expendable equipment ranges from about $57,000 to $3.65 million. The complex stabilization plan for the arid western site has the greatest material requirements and costs and, hence, the greatest equipment requirements and costs to move those materials into place.

Contractor equipment costs are calculated on the basis of a monthly charge of 6% of the capital cost of the equipment. This charge is believed to be adequate to cover equipment depreciation, maintenance and operating expenses (e.g., fuel, lubrication, etc.), the cost of decontamination following use, and return on investment.

Material and equipment costs vary with location, depending on local availability, transportation distances, and a variety of other factors. The costs used here are judged to be reasonable approximations of actual expenses that would be incurred for a project of this type and magnitude.

12.1.3 Contractor Fees for Stabilization

The contractor performing the stabilization is anticipated to receive payment consisting of reimbursement for expenses incurred (i.e., manpower, equipment, and material costs), together with a fee to provide a reasonable profit for his efforts. For this study, the contractor's fee is calculated on the basis of 8% of the expenses incurred. This rate is judged to be reasonable for the size and complexity of the decommissioning project. For the modest and complex stabilization plans, the contractor's fee is estimated to be in the range of about $150,000 to $450,000, depending on the plan considered.

12.1.4 Miscellaneous Owner Expenses

The site operator is expected to incur several miscellaneous expenses during stabilization. Estimates of these expenses are shown in Table 12.1-4.

Utility costs during stabilization are estimated at $1000 per month, or $12,000 per year. Insurance coverage is anticipated to be limited to conventional property liability insurance, assumed to cost $2000 per year. Property taxes are estimated to be about $5000 per year.

TABLE 12.1-4. Estimated Miscellaneous Owner Expenses for Stabilization

	Cost in Thousands of 1978 Dollars[(a,b)]		
	Minimal Plan	Modest Plan	Complex Plan
Western Site			
Utilities	2.5	7.0	9.0
Insurance	1.0	2.0	2.0
Taxes	2.5	5.0	5.0
Totals	6.0	14.0	16.0
Eastern Site			
Utilities	3.0	8.0	9.0
Insurance	1.0	2.0	2.0
Taxes	2.5	5.0	5.0
Totals	6.5	15.0	16.0

(a)Number of figures shown is for computational accuracy only.
(b)Contingency of 25% not included in these costs.

12.1.5 Environmental Sample Analysis Costs

Environmental sampling requirements during stabilization of the arid western site and the humid eastern site are given in Section 9.2. These requirements, together with the unit costs for environmental sample analyses given in Section H.1 of Volume 2, are used to estimate sample analysis costs for the stabilization plans considered in this study. These costs for environmental services are shown in Table 12.1-5. Costs are only estimated for normal sample analysis; costs for special analyses are not computed.

12.1.6 Records Maintenance Costs

Records maintenance costs during stabilization are estimated to be about $5000 per year. This cost includes the collection, indexing, filing, and storage of all site records.

TABLE 12.1-5. Estimated Costs of Environmental Analysis Services During Stabilization

Sample Type	Minimal Plan Total Samples	Minimal Plan Cost ($ thousands)[a,b]	Modest Plan Total Samples	Modest Plan Cost ($ thousands)[a,b]	Complex Plan Total Samples	Complex Plan Cost ($ thousands)[a,b]
Western Site						
Water	4	0.6	11	1.6	19	2.8
Air	30	2.6	87	7.4	105	8.9
Soil	20	2.3	62	7.1	74	8.5
Vegetation	1	0.1	4	0.3	4	0.3
Small Mammal	2	0.1	8	0.3	8	0.3
Game Birds	1	0.1	4	0.1	4	0.1
Fish	1	0.1	2	0.1	3	0.1
Direct Radiation	27	0.3	63	0.6	81	0.8
Totals		6.2		17.5		21.8
Eastern Site						
Water	18	2.6	53	7.7	58	8.4
Air	33	2.8	102	8.7	108	9.2
Soil	25	2.9	70	8.0	74	8.5
Vegetation	1	0.1	4	0.3	4	0.3
Small Mammal	2	0.1	8	0.3	8	0.3
Game Birds	1	0.1	4	0.1	4	0.1
Milk	3	0.4	9	1.3	9	1.3
Fish	4	0.1	12	0.4	12	0.4
Farm Crops	1	0.1	3	0.3	3	0.3
Direct Radiation	36	0.4	72	0.7	81	0.8
Totals		9.6		27.8		29.6

(a)Number of figures shown is for computational accuracy only.
(b)Contingency of 25% not included in these costs.

12.2 COST ESTIMATES FOR LONG-TERM CARE ACTIVITIES

The estimated costs for the long-term care of a stabilized LLW burial ground, based on the stabilization plans considered in this study, are summarized in Table 12.2-1. A more detailed summary, giving annual costs itemized by cost categories, is shown in Table 12.2-2. These costs are based on the long-term care activities described in Section 10.6 and on the details presented in Section H.3 of Volume 2.

A long-term care period of 200 years is assumed for this study. The annual costs of long-term care are anticipated to be greatest during the first two to three decades immediately following site stabilization. After this airborne release. Estimates of accident frequency are given as high if the occurrence of a release of similar magnitude is greater than 10^{-2}, medium if between 10^{-2} and 10^{-5}, and low if less than 10^{-5} events per year. The accidents listed in Table 13.2-5 include postulated transportation accidents, and are listed in order of decreasing magnitude of airborne release.

A summary of the 1-year dose and the 50-year committed dose equivalent to the maximum-exposed individual from accidental releases is given in Table 13.2-6. The accidents resulting in the ten highest doses to an organ of the maximum-exposed individual are listed. It should be noted that accidents involving TRU wastes lead to higher doses than accidents involving a large radioactivity release of average trench waste (inventory 3). The worst postulated accident is a severe transportation accident with a fire involving a TRU waste shipment. This accident has a low frequency of occurrence and results in a calculated 50-year committed dose equivalent to bone of 4.6 rem. A high frequency accident that is well worth mentioning is the exhumation of undetected TRU waste. Burial records may prove to be inaccurate, and core drilling may not detect all TRU waste pockets. An unexpected TRU exhumation is calculated to result in a 50-year committed dose equivalent to bone in the maximum-exposed individual of about 36 mrem. Thus, the consequences of this accident underline the need for accurate radiation monitoring methods during complete trench exhumation operations.

13.2.3 Nonradiological Public Safety

Since no major operations involving decontamination chemicals are planned, the spread of chemical pollutants from decommissioning operations is felt to be insignificant. Some of the waste in the trenches may be in a toxic chemical form, however. Little information is currently available on the hazardous chemical content of LLW waste trenches. The migration of hazardous chemicals in the environment is a very serious concern, as shown by recent events at chemical waste disposal sites.(13-15) It is beyond the scope of this study to attempt an environmental analysis of the impact of hazardous chemical migration from LLW burial trenches. Still, it is felt that such an analysis should be undertaken in the future to further understand the potential problems involved with decommissioning an LLW burial site.

TABLE 13.2-6. Summary of Radiation Doses to the Maximum-Exposed Individual from Decommissioning Accidents[(a)]

Operation/Incident	Reference Radionuclide Inventory Number[(b)]	Airborne Release (Ci)	Estimated Frequency of Occurrence[(c)]	First-Year Dose (mrem) Total Body	First-Year Dose (mrem) Bone	Fifty-Year Committed Dose Equivalent (mrem) Total Body	Fifty-Year Committed Dose Equivalent (mrem) Bone
Waste Relocation							
Severe Transportation Accident (TRU)	4	3.1 x 10	Low	6.1 x 10	1.4 x 10	2.0 x 10	4.6 x 10
Exhumation of Undetected TRU Waste	4	1.1 x 10	High	4.8 x 10	1.6 x 10	1.6 x 10	3.6 x 10
Waste Package Handling (TRU)	4	5.6 x 10	Low	2.4 x 10	5.5 x 10	7.8 x 10	1.7 x 10
Onsite Transportation Accident	3	1.0 x 10	Medium	8.9 x 10	6.3 x 10	3.5 x 10	5.3 x 10
Severe Transportation Accident (non TRU)	3	1.5 x 10	Medium	1.3 x 10	9.1 x 10	5.1 x 10	7.7 x 10
Minor Transportation Accident (TRU)	4	3.1 x 10	Low	6.1 x 10	1.4 x 10	2.0 x 10	4.6 x 10
Failure of HEPA Filters	4	7.2 x 10	Low	3.1 x 10	7.2 x 10	1.0 x 10	2.3 x 10
Spontaneous Combustion of Wastes	3	1.7 x 10	Medium	3.1 x 10	2.2 x 10	1.2 x 10	1.9 x 10
Trench Void-Space Collapse	3	4.7 x 10	Medium	8.6 x 10	6.1 x 10	3.4 x 10	5.2 x 10
Site Stabilization							
Trench Void-Space Collapse	3	4.7 x 10	Medium	8.6 x 10	6.1 x 10	3.4 x 10	5.2 x 10

(a) Inhalation doses only.
(b) Reference radionuclide inventory numbers refer to the radionuclide mixtures in Tables 1.4-1 through 1.4-4.
(c) Frequency of occurrence. High 1 x 10 ; Medium 1 x 10 to 1 x 10 ; Low 1 x 10 events per year.

13.3 OCCUPATIONAL SAFETY

Occupational safety impacts of decommissioning operations include estimates of the effects of both radiological and nonradiological events. This section summarizes occupational radiation doses and provides estimates of worker injuries and fatalities from industrial-type accidents.

Radiation doses to decommissioning workers are based on external exposure rates calculated using the computer codes ISOSHLD(16,17) for non-TRU waste forms and PUSHLD(18) for TRU waste forms. Manpower and time requirements used to calculate occupational doses are taken from the detailed work plans for site stabilization and waste relocation, summarized in Sections 10 and 11. Details of occupational dose calculations are found in Appendix I.

13.3.1 Radiological Occupational Safety

Occupational radiation doses include contributions from external exposure to radioactivity and from inhalation of radioactive dust. Inhalation doses to decommissioning workers are expected to be negligible for site stabilization and long-term care, since these operations do not normally involve direct contact with buried waste or contaminated soil. However, waste relocation operations may involve the generation of dust containing radioactive particulates, and these operations could result in substantial inhalation doses. The waste relocation options described in Section 11 assume the use of respiratory equipment (bubble suits or face masks) to minimize inhalation doses from those operations having significant potential for the generation of airborne radioactivity.

Estimated external occupational radiation doses are summarized in Table 13.3-1. For waste relocation, occupational dose data for waste exhumation/packaging are shown separately from data for all other decommissioning operations, because most of the external dose to decommissioning workers is associated with the exhumation operation. An estimate of the average dose per decommissioning worker for each decommissioning option is shown in the table. This average is simply the total dose per option divided by the total number of workers involved. The average dose calculated in this manner does not account for cases where workers may overlap effort (i.e., a member of the core drilling crew may later become a member of the waste exhumation crew). The estimated average worker dose per quarter from external radiation is also given in the table, and is obtained by dividing the total average worker dose by the fractional quarters worked.

The data in Table 13.3-1 show that external exposure doses to decommissioning workers from site stabilization and long-term care operations are expected to be small. However, waste exhumation can be a very costly operation in terms of external radiation exposure to decommissioning workers. The original work estimates made in Section 11 may have underestimated the number of workers that would be required for waste relocation operations, to keep individual occupational doses within the limits defined by regulations. To lower the occupational doses to a reasonable 2 rem/quarter, in keeping with ALARA principles, more than one worker would have to perform some of the tasks that are implicitly assigned to one individual in the operating crew estimates given in Tables 11.2-3, 11.3-3, and 11.4-2.

The occupational doses shown in Table 13.3-1 do not include contributions from inhalation of airborne radioactivity. To demonstrate the importance of inhalation as an occupational exposure pathway, the following example calculation is made of the total worker dose from both external radiation and inhalation for the case of exhumation of an entire burial trench.

TABLE 13.3-1. Summary of Occupational Doses for LLW Burial Ground Decommissioning Operations[a]

Option/Operation	Total Personnel	Duration of Option/Operation (days)	Total Personnel Dose (man-rem)	Average Dose to a Worker (rem)[b]	Estimated Average Quarterly Worker Dose (rem/quarter)[c]
Waste Relocation[d]					
Slit Trench					
Waste Exhumation/Packaging	6	72	35		
All Other Operations	11	80	0.1		
Totals	17	152	35	2.1	0.9
TRU Waste Exhumation					
Waste Exhumation/Packaging	6	40	120		
All Other Operations	18	35	1.3		
Totals	24	75	120	5.0	4.2
One Complete Burial Trench					
Waste Exhumation/Packaging	22	42	250		
All Other Operations	19	82	12		
Totals	41	124	260	6.3	3.2
Site Stabilization[e]	20 to 60	50 to 180	0.12 to 1.9	0.01 to 0.1	~0.05
Long-Term Care[e,f]	4	250	0.06 to 0.27	0.01 to 0.07	~0.01

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[a] The only exposure pathway considered is external exposure.

[b] Values in this column are determined by dividing total doses by total personnel required, assuming that no worker performs more than one task.

[c] The estimated average rem/quarter is obtained by dividing the average worker dose by the fractional quarters required.

[d] Detailed dose information for waste relocation operations is found in Tables I.2-1 through I.2-3 of Volume 2.

[e] A range is shown, since the specific value is a function of the site and the plan used to stabilize the site.

[f] Annual dose values are listed.

Using ICRP methodology,(19) the weekly dose permitted to an organ of reference (L^x) for a worker exposed to both inhalation of airborne radionuclides and external gamma radiation sources can be allocated according to the following mathematical relationship:

$$L^x = R^x_\gamma + L^x \left[\frac{C_1}{(MPC)^x_{a,1}} + \ldots \frac{C_n}{(MPC)^x_{a,n}} \right] \qquad (13.1)$$

where:

L^x • the average permitted weekly dose to organ x, (rem)

R^x_γ • the external weekly gamma dose from the mixture of radionuclides, (rem)

C_1 • the airborne concentration of radionuclide 1 in the mixture, (μCi/m^3)

$(MPC)^x_{a,1}$ • the maximum permissible concentration of radionuclide 1 in air for organ x, (μCi/m^3)

C_n • the airborne concentration of radionuclide n in the mixture, (μCi/m^3)

$(MPC)^x_{a,n}$ • the maximum permissible concentration of radionuclide n in air for organ x, (μCi/m^3).

Compliance with the weekly dose limit for situations involving both inhalation and external exposure can be demonstrated if the following condition is met for all organs of reference:

$$\frac{R^X_Y}{L^X} + \left[\frac{C_1}{(MPC)^x_{a,1}} + \ldots + \frac{C_n}{(MPC)^x_{a,n}}\right] \leq 1 \qquad (13.2)$$

In applying Equation 13.2 to the case of complete trench exhumation, ten radionuclides from reference radionuclide inventory 3 (Table I.4-3 of Appendix I) are selected for analysis. The radionuclides selected comprise about 95% of the radioactivity in inventory 3, as well as transuranic isotopes of biological concern. The air concentration in the work area is calculated using a localized mechanical mixing resuspension factor of 10^{-4} m^{-1}. This is believed to be a realistically conservative average of the literature values summarized in Table 13.2-1. An effective depth of 0.01 m is assumed, and water sprays are assumed to reduce the air particulate concentration by a factor of 10. The resulting air concentration for the mixture is calculated to be 2.9 x 10^{-7} Ci/m^3. The airborne concentration of each radionuclide is found using the concentration ratios from reference inventory 3. Airborne concentrations for individual radionuclides and ICRP values of the $(MPC)_a$ for total body, bone, and lung are listed in Table 13.3-2.

The external weekly dose to the average worker during complete trench exhumation is found from Table 13.3-1 to be 0.25 rem/week. This value is close to weekly dose limits for workers in the nuclear industry, which are 0.1 rem/week

TABLE 13.3-2. Maximum Permissible Concentrations in Air for Total Body, Bone, and Lung[(a)]

Radionuclide	Airborne Concentration ($\mu Ci/cm^3$)[(b)]	MPC_a ($\mu Ci/cm^3$)		
		Total Body	Bone	Lung(c)
^{60}Co	2.4×10^{-10}	4×10^{-7}	---[(d)]	9×10^{-9}
^{63}Ni	1.9×10^{-7}	4×10^{-7}	6×10^{-8}	3×10^{-7}
^{90}Sr	3.0×10^{-10}	2×10^{-9}	1×10^{-9}	5×10^{-9}
^{129}I	5.9×10^{-13}	2×10^{-7}	2×10^{-5}[(e)]	7×10^{-8}
^{137}Cs	5.5×10^{-8}	6×10^{-8}	2×10^{-7}	1×10^{-8}
^{238}U	6.4×10^{-11}	2×10^{-9}	6×10^{-10}	1×10^{-10}
^{238}Pu	2.7×10^{-11}	1×10^{-11}	2×10^{-12}	3×10^{-11}
^{239}Pu	3.8×10^{-12}	1×10^{-11}	2×10^{-12}	4×10^{-11}
^{241}Pu	7.3×10^{-10}	8×10^{-10}	9×10^{-11}	4×10^{-8}
^{241}Am	2.3×10^{-11}	2×10^{-11}	6×10^{-12}	1×10^{-10}

(a) MPC_a values are for a 40-hour work week and are from Reference 19.
(b) Based on a total air concentration of 2.9×10^{-7} $\mu Ci/cm^3$ of reference radionuclide inventory 3.
(c) Insoluble values are used.
(d) No value is given in Reference 19.
(e) Calculated from Total Body $(MPC)_a$ by multiplying by the ratio of acceptable dose limits (Total Body to Bone) and the ratio of organ mass (Bone to Total Body), and dividing by the ratio of the amount of material in bone to the material in total body.

for total body, 0.56 rem/week for bone, and 0.30 rem/week for lung.(20) As discussed above, work procedures would need to be altered for this case to ensure radiological safety during this exhumation operation. However, in this example calculation 0.25 rem/week is used as the external dose for comparison with the inhalation dose to decommissioning workers.

Using an average external dose value of 0.25 rem/week and the airborne concentration and $(MPC)_a$ values from Table 13.3-2, weekly doses from trench exhumation are compared with weekly dose limits using Equation 13.2. The summation of the ratios of air concentration to $(MPC)_a$, the ratio of external dose to weekly organ dose limit, and the resulting organ dose criteria are given in Table 13.3-3.

The organ dose criteria listed in Table 13.3-3 are all considerably greater than 1, indicating that exposure levels calculated for the average worker in this example are far too high. The most restrictive dose criterion is found for the bone, where the dose from inhalation and external exposure is about a factor of 31 times higher than the acceptable weekly dose.

TABLE 13.3-3. Occupational Dose Compliance Results for Complete Trench Exhumation

Organ	Summation of the Ratios of Air Concentration to $(MPC)_a$	Ratio of Weeekly External Dose to Weekly Organ Dose Limit	Total Dose Criteria[(a)]
Total Body	6.7	2.5	9.2
Bone	31	0.45	31
Lungs	8.1	0.83	8.9

(a)The total dose criterion is the sum of the two terms of Equation 13.2. Compliance with occupational dose limits is assured if the total dose criterion is less than 1.

The inhalation dose is the major contributor to the total dose criterion as shown by the data in Table 13.3-3. Calculation of the inhalation dose is highly dependent on the air concentration used. Since the resuspension model assumed for this example may either overestimate or underestimate site specific air concentrations, measurements of airborne radioactivity during waste exhumation will be required. This example calculation demonstrates that inhalation may be an important occupational exposure pathway, and that several organs, besides total body, need to be considered when determining compliance with occupational limits.

The results of this example calculation indicate that work conditions different from those considered in Section 11 may be required to reduce occupational exposure during waste relocation operations. The inhalation dose can be reduced by maintaining water sprays that are more effective than the ones assumed in this study, or by requiring the use of face masks or other respiratory protection. For the example calculation, a reduction of the inhalation dose by a factor of 100 (by the use of face masks or more effective water sprays) would bring this dose into compliance with regulatory limits. However, the external dose would also need to be reduced. Some effective ways to reduce external exposure include reducing exposure times, adding shielding to equipment, and using remote operations.

13.3.2 Nonradiological Occupational Safety

The potential exists for worker injuries and fatalities as a result of nonradiological accidents during decommissioning operations. As with any industrial operation, proper management and industrial safety practices during decommissioning can minimize the occurrence of worker accidents. Estimates of worker injuries and fatalities are based on data from the U.S. AEC for the period 1943-1970.(21) Table 13.3-4 contains a listing of estimated worker injuries and fatalities for exhumation of: 1) a slit trench, 2) a package of TRU waste, and 3) one burial trench, for a range of work categories broken down by accident potential.(22) As shown in the table, about 4×10^{-2} worker injuries are expected while exhuming a slit trench, about 2×10^{-2} injuries while removing a package of TRU waste, and about 8×10^{-2} injuries while relocating an entire trench. In all cases, the probability for accidental death to a worker is low ($<1.0 \times 10^{-3}$).

Estimates of the numbers of injuries and fatalities to workers during site stabilization and long-term care are shown in Table 13.3-5. A range of casualty numbers is presented based on manpower requirements for the stabilization and long-term care plans described in Section 10. During site stabilization, the expected number of injuries is less than 4×10^{-1} and the expected number of fatalities is less than 2×10^{-3}. During long-term care, the number of injuries expected annually is less than 4×10^{-2} and the number of fatalities expected annually is less than 2×10^{-4}.

13.4 TRANSPORTATION SAFETY

During waste relocation, radioactive material is exhumed from a burial trench and transported to a new disposal location. The new location may be another trench at the same burial ground or an offsite shallow-land or deep geologic disposal site. All waste shipments are assumed to be made by truck. The distance from a decommissioned burial ground to another shallow-land or deep geologic disposal site is assumed to be 2400 km.

TABLE 13.3-4. Estimated Occupational Lost-Time Injuries and Fatalities from Waste Relocation Operations

Activity	Frequency of Accidents Per 10^6 Man-hours		Exhume Slit Trench			Remove TRU Waste			Exhume Entire Trench		
	Injuries	Fatalities	Man-hours[a]	Injuries	Fatalities	Man-hours[a]	Injuries	Fatalities	Man-hours[a]	Injuries	Fatalities
Heavy Construction	10.0	0.042	2 160	2.2×10^{-2}	9.1×10^{-5}	1 000	1.0×10^{-2}	4.2×10^{-5}	5 620	5.6×10^{-2}	2.4×10^{-4}
Maintenance and Light Construction	5.4	0.030	2 010	1.0×10^{-2}	6.0×10^{-5}	600	3.2×10^{-3}	1.8×10^{-5}	1 960	1.1×10^{-2}	5.9×10^{-5}
Surveillance and Operational Support	2.1	0.023	2 702	5.7×10^{-3}	6.2×10^{-5}	1 600	3.4×10^{-3}	3.7×10^{-5}	3 900	8.2×10^{-3}	9.0×10^{-5}
Totals				3.8×10^{-2}	2.1×10^{-4}		1.7×10^{-2}	9.7×10^{-5}		7.5×10^{-2}	3.9×10^{-4}

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[a] Number of figures shown is for computational accuracy only.

TABLE 13.3-5. Estimated Occupational Lost-Time Injuries and Fatalities from Site Stabilization and Long-Term Care[a]

Activity	Frequency of Accidents per 10^6 Man-hours		Site Stabilization			Long-Term Care[b]		
	Injuries	Fatalities	Man-hours[c]	Injuries	Fatalities	Man-hours[c]	Injuries	Fatalities
Heavy Construction	10.0	0.042	1 920 to 28 400	1.9×10^{-2} to 2.8×10^{-1}	8.1×10^{-5} to 1.2×10^{-3}	360 to 3 120	3.6×10^{-3} to 3.1×10^{-2}	1.5×10^{-5} to 1.3×10^{-4}
Maintenance and Light Construction	5.4	0.030	960 to 18 600	5.2×10^{-3} to 1.0×10^{-1}	2.9×10^{-5} to 5.6×10^{-4}	240 to 860	1.3×10^{-3} to 4.6×10^{-3}	7.2×10^{-6} to 1.6×10^{-5}
Surveillance and Operational Support	2.1	0.023	280 to 960	5.9×10^{-4} to 2.0×10^{-3}	6.4×10^{-6} to 2.2×10^{-5}	800 to 2 400	1.7×10^{-3} to 5.0×10^{-3}	1.8×10^{-5} to 5.5×10^{-5}
Totals				2.5×10^{-2} to 3.8×10^{-1}	1.2×10^{-4} to 1.8×10^{-3}		6.6×10^{-3} to 4.1×10^{-2}	4.0×10^{-5} to 2.1×10^{-4}

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[a] Ranges are shown for the various options shown in Table H.2-2 for site stabilization and Tables H.3-1 and H.3-2 for long-term care.
[b] Numbers are based on annual requirements for long-term care.
[c] Number of figures shown is for computational accuracy only.

This section summarizes the radiological effects of routine transportation operations and the radiological and non-radiological impacts of transportation accidents. The analysis of transportation safety is based on shipment information for waste relocation summarized in Section H.4 of Volume 2. Assumptions that form the basis of the radiological portion of the safety analysis and calculational details are given in Section I.3 of Volume 2.

13.4.1 Radiological Effects of Routine Transportation Operations

Shipments of exhumed waste from the decommissioned burial ground are made in exclusive-use trucks. Department of Transportation (DOT) regulations(23) set limits on radiation levels associated with radioactive material shipments. The method used to estimate radiation doses to transportation workers and the general public from routine transportation operations is based on that used in WASH-1238(24) and in NUREG-0170.(25)

Estimated direct radiation doses from routine truck transport of radioactive wastes from the decommissioned burial ground are given in Table 13.4-1. This table summarizes the information presented in Table I.3-2 of Volume 2. Doses to the public are the same for shipments to both the deep geologic repository and an alternate shallow-land burial ground, since the shipping distances are assumed to be the same. Onlookers include persons at truck stops and service attendants. Doses to the public are not calculated for onsite shipments, since these shipments do not use public highways.

13.4.2 Radiological Effects of Postulated Transportation Accidents

Estimated airborne release quantities, frequencies of occurrence, and maximum-exposed individual radiation doses from selected accidents involving truck shipment of wastes from a decommissioned burial ground are shown in Table 13.2-6. The radioactive inventories for the accidents shown in the table are reference inventory 3 (average burial trench waste) and reference inventory 4 (TRU waste). The 50-year committed dose equivalents to the bone of the maximum-exposed individual are estimated to be 4.6 rem for a severe accident involving TRU waste and 4.6 mrem for a minor accident involving TRU waste. A severe accident involving reference radionuclide inventory 3 is estimated to result in a 50-year committed dose equivalent to the bone of the

TABLE 13.4-1. Estimated Accumulated Radiation Doses from Routine Waste Shipments

	Doses			
Shipment Origin	Maximum-Exposed Individual (rem)[a]	Population (man-rem)	Truck Drivers (man-rem)	Onlookers[b] (man-rem)
Slit Trench				
West Site	1.1×10^{-5}	1.7×10^{-1}	1.8×10^{1}	2.0×10^{0}
East Site	1.1×10^{-5}	5.0×10^{-1}	1.8×10^{1}	2.0×10^{0}
TRU Waste				
West Site	1.2×10^{-7}	1.8×10^{-3}	2.0×10^{-1}	2.2×10^{-2}
East Site	1.2×10^{-7}	5.5×10^{-3}	2.0×10^{-1}	2.2×10^{-2}
Complete Trench				
West Site	2.0×10^{-4}	3.3×10^{3}	9.9×10^{1}	2.2×10^{1}
East Site	2.0×10^{-4}	9.8×10^{3}	9.9×10^{1}	2.2×10^{1}

(a)All shipments are assumed to follow the same route; therefore, the maximum-exposed individual along the route is exposed to all shipments.
(b)Onlookers include persons at truck stops and service attendants.

maximum-exposed individual of only 0.08 mrem. A complete discussion of these and other transportation accidents is given in Section I.3 of Volume 2.

13.4.3 Nonradiological Transportation Safety

For any transport operation, a potential exists for injury or death from transportation accidents. Table 13.4-2 contains injury and fatality estimates for transportation operations associated with slit trench, TRU waste, or entire trench exhumation. The number of casualties for each decommissioning mode is calculated by finding the product of the round-trip distance, the probability of accidents per vehicle kilometer, and the injuries or fatalities expected per accident. Distances traveled per shipment and the number of shipments for each mode are given in Table I.3-1 of Volume 2. Expected frequencies of accidents are from Table I.3-3. The expected numbers of injuries and fatalities per accident are from Reference 24 (Appendix C, Table 1).

As shown in Table 13.4-2, the option of relocating an entire trench offsite could result in two to three nonradiological injuries. For no cases would a fatal injury be expected, and for the other options even the probability of nonfatal injury is slight. For all cases, results are identical for the western and eastern sites because the number of shipments and the shipment distances are assumed to be the same.

TABLE 13.4-2. Estimated Nonradiological Injuries and Fatalities from Transportation Accidents

Waste Relocation Option	Probability (Accidents per Vehicle km)	Injuries per Accident	Fatalities per Accident	Round Trip Distance (km)	Estimated Nonradiological Transportation Accidents	
					Injuries	Fatalities
TRU Waste	1.1×10^{-6}	0.51	0.03	4.8×10^{3}	2.7×10^{-3}	1.6×10^{-4}
Slit Trench	1.1×10^{-6}	0.51	0.03	4.3×10^{5}	2.4×10^{-1}	1.4×10^{-2}
Entire Trench (offsite)	1.1×10^{-6}	0.51	0.03	4.7×10^{6}	2.6×10^{0}	1.5×10^{-1}
Entire Trench (onsite)	5.5×10^{-7}	0.51	0.03	1.2×10^{3}	3.4×10^{-4}	2.0×10^{-5}
Entire Trench (Backfill)	5.5×10^{-7}	0.51	0.03	4.5×10^{3}	1.3×10^{-3}	7.4×10^{-5}

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14.0 DISCUSSION OF RESULTS

The results of this study to evaluate the technology, costs, and safety of decommissioning a low-level waste (LLW) burial ground are discussed in this section and are compared with results from other decommissioning studies on low-level waste burial grounds.

14.1 RESULTS OF THIS STUDY

Two decommissioning options are considered in this study: 1) site stabilization with long-term care, and 2) waste relocation.

Site stabilization involves the use of engineered procedures to reduce the rate and extent of radionuclide migration from buried wastes left in place after site closure. Site stabilization is followed by a period of long-term care during which administrative control of the site is maintained and surveillance and maintenance procedures are performed to ensure the continued waste containment capability of the site. Long-term care continues until the radioactivity at the site has decayed to where the wastes no longer pose a significant radiological hazard.

Waste relocation involves exhumation of the buried waste, repackaging it if necessary, and reburial at another waste disposal site or in another trench on the same site. For reasons discussed below, waste relocation would likely be considered only in situations where site stabilization and long-term care are not sufficient to ensure the capability of the site to provide adequate containment of the buried waste.

Major conclusions from this study are listed below. Each of these conclusions is discussed in detail in the sections that follow. The conclusions are:

1) Decommissioning of an LLW burial ground can be accomplished using currently available technology.
2) Decommissioning costs are significantly higher for waste relocation than they are for site stabilization and long-term care. Waste management costs (costs of packaging, shipping, and disposal of the exhumed waste) are the controlling costs for waste relocation.

3) Site stabilization and long-term care of an LLW burial ground can be accomplished with no significant impact on the safety of the general public. The impact of waste relocation operations on the safety of the general public is estimated to be small. Site stabilization and long-term care operations result in modest radiation exposure of decommissioning workers. However, waste relocation operations result in significant radiation exposure of decommissioning workers.

4) Several improvements could be made in the design and operation of LLW burial grounds to facilitate decommissioning these facilities.

5) Because of higher dollar costs and large occupational doses associated with waste relocation, the preferred mode for decommissioning an LLW burial ground is site stabilization with long-term care. Perhaps the only viable release option for existing sites that contain significant inventories of long-lived radioisotopes is conditional release with land use restrictions and administrative control of the site. To permit unrestricted release following the decommissioning of future burial grounds, it may be necessary to limit the types and quantities of radionuclides buried at these sites. Limitation of the radionuclide content of LLW burial grounds is a condition that requires further study.

14.1.1 Decommissioning Technology

A major conclusion from this study is that the technology exists for decommissioning an LLW burial ground. Decommissioning can be accomplished using techniques and equipment that are in common industrial use.

A variety of techniques exists for stabilizing a site against radionuclide transport mechanisms. These stabilization techniques are described and estimates of their effectiveness in dealing with specific transport mechanisms are given in Section 10. Effectiveness estimates are largely subjective and are based on engineering judgement. The ability of some stabilization techniques to provide the desired protection from potential transport mechanisms (e.g., techniques for erosion control, for vegetation management, or for reducing the contact of buried wastes by percolating water) has not yet been adequately demonstrated. Additional research on the adequacy and effectiveness of site stabilization procedures is needed.

The analysis of waste relocation from a single burial trench, presented in Section 11.4, is based on the use of conventional earthmoving equipment and techniques. The analysis assumes that TRU-contaminated waste has been located and selectively exhumed prior to the start of earthmoving operations. Therefore, a work enclosure is not postulated for this operation. This may oversimplify the problem of waste relocation from old trenches at existing sites. In some of these trenches, the distribution of TRU waste is diffuse and burial records are inaccurate and incomplete, thus making the location of TRU waste packages extremely difficult. In an extreme case of relocation of the waste from an old trench in which it is not possible to identify and selectively exhume the TRU waste, it might be necessary to utilize a work enclosure for the entire exhumation operation, with workers wearing bubble suits. This could significantly prolong the time required to exhume the trench, resulting in an increase in radiation exposure to decommissioning workers and an increase in the dollar cost of waste relocation.

14.1.2 Costs of Decommissioning

For the plans evaluated in this study, stabilization of a site is estimated to cost from $0.5 million to $7.7 million in 1978 dollars, depending on the location of the burial ground and on the stabilization plan chosen. Long-term care costs are estimated to be about $100,000 annually, with higher annual costs during the first 2 or 3 decades after site stabilization because of greater environmental monitoring and site maintenance requirements during the years immediately following site closure. Total costs of site stabilization plus long-term care for 200 years are estimated to be in the range of $20 million to $30 million in 1978 dollars. Costs of relocation of the waste from an entire burial ground are estimated to be in excess of $1.4 billion. Waste relocation costs are therefore about two orders of magnitude greater than the costs of site stabilization plus long-term care (for 200 years).

Waste management costs (costs of packaging, shipping, and disposal of the exhumed waste) represent about 93% of the total cost of burial ground waste relocation. Some of the waste is assumed to be reburied at another shallow-land diposal site, with the remainder of the waste shipped to deep geologic disposal. Since a deep geologic waste repository has not operated in this country, waste disposal charges for such a facility are speculative. Deep geologic disposal charges assumed in this and other studies are about one order of magnitude higher than charges for shallow-land burial.

14.1.3 Public and Occupational Safety

Because site stabilization does not involve direct contact with buried waste, the impact of normal stabilization activities on public safety is estimated to be insignificant. Decommissioning workers receive modest exposures to external radiation during site stabilization.

Waste relocation is postulated to result in airborne releases of radioactivity, and radiation doses to the maximum-exposed individual and to the total population within 80 km of the reference site are calculated in this study for these postulated releases. Estimated doses to members of the public from complete trench exhumation are between 3 and 6 orders of magnitude greater than slit trench or TRU waste exhumation doses. (TRU waste exhumation is postulated to take place inside an enclosure designed to limit the spread of airborne contamination.) Exhumation of the waste from a single burial trench is estimated to result in a first-year dose to the bone of the maximum-exposed individual of about 12 mrem and a 50-year committed dose equivalent to the bone of the maximum-exposed individual of about 80 mrem. While these doses appear high, they are only a fraction of the doses that this same individual would receive from natural background radiation over the same time periods. Population dose calculations for complete trench exhumation reflect the same results as seen for the maximum-exposed individual with an estimated 50-year committed dose equivalent to the bone of about 70 man-rem.

A wide spectrum of accidents, including both decommissioning and transportation accidents, is considered for the waste relocation cases analyzed in this study. Reasonable assumptions are made leading to estimated airborne releases of radioactivity and resulting radiation doses to the maximum-exposed individual. An estimate of the frequency of occurrence of these accidents is also made. Results shown in Table 13.2-6 indicate that some accidents, especially those postulated to occur during the transportation of exhumed waste, have the potential for resulting in a significant radiation dose to the maximum-exposed individual.

Occupational radiation doses from waste relocation operations include contributions from inhalation of radioactive dust and from external exposure to radioactivity. Relocation of the waste from an entire burial trench is an operation with a significant potential for the generation of airborne radioactivity. For this operation, an example calculation indicates that the inhalation dose is the major contributor to the total occupational radiation dose. The inhalation dose can be reduced by maintaining water sprays on the face of the excavation and by requiring the use of face masks or other respiratory protection. Exhumation of TRU waste is also an operation with a significant potential for the generation of airborne radioactivity. In this study, bubble suits are assumed to be worn by all workers engaged in TRU waste exhumation operations.

External occupational doses are estimated to be about 35 man-rem for exhumation of high beta-gamma radioactivity waste from a slit trench, about 120 man-rem for exhumation of a package of TRU waste from a burial trench, and about 260 man-rem for complete relocation of the waste from a burial trench. The high external radiation dose from TRU waste exhumation results from the fact that workers are confined within an excavation pit and work enclosure where a significant gamma background from non-TRU waste exists (principally from ^{60}Co and ^{137}Cs). Because the work is performed inside an enclosure by workers wearing bubble suits, the work proceeds at a relatively slow pace, resulting in long periods of exposure.

The number of workers assigned to operating crews for the waste relocation operations described in Tables 11.2-3, 11.3-3 and 11.4-2 is based solely on personnel requirements for efficient performance of the work. Estimates of the average worker dose per quarter indicate that using work requirements as the sole criterion for determining crew size results in an underestimate of the number of workers required. If individual occupational doses are to be kept within the limits defined by regulations, additional workers will be required. To limit occupational exposure, more than one individual would perform some of the tasks that are implicitly assigned to one person in the operating crew estimates given in Section 11. The alternative would be to develop remote capabilities for the exhumation and repackaging of buried waste, with equipment operators working from shielded enclosures.

14.1.4 Facilitation of Decommissioning

Several factors related to burial ground design and operation have a significant influence on decommissioning procedures and costs. Among the most important factors are site selection, trench design, waste segregation practices, and records management.

Careful site selection allows reliable estimates to be made of decommissioning needs and facilitates the evaluation of the effectiveness of decommissioning activities. Geologic and hydrologic conditions at proposed sites should be simple enough to permit reliable estimates to be made of radionuclide residence times and of potential radionuclide migration pathways. Experience at existing commercial and DOE sites has demonstrated that care in site selection and in the location and design of burial trenches should substantially reduce the need for extensive trench repairs and site stabilization procedures, permitting the use of relatively simple and less costly decommissioning alternatives.

Waste segregation is practiced to a degree at some existing burial grounds. Wastes could be segregated according to half life or potential hazard (i.e., TRU content or high total or specific radioactivity). Segregation of long-lived and/or hazardous wastes could significantly reduce the magnitude and cost of the decommissioning effort by making it possible to restrict certain decommissioning procedures to specific areas of the burial ground where such wastes are buried. Engineered storage could be provided for wastes likely to require relocation at some future time.

Burial ground records include the operating history of the site, radionuclide inventory data, and environmental surveillance data. These records provide an important tool for planning and carrying out decommissioning operations. The importance of accuracy and completeness of burial ground records cannot be overemphasized. Records should be preserved in such a way that they are available for the entire period of administrative control of the site and should be in a form that facilitates processing by automatic data processing equipment.

14.2 COMPARISON WITH OTHER STUDIES

Studies have been made at both Morehead (Maxey Flats), Kentucky, and West Valley, New York, to determine the costs of decommissioning and long-term care of the commercial LLW burial grounds at these sites. Cost data from the Maxey Flats and West Valley studies are summarized in this section and compared with cost data from this (PNL) study.

14.2.1 Morehead, Kentucky

A recent news release(1) states that a Kentucky state advisory committee estimates that maintenance costs at the Morehead (Maxey Flats) site could run as high as $350,000 per year. The site occupies about 134 hectares in eastern Kentucky. No information is given in the news release about the nature of the maintenance activities planned for the site. However, one ongoing activity is the pumping of water from some of the burial trenches and the processing of this water through an evaporator system.

14.2.2 West Valley, New York

In February, 1978, the Congress of the United States instructed the Department of Energy to conduct a study of options for the future of the Western New York Nuclear Service Center at West Valley, New York. The published results of this study(2) include recommended options for the New York state-licensed burial grounds that were operated by Nuclear Fuel Services, Inc. on 8.9 hectares of the West Valley site. The two options considered for the LLW burial ground are 1) extended care, and 2) exhumation and shipment of the waste to a federal repository.

The extended-care option for West Valley involves the permanent closing of the burial area and provisions for the monitoring and maintenance necessary for the long-term protection of the public. A confirmatory assessment of site conditions would be performed to assure erosion stability, radioactivity retention, and water infiltration resistance. Security procedures would be limited to provision and maintenance of a perimeter barrier consisting of a 2.4-m-high chain-link fence topped with barbed wire. Trench water, ground water, soil, and vegetation would be sampled on a quarterly basis and analyzed for gross alpha, gross beta, and gross gamma activity. Monthly inspections would be made of the area to detect any intrusion, erosion, or subsidence. Eroded areas and depressions resulting from subsidence would be filled with soil during these inspections and the vegetative cover restored. The vegetative cover would be mowed three times annually to prevent the growth of large plants whose roots might reach the wastes. Costs for this extended-care option would be limited to those associated with installation of the additional fencing and with site monitoring, maintenance, and surveillance. The initial site suitability studies and the fence are estimated to cost about $110,000. Monitoring, maintenance, and surveillance costs, including the amortized cost of replacing the fence every 15 years, are estimated to be about $40,000 per year.

The exhumation option at West Valley would begin with a detailed survey of the site, which would include a record search and a program of core sampling to identify potential radiological and nonradiological hazards. Large-scale retrieval equipment would be used for the actual exhumation. Uncontaminated soil would be removed to within about 0.5 m of the top of the wastes, and the wastes would be exhumed in bulk. Drums and boxes would not be handled individually but would be placed in 5.6-m^3 liners, along with loose waste, contaminated soil, and wastes generated by the retrieval operations. All exhumation procedures would be performed within a mobile double-walled building. Exhumed wastes (about 164,000 m^3) would be transported by rail in reusable overpacks to a federal repository 4,800 km distant. Disposal costs are based on deep geologic disposal of low-level transuranic wastes.

The total time required for waste relocation operations, including planning and procurement, site characterization, and waste exhumation, is estimated to be about 10 years. The total cost of waste exhumation at the West Valley site is estimated to be about $570 million. About 93% of this cost is associated with the transport and disposal at a federal repository of the exhumed waste. A cost summary is presented in Table 14.2-1.

14.2.3 Comparison of Costs

Care must be exercised in comparing decommissioning cost estimates from this PNL study with the cost estimates from the Morehead and West Valley

TABLE 14.2-1. Summary Cost Estimate for Exhumation of the State-Licensed Burial Ground at West Valley (from Reference 2)

Item	Cost ($ millions)[a]
Preliminary Requirements	0.4
Records Review	
Trench Surveys	
Engineering and Design	1.9
Capital	1.6
Facilities	
Equipment	
Operations	31.8
Labor and Equipment	
Fuel	
Waste Transport	115.8
Waste Disposal	416.1
Facility Decommissioning	(<0.1)
Total[b]	570

(a)Costs are in 1978 dollars.
(b)Total rounded to two significant figures.

studies. Because of differences in site characteristics and in decommissioning objectives and procedures, a direct comparison is not possible.

On a unit cost basis, the initial site stabilization cost for the West Valley site is estimated to be about $12,000/ha. Stabilization costs for the PNL study for the eastern reference site range from about $7,000/ha for the minimal plan that assumes stabilization of burial trenches as they are filled to about $56,000/ha for the modest plan and $80,000/ha for the complex plan. The modest and complex stabilization plans for the PNL study require considerably more decommissioning activity than that described in Reference 2 for the West Valley site.

Annual costs of long-term care are estimated to be about $2,000/ha for Morehead, about $4,500/ha for West Valley, and to range from about $1,900/ha to $5,200/ha for the eastern reference site of the PNL study (depending on the prior stabilization option and on the elapsed time since site closure).

Waste relocation costs are estimated at about $63 million/ha for the West Valley study and at about $28 million/ha for the PNL study. Both the West Valley study and the PNL study conclude that waste management (packaging, shipment and disposal of exhumed waste) is the cost-controlling factor in estimating the total cost of waste relocation from an LLW burial ground.

Both the PNL study and other studies have shown that the costs, in both dollars and occupational exposure, are significantly higher for waste relocation than they are for site stabilization and long-term care. A report by the Committee on Radioactive Waste Management of the National Academy of Sciences(3) has warned that waste exhumation is a difficult and costly operation, and that the exhumation of wastes not originally buried with intent of later retrieval might be more hazardous to man and to the environment than if the wastes were left in place. Waste relocation would therefore likely be considered only in situations where other decommissioning procedures are not adequate to assure that future risk from the burial ground is within acceptable bounds.

REFERENCES

1. Nucleonics Week, Vol. 19, No. 43, October 26, 1978.
2. Western New York Nuclear Service Center Study, TID-28905 (2 volumes), U.S. Department of Energy, Washington, DC, November 1978.
3. Committee on Radioactive Waste Management, The Shallow Land Burial of Low-Level Radioactively Contaminated Solid Waste, TID-27341, National Research Council/National Academy of Sciences, Washington, DC, 1976.

15.0 DESIGN CONSIDERATIONS, OPERATING PRACTICES, AND RESEARCH NEEDS TO FACILITATE DECOMMISSIONING

Several factors that would facilitate the decommissioning of low-level waste (LLW) burial grounds are considered in this section. These factors can be conveniently grouped into three categories: 1) design considerations, 2) operating practices, and 3) research needs.

Design considerations, discussed in Section 15.1, include procedures for site selection and criteria for the design and construction of burial trenches.

Operating practices, discussed in Section 15.2, refer to waste form and packaging requirements, waste burial practices, and records maintenance procedures.

Research needs, discussed in Section 15.3, refer to technical issues that require attention to ensure that LLW burial sites are properly decommissioned. A recent Department of Energy (DOE) report(1) outlines research needs in several areas where investigations could improve the operational and post-operational characteristics of existing and future LLW burial grounds. The discussion of research needs in Section 15.3 is confined to two broad areas where additional research could facilitate the decommissioning of LLW burial grounds. These areas (which overlap to some extent the research areas discussed in Reference 1) are 1) site/waste stabilization procedures, and 2) modeling techniques used to predict release conditions for LLW burial grounds after burial operations cease.

15.1 DESIGN CONSIDERATIONS

Design considerations to facilitate decommissioning include criteria for site selection and for the design and construction of burial trenches.

Site selection refers to measures to ensure that a burial site meets prescribed geologic, hydrologic, and demographic criteria. Several recent reports on LLW burial grounds have included discussions of burial ground siting.(2-4) Careful site selection allows reliable estimates to be made of decommissioning needs and facilitates the evaluation of the effectiveness of decommissioning activities. Geologic and hydrologic conditions at a proposed site should be simple enough to permit reliable estimates to be made of radionuclide residence times and of potential radionuclide migration pathways. If water is a potentially significant radionuclide transport mechanism, the burial zone should be separated from zones through which water can move with relative ease (e.g., sand lenses or fractured bedrock) by an interval of geologic deposits sufficient to prevent significant migration of radionuclides into these more porous zones. The demography and the projected land use of the area around a site should be carefully considered in the site selection process to ensure reliable estimates of potential radiation doses to the population in the vicinity of the site.

Several existing LLW burial grounds have not proven totally effective in waste containment.(5,6) Efforts have been initiated to develop conceptual designs for burial trenches that would improve the waste containment capability of these structures.(1,7,8) These efforts include the design of trench caps to minimize the infiltration of moisture into trenches and the design of surface and subsurface diversion systems to drain water away from buried wastes. Care in the design and construction of burial trenches should improve their waste containment capability, thereby substantially reducing the need for costly trench repairs and stabilization procedures when a site is closed.

15.2 OPERATING PRACTICES

Some operating practices at LLW burial grounds that might reduce the requirements for decommissioning at the time of facility shutdown are discussed in References 1, 4, and 8 through 10. Operating practices to facilitate decommissioning include waste-form and packaging considerations, waste burial practices, and records maintenance procedures.

Waste-form and packaging considerations important to decommissioning include the standardization of waste form and packaging requirements for buried wastes, the compaction of wastes prior to burial, and the chemical immobilization of complexing agents. Standardization of waste forms and packages would facilitate the placement of waste in a burial trench. This could have several desirable consequences, including 1) reduction of void spaces, with consequent reduction in subsidence rates, 2) aid in future relocation of waste, should this be necessary, and 3) possible simplification of waste migration analysis. Compaction of wastes prior to burial could reduce the incidence of trench cap subsidence. Chemical immobilization of complexing agents could reduce radionuclide migration rates.

Two important related burial practices that could significantly affect decommissioning requirements and influence land use decisions following site closure are waste segregation and the use of engineered storage. Waste segregation is already practiced to a degree at some existing burial grounds. Radioactive wastes could be segregated according to half-life, so that those wastes with long decay periods (e.g., greater than 30 years) are not intermingled with short-half-life materials. Wastes requiring special handling (e.g., wastes with high TRU content or high radioactivity sources) could also be segregated from other wases. In conjunction with these segregation requirements, it would be necessary for a site operator to reject shipments that are not properly identified. Segregation of long-lived and/or hazardous wastes could significantly reduce the magnitude and cost of decommissioning by making it possible to limit certain decommissioning procedures to those specific areas of the burial ground where such wastes are buried.

Some wastes may require relocation at a future time. Engineered storage (either above or below ground) could be provided for these wastes. Burial would be restricted to wastes whose radioactive content would not be of concern after an extended period (e.g., 200 years) of administrative site control.

Burial ground records can be conveniently classified into three categories:

1. burial ground operating history
2. radionuclide inventory data
3. environmental surveillance data.

Records in these categories provide information essential to planning and implementing site decommissioning and long-term care activities.

The burial ground operating history includes information about periodic site inspections, maintenance activities, and stabilization activities during the operating lifetime of a site. All stabilization procedures should be carefully documented. Radionuclide inventory data include information about quantities, forms, and locations of radioactive waste buried at the site. Environmental surveillance data include information about sampling locations and frequencies, analyses of environmental samples, and data evaluation to determine the adequacy and effectiveness of confinement systems or to demonstrate compliance with applicable regulations concerning releases to the environment.

The importance of accuracy and completeness of burial ground records as an aid to the planning and performance of burial ground decommissioning cannot be overemphasized. Guidance for improving the content and quality of burial ground records is contained in References 3 and 11. Recommendations include:

1. Duplicate records should be made and filed with more than one record bank.
2. Records should be of a form that can be handled by automatic data processing equipment.
3. All burial grounds should adopt a uniform records format.
4. Records must be available for the length of time that a burial ground will require human attention.

The U.S. Nuclear Regulatory Commission (NRC) has recently prepared a Low-Level Waste Branch Position titled "Low-Level Waste Burial Ground Site Closure and Stabilization."(12) The Branch Position describes performance objectives that should be met by a site operator to prepare a site for transfer to a custodial government agency. These performance objectives include the following provisions:

- eliminate the potential for erosion or loss of site or trench integrity due to factors such as ground water, surface water, wind, subsidence, and frost action
- demonstrate that the rate of release of radionuclides through the air and ground or surface water pathways are at or below acceptable levels

- render a site suitable for surface activities during custodial care
- stabilize the site in a manner to minimize environmental monitoring requirements and to eliminate the need for active water management measures
- compile and transfer to the custodial agency complete records of site maintenance and stabilization activities, trench elevations and locations, trench inventories, and monitoring data obtained during the operating phase of the site
- document arrangements for the orderly transfer of site control to the government custodian for long-term care.

With these performance objectives as a basis, it is anticipated that a site operator will take appropriate measures during the operating lifetime of the burial ground to minimize the need for extensive decommissioning procedures when waste burial operations cease.

15.3 RESEARCH NEEDS

Several technical issues require attention to ensure the proper decommissioning of LLW burial grounds after waste disposal operations cease. In this section, research needs related to site/waste stabilization techniques and to the improvement and verification of models used to define release conditions for a decommissioned site are described.

Existing commercial burial grounds, some of which may require decommissioning in the near future, provide an excellent arena for research to improve the technical information base regarding decommissioning. The development of confidence in engineering techniques for burial ground stabilization and the validation of pathway analysis models could lead to the possible future release of these sites on a conditional or unrestricted use basis.

15.3.1 Site/Waste Stabilization

Engineered techniques for the stabilization of LLW burial grounds are described in Section 10.1.2. Site/waste stabilization plans that incorporate these techniques are described in Section 10.3 for the reference western site and in Section 10.4 for the reference eastern site. The selection of appropriate techniques for burial ground stabilization involves a consideration of many factors including site characteristics, operating practices during waste disposal operations, and the effectiveness and cost of specific techniques.

Many site/waste stabilization techniques are still in the developmental stage. Research is needed to assess the effectiveness of candidate techniques, to determine their useful lifetimes, and to evaluate costs of implementation and maintenance. Some information about specific stabilization procedures is available.(9) However, much of the analysis of Section 10 is based on engineering judgement. Further research must be performed to develop confidence in the use of engineered procedures for burial ground stabilization. Examples of needed research in the areas of site revegetation and of surface and subsurface barriers are described below.

Revegetation of tailings piles, strip-mined areas, and waste burial sites is a common technique for erosion control. Studies have been reported of methods for establishing vegetative cover to aid in the reclamation of nonradioactive mineral ore waste heaps.(13,14) Research on the revegetation of LLW burial sites has also been reported.(15,16)

Objectives of desirable revegetation methodologies for which additional information is needed include:

- Selection of appropriate species and development of methods for the rapid revegetation of disturbed land surfaces to minimize wind/water erosion.
- Selection of vegetation species that maximize near-surface soil moisture utilization, thus reducing moisture seepage into burial zones.
- Selection of shallow-rooted species to minimize biological uptake of radioactive contaminants.
- Establishment of a plant cover that is capable of long-term survival with a minimum of anticipated maintenance within the range of environmental conditions anticipated at the site which might include drought, fire, and known plant diseases.

Field studies of revegetation are needed for a range of climatic conditions and soil properties. Long-range considerations such as plant succession must be examined to evaluate the possible importance of such problems as deep-rooted plant species invading a burial site with subsequent uptake and transfer of radionuclides to the bioshere.

Surface or subsurface barriers (rock, asphalt, bentonite clay, etc.) represent a technique to prevent plant and animal intrusion and to control the infiltration of moisture into burial trenches. The use of surface and subsurface barriers is a well-developed technology for many industrial and agricultural applications such as industrial effluent containment, seepage control, and moisture conservation. However, the application of this technology to long-term waste management is difficult because of the many unique, and sometimes conflicting, requirements for burial ground stabilization. Barriers must be effective in controlling the penetration of plant roots and animals into contaminated zones. They must also be effective in controlling the movement of soil moisture. They should have a long life and require a minimum of maintenance. They should perform within design specifications for the complete range of environmental conditions anticipated at the site. Barrier flexibility requirements related to compaction and settling of the waste and cover materials must be defined. The optimum degree of waste compaction and surface seal compaction should be established. Potential advantages and disadvantages of placing the barrier at or below the land surface should be explored.

An example of research to determine the capabilities and limitations of a particular type of engineered surface barrier is the study of the suitability of bentonite clay to prevent the infiltration of rainwater into buried waste.(17) The study concluded that a 1-inch-thick layer of bentonite significantly reduced the infiltration of rainwater into the test area. To protect the layer from excessive drying and cracking, a 2-ft-thick soil cover was required. The subsurface bentonite layer has little resistance to penetration by plant roots, hence it is not an effective biobarrier.

Properly placed deflectors may be useful in directing surface and/or groundwater flow. Engineered structures have been used for this purpose at the LLW burial grounds at Oak Ridge National Laboratory in Tennessee.(10) Where the use of deflectors is contemplated, site-specific studies will be required to address such factors as optimum materials for construction, curtain shape, and curtain placement for various waste burial configurations. Methods of directing ground water by use of physical entities such as secondary trenches need to be explored. Pipe drain networks designed to direct water flow down and away from buried radioactive waste should be investigated.

A comparative investigation of the relation between burial site characteristics and waste containment is not known to be underway at present. The results of corrective actions taken in the past to prevent loss of buried contaminants should be analyzed and incorporated into future studies of the effectiveness and cost of erosion and intrusion control barriers.

Results of research into burial ground stabilization techniques have applicability both to the decommissioning of existing LLW burial sites and to the design of future sites.

15.3.2 Models for Analysis of Radionuclide Transport

Since the late 1960s, mathematical models have been used to predict radionuclide transport in hydrologic systems. The radionuclide transport models used to develop release conditions for LLW burial grounds are described in Sections 8.1.2, 8.4, and C.2.4. The modeling analysis of Section 8 uses state-of-the-art methodology to predict radionuclide migration via ground and surface water pathways and to estimate doses to a maximum-exposed individual from radioactivity leached from an LLW burial ground.

Uncertainties in pathway modeling, described in Section 8.1.2, point to the need for additional research in this area. Models need to be upgraded and verified, and more realistic values for the parameters used with the models (e.g., distribution coefficients, leach times, etc.) need to be determined. Research to improve and verify the models is discussed in this section. Research to provide better values for model parameters is described in the following section.

Research needs related to the development of models for predicting radionuclide migration from LLW burial grounds via water pathways can be summarized as follows:

1. Development of more realistic transport models for evaluating radionuclide migration via the groundwater pathway
2. Development of transport models for overland flow
3. Verification of models by comparison of predicted values with experimental results for real sites.

To mathematically simulate radionuclide transport by ground water through a geologic medium, certain assumptions are made. These assumptions, which make the problem tractable to mathematical analysis, often oversimplify the models and may lead to erroneous results. Modeling assumptions relate generally to the homogeneity of the medium and to the rates at which reactions occur within the medium. The assumptions usually include the following:

1. the geologic formation can be represented as a continuous, homogeneous medium
2. the medium is saturated with water
3. exchange reactions of nuclides between the geologic medium and the solution are reversible
4. nuclide-medium reactions are instantaneous so that equilibrium of the nuclide between solution and geologic medium is locally maintained within the medium
5. the concentration of each nuclide is sufficiently small that nuclides react independently of each other and do not affect the macroscopic properties of the solution.

Given these simplifying assumptions, nuclides are expected to migrate through the medium with a well-defined velocity. Dispersion is accounted for by a single dispersion coefficient that results in a Gaussian distribution in the concentration of radioactive material with time at a given point in the medium.

An experimental program developed at the Argonne National Laboratory(18) has provided some information on the migration behavior of nuclides in aqueous solution-rock systems and has tested some of the simplifying assumptions of current radionuclide migration models. The program utilized three types of experiments: column infiltration, static absorption and desorption, and batch partitioning. The conclusion of the Argonne study was that the observed behavior of migrating nuclides in these experiments could not be accurately described by models that predict a single migration rate based on simple absorption properties and local chemical equilibrium. A dispersive model of fluid flow was needed to accurately characterize the skewed distribution of migrating nuclides observed in the column-distribution experiments. Static absorption experiments indicated that the reaction rates of nuclides in solutions and rocks vary greatly for different rock-nuclide systems. Therefore, for a solution containing several nuclides and moving through rock, conditions of local equilibrium may exist for some nuclides and not for others. Thus, models of nuclide migration need to provide for the reaction rates of individual nuclides.

The chemical mechanisms involved in groundwater transport of radionuclides are a function of the chemical form of the waste, the groundwater quality, and the mineralogy of the geologic formation through which transport is occurring. In addition, radionuclide movement is strongly influenced by the degree of water saturation in the flow system and by whether the flow is homogeneous or is occurring primarily in fractures. Thus, the transport of radioactivity away from a burial ground is affected by many site-specific factors that are difficult to model.

Measurements at the LLW burial grounds at Oak Ridge National Laboratory(19) indicate that in some instances of radionuclide migration there is a much greater and more rapid movement of radioactivity away from burial trenches than is predicted on the basis of a simple migration model. Possible reasons for an observed rate of radionuclide migration greater than the predicted rate include: 1) lack of contact of radionuclides in water flowing in a fracture with the soil or rock formation (water in the central portion of the opening does not interact with the shale walls of the fracture), 2) the presence in the soil of competing cations that fill adsorption sites that might otherwise be available for radionuclide adsorption, 3) the presence in the waste of chelating agents that form complexes with the radionuclides and increase the mobility of these ions, and 4) chemical reactions that change the oxidation state of an ion, thereby changing its mobility.

There are no well-established models for treating overland flow. For this study, the MMT model(20) was used with conservative assumptions about leach times, flow paths, and sorption of radionuclides onto the ground surface. (See Section C.2.4.1 for details.) Because of the possibility of an unusually heavy rainfall inundating a burial site and leaching radionuclides from the buried waste, a model is needed that realistically treats the problems of overland flow.

Little attention has been given to the verification of transport models by field tests at existing sites. In part, this is because of the lack of an appropriate experimental apparatus for monitoring waste burial sites to assess the influence of environmental factors on radionuclide migration rates. Some beginning steps have recently been taken to correct this deficiency. A program is underway at Pacific Northwest Laboratory to develop geohydrologic monitoring systems to evaluate burial sites located in arid regions.(21) A field test facility has been designed and constructed to assess the migration of radionuclides and water in the partially saturated groundwater zone of arid shallow-land radioactive waste burial sites. The project has developed new monitoring devices to determine mass balance and energy transfer in addition to integrating existing monitoring components into an overall monitoring system. The test facility is used as a source of information to verify predictions of water and radionuclide transport through the geologic media pathway.

15.3.3 Transport Model Parameters

Large uncertainties exist in the values of some parameters such as soil permeability, dispersion coefficients, distribution coefficients, and leach rates used in current models to simulate radionuclide migration via the groundwater pathway. Examples of the range of values reported in the literature for some of these parameters are given in Section C.2.4.1 of Appendix C. Because of these uncertainties, an attempt was made to use conservative parameter values in the analysis of burial ground release conditions described in Section 8. Examples of research needs to reduce the uncertainties in transport model parameter values are given below.

Research is needed to identify and quantify differences between field and laboratory measured values of distribution coefficients. Because of the difficulty of field measurement of K_d, values determined by laboratory measurements are normally used in models to calculate the groundwater transport of radionuclides. However, the application of laboratory measurements to field situations is of questionable validity. Measured values of the distribution coefficient depend strongly on the physical and chemical conditions of measurement. Among other variables, soil type, nature of the solution, and chemical form of the radioactive species are important. Several authors(22-24) have emphasized the importance of actual field measurements to verify the values of distribution coefficients used in radionuclide transport modeling.

In a cooperative program with the NRC and the U.S. Geological Survey, Brookhaven National Laboratory is conducting a study(22) to characterize the waters that accumulate in trenches and wells at commercially operated low-level radioactive waste disposal sites. Work in progress or planned for this investigation includes the measurement of K_d dependencies on actual trench water and burial ground soils. The Brookhaven work on the migration of radionuclides is an example of the kind of site-related research needed to characterize the parameters that affect rates of radionuclide migration from burial grounds.

A study was performed at Los Alamos Scientific Laboratory(23) to obtain information on radionuclide retention and migration in soils as a function of soil type and radionuclide species. The study showed that the K_d value is a function not only of soil type but also of the physical form and chemical species of the migrating radionuclide and of the solid-to-liquid ratio in the medium through which material is moving. In using laboratory values of K_d, the assumption is made that the value of the distribution coefficient is independent of the solid-to-liquid ratio. In practice, however, equilibrium is rarely attained in an environmental system. Evidence suggests that K_d is not independent of the solid-to-liquid ratio.(23) This has profound impact when measuring K_d in the laboratory using a 2-part liquid to 1-part solid ratio and then applying that data to a system of water flow in a similar soil or geologic medium where the effective water-to-soil ratio may be 1 to 100.

Research is needed to determine the effect of complexing agents on the modification and transport of radionuclides from LLW burial grounds. Studies of the migration of radioactivity from seepage pits and burial trenches at the Oak Ridge National Laboratory(25) have indicated that ethylenediaminetetraacetic acid (EDTA) is forming complexes with ^{60}Co and causing the migration of this radionuclide from disposal facilities. The studies indicate that K_d values for ^{60}Co in Conesauga shale may be reduced by 3 or 4 orders of magnitude as a result of the complexing action of EDTA. Because it forms extremely strong complexes with rare earths and actinides, EDTA or similar chelates may also be contributing to the mobilization of these radioncuIides from other LLW burial sites throughout the country.

Large quantities of organic wastes (e.g., scintillation liquids, solvents, and liquids used for decontamination) are disposed of in shallow-land burial grounds. Many of these organic chemicals are complexing agents that can affect the leachability, solubility, and movement of radionuclides. Literature and field surveys should be undertaken to determine the types and quantities of complexing agents that are disposed of in LLW burial grounds and to identify and assay the species of radionuclide complexes present in trench leachates. (Some research on organic complexes in trench leachates is being performed in the Brookhaven study described in Reference 22.)

Research is needed to determine leach rates for specific radionuclides under field conditions. Published leach rate data come mainly from laboratory experiments in which small samples are leached by distilled water or by actual or simulated disposal environmental water. Leach rates should be examined with respect to variability with soil type, leaching water, chemical and physical form of the buried radionuclides, and the effect of containers on reducing or delaying leaching. The effect of leach rates on radioactivity concentrations in ground and surface water in the vicinity of a burial ground is much greater for radionuclides with short half lives than it is for radionuclides with long half lives.(24)

Research is needed to determine the effects of soil microorganisms on the transport of radionuclides. Soil microbes may act either to enhance or to retard the mobility of radionuclides in buried waste. The organisms are known to solubilize various chemical elements in the soil by the production of organic and mineral acids and other byproducts that may form complexes with radionuclides or may alter the chemical conditions of the solution, such as pH, which affect solubility. Conversely, microorganisms may degrade organic material, reducing organo-radionuclide complexes and retarding the migration of the radionuclides. Very little information has been reported about the effects of soil microorganisms on the transport of radionuclides. This subject needs further investigation.

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16.0 GLOSSARY

Abbreviations, terms, definitions, and symbols directly related to burial ground decommissioning (including site/waste stabilization, waste relocation, and long-term care activities) are defined and explained in this section. The section is divided into two parts, with the first part containing abbreviations and symbols, and the second part containing terms and definitions (including those used in special context for this study). Common terms covered adequately in standard dictionaries are not included.

16.1 ABBREVIATIONS AND SYMBOLS

Abbreviations

AEC	Atomic Energy Commission
ALARA	As Low As is Reasonably Achievable(a)
ANSI	American National Standards Institute
ASWS	Air-Support Weather Shield
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations(a)
Ci	Curie(a)
DF	Decontamination Factor(a)
DOE	Department of Energy
DOT	Department of Transportation
DPM	Disintegrations per Minute(a)
EPA	Environmental Protection Agency
EWR	Early Waste Retrieval
FSAR	Final Safety Analysis Report
HEPA	High Efficiency Particulate Air (filters)(a)
HP	Health Physicist(a)
HVAC	Heating, Ventilation and Air Conditioning
IDR	Initial Drum Retrieval
INEL	Idaho National Engineering Laboratory

(a)See Section 16.2 for additional information or explanation.

KDHR	Kentucky Department for Human Resources
LASL	Los Alamos Scientific Laboratory
LLW	Low-Level Waste
LWR	Light Water Reactor
mR	Milliroentgen, see roentgen
mrad	Millirad, see rad
mrem	Millirem, see rem
MPC	Maximum Permissible Concentration(a)
MT	Metric Ton(a)
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PVC	Polyvinyl Chloride
PWR	Pressurized Water Reactor
Q.A.	Quality Assurance(a)
Q.C.	Quality Control(a)
R	Roentgen(a)
rad	Radiation Absorbed Dose(a)
rem	Roentgen Equivalent Man(a)
RSR	Radioactive Shipment Record
SNM	Special Nuclear Material(a)
SRL	Savannah River Laboratory
TLD	Thermoluminescent Dosimeter(a)
TRU	Transuranic(a)

Symbols

α	Alpha Radiation(a)
β	Beta Radiation(a)
γ	Gamma Radiation(a)
χ	Chi, Concentration, pCi/m^3
Q	Released Quantity of Radioactive Material, Ci
Q'	Release Rate of Radioactive Material, Ci/sec
$\bar{\chi}/Q'$	Chi-bar/Q prime, normalized annual average air concentration (pCi/m^3 per Ci/sec released, also written sec/m^3). Also called the annual average atmospheric dilution factor.

(a)See Section 16.2 for additional information or explanation.

16.2 GLOSSARY DEFINITIONS

Actinides:	A series of heavy radioactive metallic elements of increasing atomic number (Z) beginning with actinium (89) or thorium (90) through element hahnium of atomic number 105.
Activity:	See Radioactivity.
Adsorption:	Adhesion of ions or molecules to the surface of liquids or solid bodies with which they come in contact, adhering to a surface.
Airborne Radioactive Material:	Radioactive particulates, mists, fumes, and/or gases in air.
ALARA:	A philosophy to maintain exposure to radiation As Low As is Reasonably Achievable.
Alpha Decay:	Radioactive decay in which an alpha particle is emitted. This transformation lowers the atomic number of the nucleus by two and its mass number by four.
Alpha Particle:	A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons; hence it is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, and gamma) emitted by radioactive material.
Aquifer:	A subsurface formation containing sufficient saturated permeable material to yield significant quantities of water.
Atomic Number (Z):	The number of protons in the nucleus of an atom; also its positive charge. Each chemical element has its characteristic atomic number, and the atomic numbers of the known elements form a complete series from 1 (hydrogen) through 105 (hahnium).
Background:	That level of radioactivity from sources existing without the presence of a nuclear plant, including nonplant-related sources, such as might result from atmospheric weapons testing.
Bentonite:	A porous clay, produced by the natural decomposition of volcanic ash, that is able to absorb much water and swell greatly as a result.

Beta Decay:	Radioactive decay in which a beta particle is emitted or in which an orbital electron capture occurs.
Beta Particle:	An electron, of either positive or negative charge, that has been emitted by an atomic nucleus in a nuclear transformation.
Burial Grounds:	An area specifically designated for the subsurface disposal of solid radioactive waste. A burial ground is used to temporarily isolate the waste from man's environment.
Byproduct Material:	Any radioactive material (except source material and special nuclear material) obtained during the production or use of source or special nuclear material. Byproduct material includes fission products and other radioisotopes.
Caisson:	A vertically oriented cylindrical structure used for the subsurface disposal or storage of materials.
Cask:	A heavily shielded shipping container for radioactive materials. Some casks weigh as much as 100 metric tons.
Chemical Limits:	Maximum concentrations or quantities imposed upon chemical releases to the environment in gaseous or liquid effluents discharged from a facility, and consistent with known air or water quality standards.
Code of Federal Regulations (CFR):	The Code of Federal Regulations is a documentation of the general rules by the Executive departments and agencies of the federal government. The Code is divided into 50 titles that represent broad areas subject to Federal regulation. Each title is divided into Chapters that usually bear the name of the issuing agency. Each Chapter is further subdivided into Parts covering specific regulatory areas.
Complexing Agent:	A substance, usually organic, that forms compounds with radioactive material leached from buried waste. The usual end result of the complexing process is to increase the mobility of the radioactive material leached from the waste.
Contamination:	Undesired materials that have been deposited on the surfaces of, or are internally ingrained into, structures or equipment, or that have been mixed with another material.

Convection:	The movement of a fluid with respect to a porous medium. This movement is due to pressure differentials within the fluid, or to temperature differences at two points in the medium.
Curie:	A special unit of radioactivity. One curie equals 3.7×10^{10} nuclear transformations per second. (Abbreviated Ci.) Several fractions of the curie are in common usage: • Millicurie. One-thousandth of a curie. Abbreviated mCi (3.7×10^{7} d/s). • Microcurie. One-millionth of a curie. Abbreviated μCi (3.7×10^{4} d/s). • Nanocurie. One-billionth of a curie. Abbreviated nCi (37 d/s). • Picocurie. One-millionth of a microcurie. Abbreviated pCi; replaces the term $\mu\mu$Ci (0.037 d/s).
Custodial Safe Storage:	A minimum cleanup and decontamination effort is made initially, followed by a period of interim care with the active protection systems (i.e., ventilation, utilities, fire) kept in service. The site is secured by physical barriers and by guards against intrusion. Use of the facility and site is limited to nuclear activities.
Decay, Radioactive:	A spontaneous nuclear transformation in which a particle, gamma radiation, or x-ray radiation are emitted.
Decommissioning:	Preparations taken for retirement from active service of nuclear facilities, accompanied by the execution of program to reduce or stabilize radioactive contamination. The objective of decommissioning is to place the facility in such a condition that future risk to public safety from the facility is within acceptable bounds.
Decontamination:	Those activities employed to reduce the levels of contamination in or on structures, equipment, and materials.
Decontamination Factor (DF):	The ratio of the initial concentration of an undesired material to the final concentration resulting from a treatment process. The term may also be used as a ratio of quantities.
De minimus Level:	That level of contamination that is acceptable for unrestricted public use or access.

Design Basis: Accident:	A postulated accident believed to have the most severe expected impacts on a facility. It is used as the basis for safety analysis and structural design.
Discount Rate:	The rate of return on capital that could have been realized in alternative investments, if the money were not committed to the plan being evaluated (i.e., the opportunity costs of alternative investments). This cost is equivalent to the weighted average cost of capital.
Disintegration, Nuclear:	The transformation of the nucleus of an atom from one element to another, characterized by a definite half life and the emission of particles or radiation.
Dismantlement:	Those actions required to disassemble and remove sufficient radioactive or contaminated materials from the facility and site, to permit release of the property for unrestricted use.
Dispersion:	A process of mixing one material within a larger quantity of another. For example, the mixing of material released to the atmosphere with air causes a reduction in concentration with distance from the source.
Dispersion Coefficient:	The dispersion coefficient is a measure of the movement of a containant with respect to the fluid as it moves with the fluid through a porous medium. This coefficient takes into account movement as a result of spatial gradients, pore-water velocity distribution within the medium, eddy currents, and molecular diffusion.
Disposal:	The disposition of materials with the intent that they will not enter man's environment in sufficient amounts to cause a significant health hazard.
Disposition Criteria:	For building or sites with surface deposits, the disposition criteria are the residual radioactive contamination levels acceptable for public use of the decommissioned facility. For a burial ground where subsurface radioactive inventories remain, the disposition criteria consist of a combination of waste relocation requirements, stabilization techniques, institutional controls, and property-use restrictions for the general public. The acceptability of disposition criteria are determined based on a maximum annual dose limit.

Distribution Coefficient (k_d):	Distribution coefficient is a measure of the reaction between a particular contaminant and the chemical properties of the porous medium and the fluid. In this study, it is taken as the proportionality constant between the concentration of the sorbed contaminant on the solid phase (the porous medium) and the concentration in the fluid at equilibrium. It is expressed in units of mℓ/g.
Dose, Absorbed:	The mean energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad equals 0.01 joules/kilogram in any medium (100 ergs per gram).
Dose, Equivalent:	Expresses the amount of radiation that is effective in the human body, expressed in rems. Modifying factors associated with human tissue and body are considered. Equivalent dose is the product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. Referred to as Dose in this report.
Dose, Occupational:	An individual's exposure to radiation as a result of his employment, expressed in rems.
Dose Rate:	The radiation dose delivered per unit time and measured, for instance, in rems per hour.
Dosimeter:	A device, such as a film badge or ionization chamber, that measures radiation dose.
Enrichment:	The ratio (usually expressed as a percentage) of fissile isotope to the total amount of the element (e.g., the % of ^{235}U in uranium.)
Entombment:	The encasement of radioactive materials in concrete or other structural materials sufficiently strong and durable to assure retention of the radioactivity until it has decayed to levels that permit unconditional release of the site.
Environmental Surveillance:	A program to monitor the impact of discharges from industrial operations on the surrounding region. As used in this study, it is the program to monitor the extent and consequences of releases of radioactivity from a burial ground.
Evapotranspiration:	The loss of water from the ground by both evaporation from the soil and from the surfaces of vegetation.

Exhumation:	The process of removing buried waste from the earth by digging.
Exposure:	A measure of the ionization produced in air by x-ray or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the roentgen. (See Roentgen.)
Facility:	A burial site with its complex of trenches and equipment.
Fission:	The splitting of a heavy atomic nucleus into two lighter parts (atomic nuclides of lighter elements), accompanied by the release of a relatively large amount of energy and, generally, one or more neutrons. Fission can occur spontaneously but usually it is caused by nuclear absorption of gamma rays, neutrons, or other particles.
Fission Products:	The lighter atomic nuclides (fission fragments) formed by the fission of heavy atoms. It also refers to the nuclides formed by the fission fragments' radioactive decay.
Food Chain:	The pathways by which any material (such as radioactive material from fallout) passes through man's environment through edible plants and/or animals to man.
Fuel Cycle:	The series of steps involved in supplying fuel for nuclear power reactors and handling the spent fuel and the radioactive waste, including transportation. Head end: Mining, milling, conversion, enrichment, and fabrication of fuel. Back end: Includes reactors, spent fuel storage, spent fuel reprocessing, mixed-oxide fuel fabrication, and waste management.
Fuel Element:	A rod, tube, or other form into which nuclear fuel is fabricated for use in a reactor.
Gamma Rays:	Short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are best stopped or shielded against by dense materials such as lead or uranium. These rays usually originate from within the nucleus of the atom.

Glaciofluvial Deposit:	Sediment deposited from a river fed by a glacier.
Greenhouse:	In nuclear terms, a temporary structure, frequently constructed of wood and plastic film, used to provide a confinement barrier between a radioactive work area and a nonradioactive area.
Ground Water:	Water that exists or flows below the surface (within the zone of saturation).
Half Life Biological:	The time required for a biological system, such as a man or animal, to eliminate by natural processes half the amount of a substance that has been absorbed by it.
Half Life, Effective:	The time required for a radionuclide contained in a biological system, such as a man or animal, to reduce its radioactivity by half as a combined result of radioactivity decay and biological elimination.
Half Life, Radioactive:	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Each radionuclide has a unique half life. Measured half lives vary from millionths of a second to billions of years.
Health Physicist:	A person trained to perform radiation surveys, oversee radiation monitoring, estimate the degree of radiation hazard, and advise on operating procedures for minimizing radiation exposures.
Heavy Metal:	Jargon used in reference to metals with atomic numbers of 90 and greater. It usually refers to nuclear fissile or fertile fuels such as thorium, uranium, and plutonium.
High Efficiency Particulate Air Filter (HEPA)	An air filter capable of removing at least 99.97% of the particulate material in an air stream.
Hot Spots:	Areas of radioactive contamination higher than average.
Hydraulic Gradient:	The slope of a water table, found by determining the difference in height between two points and dividing by the horizontal distance between them.
Hydrology:	The science dealing with the waters of the earth, their distribution on the surface and underground, and the cycle involving precipitation, flow to the seas, evaporation, etc.

Immobilization:	Treatment and/or emplacement of material (e.g., radioactive contamination) so as to impede its movement.
Interim Storage:	Storage operations for which a) monitoring and human control are provided and b) subsequent action including final disposition is expected. Concepts for interim storage include bulk or compartmented storage of solid, liquid and gaseous wastes or other materials.
Intrusion Alarm:	A means of detecting intrusion of individuals into a protected area utilizing an electromechanical, electro-optical, electronic, mechanical or similar device with a visible or audible alarm signal.
Ion Exchange:	A chemical process involving the selective absorption or desorption of various chemical ions in a solution onto a solid material, usually a plastic or resin. The process is used to separate and purify chemicals, such as fission products from plutonium or "hardness" from water (i.e., water softening).
Leachability:	The susceptibility of the conditioned waste form to the removal of soluble constituents by water. These can be both radioactive nuclides and also nonradioactive constituents that form a part of the basic structure of the waste form.
Leachate:	The solution or product obtained from leaching.
Licensed Material:	Nuclear source material, special nuclear material, or nuclear byproduct material received, possessed, used, or transferred under a license issued by the Nuclear Regulatory Commission.
Loess:	Wind-deposited silt, usually accompanied by some clay and some fine sand.
Long-Lived Nuclides:	For this study, radioactive isotopes with long half lives typically taken to be greater than about ten years. Most nuclides of interest to waste management have half lives on the order of one year to millions of years.
Long-Term Care:	Refers to the period following termination of burial operations during which institutional control of the site is maintained. Activities performed during this period include environmental monitoring and routine surveillance and maintenance of the site.

Man-rem:	A measure of radiation dose. To calculate radiation dose to the population, the dose equivalent in rem received by each person in the population is summed.
Mass Number:	The number of nucleons (protons and neutrons) in the nucleus of an atom. (Symbol: A).
Maximum-Exposed Individual:	The hypothetical member of the public who receives the maximum radiation dose to an organ of reference. For the common case where exposures from airborne radionuclides result in the highest radiation exposure, this individual resides at the location of the highest airborne radionuclide concentration and eats food grown at that location.
Maximum Permissible Concentration (MPC):	The average concentration of a radionuclide in air or water to which an individual may be continuously exposed without exceeding an established standard of radiation dose limitation.
Metric Ton (MT):	1000 kilograms, or 2205 pounds.
Monitoring:	Making measurements or observations for recognizing the status or adequacy of, or significant changes in, conditions or performance of a facility or area.
Normal Operating Conditions:	Operation (including startup, shutdown, and maintenance) of systems within the normal range of facility operating parameters.
Nuclear Reaction:	A reaction involving a change in an atomic nucleus, such as fission, fusion, particle capture, or radioactive decay.
Offsite:	Beyond the boundary line marking the limits of site property.
Onsite:	Within the boundary line marking the limits of site property.
Overpack:	Secondary (or additional) external containment or cushioning for packaged materials.
Package:	The packaging plus the contents of radioactive materials.
Packaging:	The assembly of radioactive material in one or more containers and other components necessary to assure compliance with prescribed regulations.

Perched Water:	Subsurface water existing or trapped in a restricted aquifer above the active water table.
Permeability:	The capacity of a medium for transmitting a fluid.
Porosity:	The ratio of the aggregate volume of interstices in a rock soil to its total volume.
Possession-only License:	A license issued to a nuclear facility owner by the NRC entitling the licensee to own a facility containing nuclear materials but not to operate it.
Present Value of Money:	The present value of a future stream of costs or payments is the present investment necessary to secure or yield the future stream of payments, with compound interest at a given discount or interest rate.
Protective Clothing:	Special clothing worn by a person in a radioactively contaminated area to minimize the potential for contamination of his body or personal clothing.
Protective Survey:	An evaluation of the radiation and its hazards incidental to the production, use, or existence of radioactive materials. It normally includes a physical survey of the arrangement and use of equipment and measurements of the radiation dose rates under expected conditions of use. Also called protection survey.
Quality Assurance:	The systematic actions necessary to provide adequate confidence that a material, component, system, process, or facility performs satisfactorily, or as planned, in service.
Quality Control:	The quality assurance actions that control the attributes of the material, process, component, system, or facility in accordance with predetermined quality requirements.
Rad:	A unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joule/kilogram of absorbing material.
Radiation:	1) The emission and propagation of radiant energy: for instance, the emission and propagation of electromagnetic waves, or of sound and elastic waves. 2) The energy propagated through space or through a material medium: for example, energy in the form of alpha, beta, and gamma emissions from radioactive nuclei.

Radiation Area:	Any area, accessible to personnel, in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirems. (See 10 CFR 20.202.)
Radiation Background:	See background.
Radiation, Leakage (Direct):	All radiation coming from a source housing except the useful beam.
Radioactive Material:	Any material or combination of materials which spontaneously emit ionizing radiation and which has a specific radioactivity in excess of 0.002 microcuries per gram of material. (See 40 CFR 173.389(e).)
Radioactive Series:	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nonradioactive nuclide results. The first member is called the "parent," the intermediate members are called "daughters," and the final stable member is called the "end product."
Radioactivity:	The property of certain nuclides of spontaneously emitting particles or electromagnetic radiation or of undergoing spontaneous fission. The quantity of radioactivity, usually shortened to "activity," is the number of nuclear transformations occurring in a given quantity of material per unit time.
Radiological Protection:	Protection against the effects of internal and external exposure to radiation and radioactive materials.
Regulatory Guides:	Regulatory Guides are issued by the NRC to describe and make available to the public methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide other guidance to applicants for nuclear operations. Guides are not substitutes for regulations, and compliance with them is not explicitly required. Methods and solutions different from those set out in the guides may be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the NRC.
Release Agent:	The first in any series of radionuclide transport mechanisms, acting at the point of radionuclide release from a burial trench, initiating the release.

Rem:	A unit of radiation dose equivalence. The radiation dose equivalence in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.
Reporting Levels:	Those levels or parameters called out in the Environmental Technical Specifications, the Decommissioning Order, and/or the Possession-Only License that do not limit decommissioning activities, but that may indicate a measurable impact on the environment.
Repository (Federal):	A site owned and operated by the federal government for long-term storage or disposal of radioactive materials.
Restricted Area:	Any area to which access is controlled for protection of individuals from exposure to radiation and radioactive materials.
Roentgen:	A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions. One roentgen equals 2.58×10^{-4} coulombs per kilogram of air. (See also Exposure.)
Safe Storage:	Those actions required to place and maintain a nuclear facility in a condition such that future risk from the facility to public safety is within acceptable bounds, so that the facility can be safely stored for the time desired.
Saturated Zone:	The subsurface zone in which all of the interconnecting interstices(void spaces or pores) are filled with water.
Security Officer:	A guard or watchman whose primary duty is the protection of material and property.
Shield:	A body of material used to reduce the passage of particles or electromagnetic radiation. A shield may be designated according to what it is intended to absorb (as a gamma ray shield or neutron shield), or according to the kind of protection it is intended to give (as a background or thermal shield). It may be required for the safety of personnel, or to reduce radiation enough to allow use of counting instruments for research or for locating contamination or airborne radioactivity.

Short-Lived Radionuclides:	For this study, those radioactive isotopes with half lives less than about 10 years.
Shutdown:	The time during which a facility is not in productive operation.
Silt:	Sediment particles having diameters larger than 4 microns and smaller than 0.0625 mm (about the lower limit of visibility of individual particles with the unaided eye).
Site:	The geographic area upon which the facility is located that is subject to controlled public access by the facility licensee (includes the restricted area as designated in the NRC license).
Site/Waste Stabilization:	The use of engineered procedures to reduce the mobility of buried waste and to protect the waste from the effects of potential release agents.
Solid Radioactive Waste:	Material that is essentially solid and dry, but may contain sorbed radioactive fluids in sufficiently small amounts as to be immobile.
Sorption:	A general term used to encompass the processes of absorption, adsorption, ion exchange, ion retardation, chemisorption, and dialysis.
Source Material:	Thorium, natural or depleted uranium, or any combination thereof. Source material does not include special nuclear material.
Special Nuclear Material (SNM):	Plutonium, ^{233}U, uranium containing more than the natural abundance of the isotope 235 or any material artificially enriched with the foregoing substances. SNM does not include source material.
Spent Resin:	The waste ion-exchange resin used to treat liquid streams. The spent resin is generally composed of styrene copolymers in bead or powdered form.
Subsidence:	A sinking or collapse of the trench cap or ground surface, which may expose buried waste materials or contaminated soil.
Surface Contamination:	The result of the deposition and attachment of foreign materials to a surface.

Surveillance:	Those activities necessary to ensure that the site remains in a safe condition (including inspection and monitoring of the site, maintenance of access barriers to radioactive materials left on the site, and prevention of activities on the site that might impair these barriers).
Survey:	An evaluation of the radiation hazards incidental to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions.
Technical Specifications:	Requirements and limits that encompass nuclear safety but are simplified to facilitate use by plant operation and maintenance personnel. They are prepared in accordance with the requirement of 10 CFR 50.36, and are incorporated by reference into the Operating license issued by the NRC.
Thermoluminescent Dosimeter:	A chip of semiconducting material used to measure radiation doses. Absorption of energy from radiation excites the atoms in the material, resulting in the creation of free electrons and holes. Heating the crystal releases the excitation energy as light. The total amount of light emitted when the material is heated is proportional to the amount of energy absorbed from the radiation.
Till:	Nonsorted glacial drift.
Transuranic Elements:	Elements with atomic number (Z number) greater than 92.
Transuranic Waste:	Any waste material measured or assumed to contain more than a specified concentration (i.e., proposed as 10 nanocuries of alpha emitters per gram of waste, or more presently proposed as 100 nanocuries ^{239}Pu/cm^3 of waste of transuranic elements.
Vadose Zone:	The unsaturated region of soil between the ground surface and the water table.
Waste Management:	The planning and execution of essential functions related to radioactive waste (i.e., treatment, packaging, interim storage, transportation and disposal).
Waste Relocation:	The exhumation of buried waste, repackaging of the waste if necessary, and reburial of the waste at another repository or in another trench on the same site.
Wastes, Radioactive:	Equipment and materials (from nuclear operations) that are radioactive and have no further known use.

Wastes, Low-Level:	Wastes containing types and concentrations of radioactivity such that little or no shielding to minimize personnel exposure is required.
Wastes, High-Level:	Wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, in a facility for reprocessing irradiated reactor fuels. (See 10 CFR 50, App F.2.) The term is also applied generally to radioactive wastes of other origins, where the rate of heat evolution becomes of concern in waste disposal or the external radiation dose rates are extremely high.
Wastes, Intermediate-Level:	All other radioactive wastes (other than low- and high-level wastes as defined above).
Water Table:	The upper boundary of an unconfined aquifer below which saturated ground water occurs. Defined by the levels at which water stands in wells that barely penetrate the aquifer.
X-ray:	A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (characteristic x-rays) or when a metal target is bombarded with high speed electrons. X-rays are always non-nuclear in origin; i.e., they originate external to the nucleus of the atom.

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Technology, safety and cost information is presented for the conceptual decommissioning of a reference low-level waste burial grounds, both on a dry and wet site. Two basic approaches to decommissioning, stabilization followed by at least 200 years of surveillance and disinterment, were studied to obtain comparisons between costs and occupational radiation doses, potential dose to the public and other safety impacts.

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