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Alternative Methods for Disposal of Low-Level Radioactive Wastes

Task 1: Description of Methods and Assessment of Criteria

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ABSTRACT

The study reported herein contains the results of Task 1 of a four-task study entitled "Criteria for Evaluating Engineered Facilities." The overall objective of this study is to ensure that the criteria needed to evaluate five alternative low-level radioactive waste (LLW) disposal methods are available to the Nuclear Regulatory Commission (NRC) and the Agreement States. The alternative methods considered are belowground vaults, aboveground vaults, earth mounded concrete bunkers, mined cavities, and augered holes. Each of these alternatives is either being used by other countries for low-level radioactive waste (LLW) disposal or is being considered by other countries or US agencies or states.

In this report the performance requirements are listed, each alternative is described, the experience gained with its use is discussed, and the performance capabilities of each method are addressed. Next, the existing 10 CFR Part 61 Subpart D criteria with respect to paragraphs 61.50 through 61.53, pertaining to site suitability, design, operations and closure, and monitoring are assessed for applicability to evaluation of each alternative. Preliminary conclusions and recommendations are offered on each method's suitability as an LLW disposal alternative, the applicability of the criteria, and the need for supplemental or modified criteria.

Detailed or conceptual designs were not developed, and cost estimates were not prepared for these methods. These tasks were outside the scope of this study. Evaluation of waste classification and waste form requirements were also beyond the scope of this study.

In general, each of the methods offers some advantages over shallow land burial in meeting the performance objectives. Although costs were beyond the scope of this study, the design, construction and operating costs for these methods probably would be higher than for shallow land burial. Site suitability requirements would be similar for all the alternatives except for mined cavities. The design of and operating procedures for each of these methods would probably be more complex than shallow land burial operations. For example, emplacement and stacking of wastes in vaults and bunkers and mined cavities may require more time and care than current shallow land burial practices. However, several underground storage facilities exist in the U. S. and abroad and show that various products may be economically and safely stored in suitable mined cavities. Above- and belowground vaults are routinely used for warehousing a wide variety of manufactured goods, meat and produce, and raw materials, and in Canada, vaults have been used for storage of low-level radioactive wastes (LLW). Use of earth mounded concrete bunkers has been demonstrated to be an effective LLW disposal method in France since 1969. Augered holes or shafts have been used in several locations in the U. S. and Canada for storage of LLW and transuranic (TRU) wastes.

Monitoring requirements, i.e., the parameters monitored and sampling frequencies would be similar for each disposal method but the techniques used may be varied to better suit the individual facility. Consideration should be given to a short-term monitoring program that could be phased out as satisfactory performance is established.

Facility closure would share some common features for each disposal method but the closure of units within the facility would be unique for each method.

With the exception of mined cavities and deep vaults, none of the methods studied is substantially different than present shallow land burial practices. Consequently, many of the criteria required to evaluate these methods were found to be consistent with those presented in 10 CFR Part 61, paragraphs 61.50 through 61.53. Suggested modifications and supplemental criteria are identified in the report.

Future efforts under this study will include development of the modified and supplemental criteria needed for complete evaluation of each alternative, guidance to license applicants on minimum submittal requirements, and development of suggested license application review procedures for use by the NRC or the Agreement States.

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1. INTRODUCTION

1.1 Background

Techniques for engineered disposal of low-level radioactive waste other than shallow land burial are likely to be introduced to the NRC or Agreement States for licensing consideration within the next two years. These techniques include (1) belowground engineered vaults, (2) aboveground engineered vaults, (3) earth mounded concrete bunkers, (4) mined cavities, and (5) augered holes.

Each of these disposal techniques has either been proposed as an alternative to shallow land burial or is currently being used or considered for use in other countries.

Shallow belowground vaults are currently being used for storage of low-level wastes (LLW) in Canada and for storage of transuranic wastes at Oak Ridge National Laboratory in Tennessee. Deep vaults in hard crystalline rock are being studied in Canada for final disposal of LLW.

Aboveground vaults are also being used in Canada for LLW storage and have been promoted by a private firm involved in waste disposal technology for disposal of LLW at the Maxey Flats site in Kentucky. Aboveground vaults are also being promoted by other groups in the U. S.

Earth mounded concrete bunkers are being used in France for disposal of low and intermediate level wastes. In Canada rectangular concrete trenches and cylindrical concrete chambers with removable covers are used for LLW storage and these may be considered as variations of the bunker concept.

Mined cavities have been used in West Germany for disposal of both low-level and high-level radioactive waste and hazardous wastes. In Sweden, construction has recently begun on a 400,000 m^3 underground repository for low- and intermediate-level radioactive wastes. The U. S. Department of Energy (DOE) and the Tennessee Valley Authority (TVA) have studied mined cavity disposal of both low-level radioactive waste (LLW) and high-level radioactive waste (HLW).

Augered hole disposal is also being studied by the DOE. In Canada variations of augered holes called tileholes are used for storage of ion exchange resins and filter cannisters. Oak Ridge National Laboratory uses augered holes for storage of LLW, and in West Germany a disposal system of boreholes in the floor of a salt mine at Gorlebon is being considered.

The status of each alternative is shown on the following page.

The NRC has established evaluation criteria for shallow land burial of low-level radioactive waste. The criteria set forth in the Code of Federal Regulations 10 CFR Part 61 Subpart D and related regulatory guidance are directed towards near-surface disposal facilities, with subsections reserved for methods other than near-surface disposal. Criteria established specifically for evaluating alternative methods of disposal have yet to be developed either as part of a statutory requirement or regulatory guidance.

Status of Alternative Methods

Alternative	Status
Belowground Vaults	Research: Canada, Atomic Energy of Canada, Ltd (AECL), deep vaults Whiteshell Nuclear Research Establishment (WNRE), Manitoba, Canada
	Storage: Chalk River National Laboratory (CRNL), Ontario, Canada, shallow vaults WNRE, Manitoba, Canada, shallow vaults Oak Ridge National Laboratory (ORNL), Tennessee, US, shallow vaults
Aboveground Vaults	Storage: Ontario Hydro, Bruce Site, Ontario, Canada New Brunswick Electric Power Commission, Pt Lepreau Site, New Brunswick, Canada
Earth Mounded Concrete Bunkers	Storage: Hydro Quebec, Gentilly Site, Quebec, Canada CRNL, Ontario, Canada WNRE, Manitoba, Canada
	Disposal: Centre de la Manche site, France
Mined Cavity	Research: AECL, Canada, deep vaults Sweden, Low Level Wastes (LLW) and Intermediate Level Wastes (ILW) Gorlebon, W. Germany, boreholes in mine floors in bedded salt US Department of Energy (DOE) Tennessee Valley Authority, US
	Storage and Disposal: W. Germany, Asse Salt Mine (Radioactive Waste Facility) W. Germany, Herfa-Neurode Potassium mine (Hazardous Waste Facility)
Augered Holes	Research: DOE, Nevada, US, Greater Confinement Disposal Test (GCDT) Gorlebon, W. Germany, boreholes in mine floor, bedded salt AECL, Canada, boreholes in glacial till
	Storage: ORNL, Tennessee, US Los Alamos National Laboratory (LANL), New Mexico, US Ontario Hydro, Ontario, Canada Bruce site "tileholes" CRNL, Ontario, Canada, "tileholes"

It is reasonable to anticipate that any or all of these disposal concepts may be proposed as alternative methods to shallow land burial either for facilities to be licensed by the NRC or by Agreement States.

Therefore, it is important that the NRC establish uniform criteria by which these engineered facilities may be evaluated and that such criteria are compatible with the minimum performance objectives set forth in 10 CFR Part 61, Subpart C. Criteria must be considered for site suitability, design, operation, closure, and monitoring requirements.

The NRC requested that the Waterways Experiment Station (WES) assist it in the evaluation of existing criteria relative to these alternative methods, and if necessary, to assist it in the development of modified or supplemental criteria. NRC entered into an interagency agreement with WES for this purpose on 31 May 1983.

1.2 Purpose and Scope

The overall purpose of this study is to ensure that uniform criteria required to completely evaluate these five alternative methods of low-level radioactive waste disposal are available to NRC and the Agreement States. Criteria related to site suitability, design, operations, closure and monitoring, as contained in 10 CFR Part 61, Subpart D, are to be assessed for each alternative. If necessary, criteria will be modified and supplemental criteria will be developed.

This report lists the performance requirements which must be met by any LLW disposal facility and describes the five alternative methods for low-level radioactive waste disposal mentioned previously. The performance capabilities of each method are addressed, and existing criteria contained in paragraphs 61.50 through 61.53 of Subpart D of 10 CFR Part 61 are assessed for applicability to the evaluation of each alternative.

This study addresses only these technical requirements and related performance capabilities.

Development of guidance for acceptable waste form or waste classifications for disposal by any of these methods was outside the scope of this study. Development of site-specific or conceptual designs were also not part of this study. Neither were cost estimates prepared or reported for any of these disposal concepts.

It is recognized that guidance on acceptable waste forms and classifications and conceptual designs would be useful to individuals or agencies considering these methods, and that detailed cost estimates would be an important consideration in their adoption.

However, the most important considerations are whether these methods can satisfy the performance objectives of Subpart C and how their performance can be judged. This task is the subject of the present study. Guidance on waste forms, waste classifications and conceptual designs and cost estimates would

be logical next steps after the potential for satisfaction of the performance objectives is established for each of these methods, and evaluation criteria are in place.

The study was divided into four tasks. The purpose of Task 1, reported herein, was to describe and summarize the performance capabilities of each alternative, and to assess the applicability of 10 CFR 61 Subpart D (61.50 through 61.53) criteria for evaluating each alternative. An assessment of existing criteria was considered necessary to identify whether modifications or supplemental criteria are required. Under Task 2, modified or supplemental criteria will be developed for each alternative. Task 2 will also include development of suggested guidance for minimum submittal requirements from license applicants. Under Task 3, guidance for suggested license application review procedures for use by NRC and the Agreement States will be developed. The draft reports prepared for each of the above tasks will be combined into one final project report, and published as a NUREG report in FY 85. Under Task 4 WES will provide, on an as needed basis, license application review assistance. The project and task completion schedules for Tasks 1, 2, and 3 are shown in Figure 1.

1.3 Approach

As a first step, the literature was reviewed to evaluate the performance capabilities of each alternative. This review included case histories and conceptual plans, and focused upon, but was not limited to, low-level radioactive waste disposal. The review also included literature on high-level radioactive waste studies, hazardous waste disposal feasibility studies, and general design principles and practices related to each alternative and shallow land burial.

Site visits were made to gain firsthand knowledge of the operation and management of existing facilities and to gain insight about potential advantages and/or problems. In addition, other researchers involved in radioactive and hazardous waste disposal and management studies were consulted to maintain cognizance of recent activities and the current state-of-the-art.

The existing 10 CFR Subpart D criteria were then assessed for applicability to the evaluation of each alternative with respect to the technical requirements for site suitability, design, operations, closure, and monitoring. This part of the task was accomplished by considering the similarities and differences of each alternative concept and each detailed criterion's application to the concept. Needed changes and additions were outlined and will form the basis for Task 2.

The results of this phase of the study (Task 1) are reported herein. Task 2 will include development of the modified and/or supplemental criteria required for complete evaluation of each alternative, and recommended minimum submittal requirements from license applicants. The Task 2 final draft report is scheduled for completion by 19 January 1985.

NRC Project Schedule

"Criteria for Evaluating Engineered Facilities"

USAE Waterways Experiment Station

TASK 1	TASK 2	TASK 3
1June 1983—7 January 1984	20 Jan 1984——19 Jan 1985	21 Jan 1985 ——15 April 1985
Evaluation of Alternatives & Assessment of Criteria	Development of Modified / Supplemental Criteria	Development of License Application Review Procedures Final Project Report Tasks 1,2&3

Figure 1

The Task 3 report will provide suggested license application review procedures for use by NRC or the Agreement States and is scheduled for completion by 15 April 1985.

2. ALTERNATIVE METHODS FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTES

In the following paragraphs, each alternative is described, the experience gained with its use is summarized, and performance capabilities are discussed.

It should be noted that for any method to be considered by the NRC for licensing for disposal of low-level radioactive wastes, it must be capable of satisfying the performance objectives of 10 CFR Part 61 Subpart C (paragraphs 61.40 through 61.44). These performance objectives are quoted below.

The discussion of performance capabilities of each alternative is directed toward satisfaction of these performance objectives.

"Subpart C - Performance Objectives

Paragraph 61.40 - General requirement. Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in paragraphs 61.41 through 61.44.

Paragraph 61.41 - Protection of the general population from releases of radioactivity. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

Paragraph 61.42 - Protection of individuals from inadvertent intrusion. Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

Paragraph 61.43 - Protection of individuals during operations. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter, except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Paragraph 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable.

Paragraph 61.44 - Stability of the disposal site after closure. The disposal facility must be sited, designed, used, operated, and closed to achieve long-term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

2.1 Belowground Vaults

2.1.1 Description and Experience

As used in this report, the term 'belowground vault alternative' refers to any enclosed engineered structure constructed below the surface of the earth and used for the disposal of low-level radioactive waste materials.

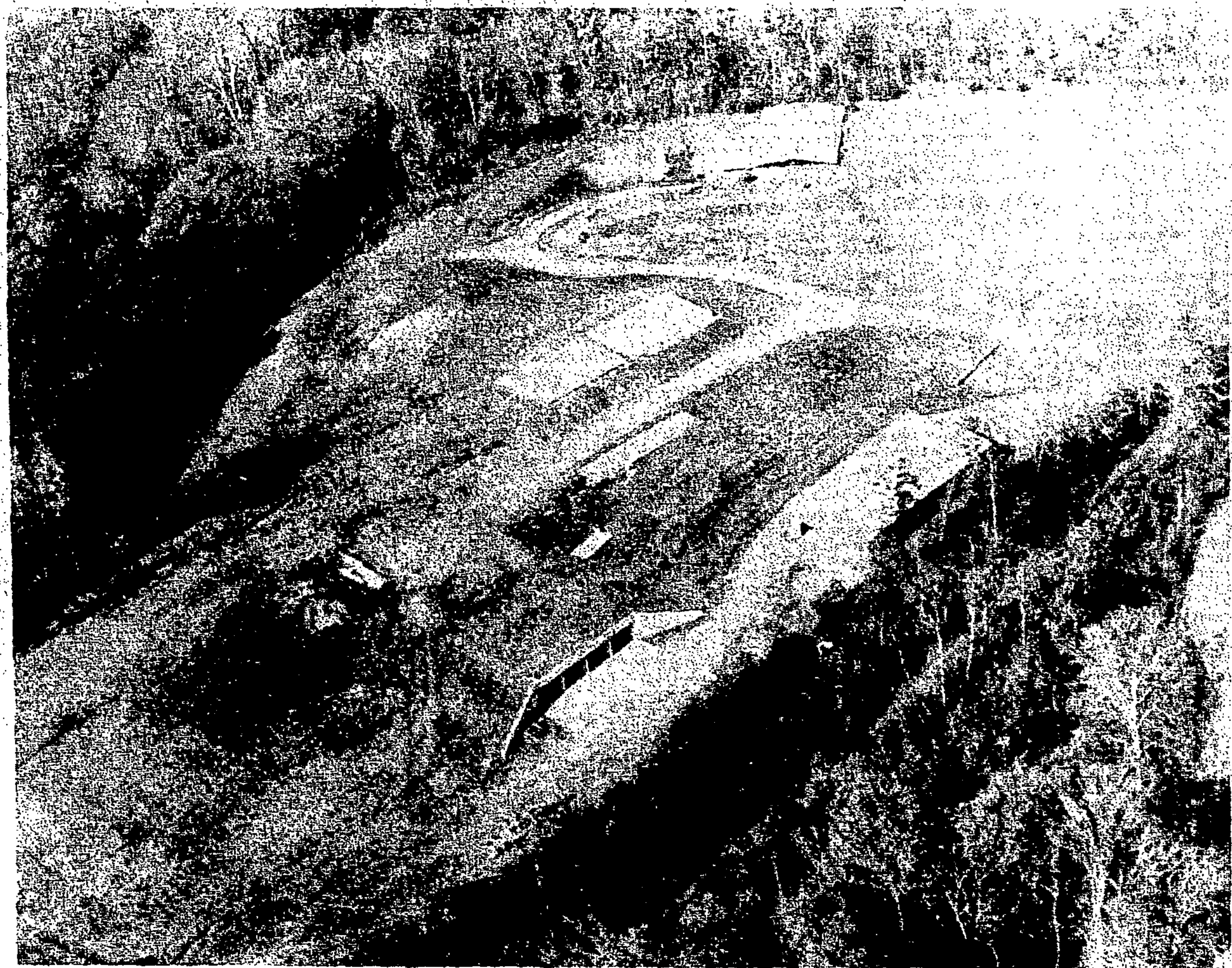
Belowground vaults are visually unobtrusive and physically secure to purposeful intrusion because of their siting below the ground surface.

Access to the foundation elevation may be directly from the earth's surface in the form of a conventional excavation in which the vault is built and then covered over. Alternatively, the belowground vault may be an engineered structure built in a mined cavity such as proposed by Atomic Energy of Canada Ltd (AECL) (Feraday, 1983) with access from a portal or shaft. However, as used in this report, a belowground vault refers to shallow vaults built by cut and cover construction methods. Deep vaults in mined cavities are included in the mined cavity alternative.

The vault structure can be built from masonry blocks, reinforced formed or sprayed concrete, fabricated metal shapes, or plastic or fluid media molded into solid shapes onsite. In terms of configuration a vault may or may not have a floor constructed of man-made materials but will be laterally bounded by constructed walls and have an intact roof structure. The architectural shape will be controlled primarily by the materials used and the stability to be achieved and may range from rectilinear to arched enclosures, to quasi-spherical dome-like structures.

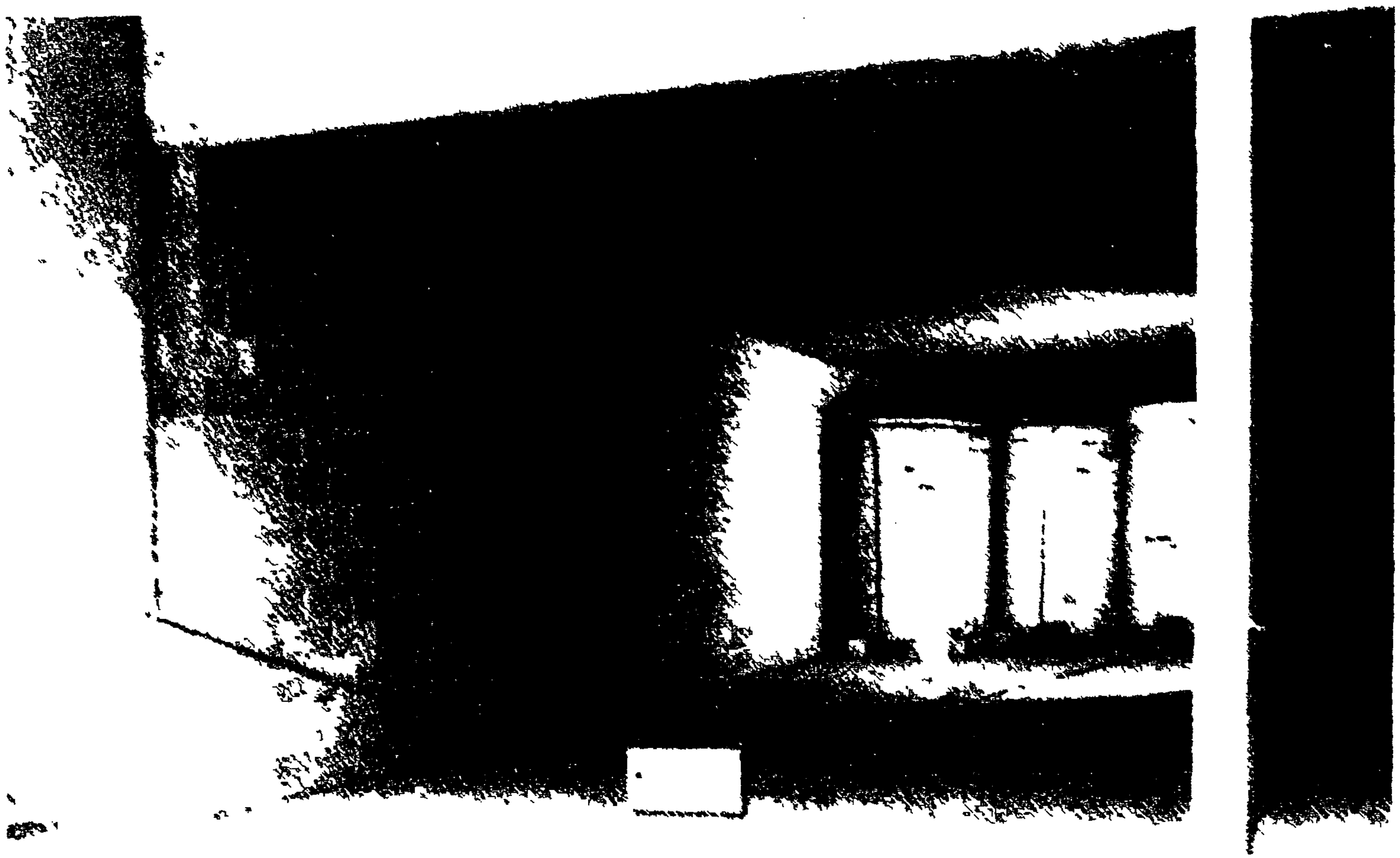
The vault, as an integrated structure, also has the characteristic of limited access to its interior space, i.e., a doorway or portal or hatch opening. However, during operations the vault may have more extensive access, depending on design.

Oak Ridge National Laboratory uses belowground vaults in its Solid Waste Storage Area No. 5. The facility is termed the 'TRU' structure and is currently used for retrievable storage of transuranic radioactive waste materials. Figure 2 is an aerial photograph of Area No. 5, showing the belowground vault in the middle foreground. The structure was not designed or built with expectation of use for long-term LLW disposal but the design does incorporate a number of features in common with the concept of a LLW belowground disposal vault. The structure is constructed with three walls, a floor, and a roof fabricated from reinforced cast-in-place concrete. Earth was placed as fill above the completed structure. In tunnel engineering terms the mode of construction was 'cut-and-cover.' Figure 3 shows waste-bearing concrete casks inside one of the bays. The bays are separated by masonry walls in this structure. Water drainage is achieved with a grate-covered floor channel in each bay and a perimeter drain system outside the vault. The floor drain carries any contaminated water to a monitored collection sump and has possible application to long-term disposal vault design. The exterior drain was not intended for monitoring but is a requirement for stability of the underground structure. The perimeter exterior drain system does not discharge in a



The belowground vault shown in the middle foreground is currently used for retrievable storage of transuranic radioactive waste. The structure was constructed from reinforced cast-in-place concrete and has earth placed as fill above the completed structure. Individual bays within the vault are separated by masonry walls.

Figure 2. Belowground Vault at the Oak Ridge National Laboratory, Solid Waste Storage Area No. 5. Source: Photograph courtesy of Oak Ridge National Laboratory.



The concrete casks shown within the bay contain transuranic radioactive wastes. The bays within the vault are separated by masonry walls. The grate-covered floor drain within each bay carries any drainage water to a collection sump for monitoring. Not visible in the photo are two 3-in.-diam access holes in the ceiling for monitoring purposes.

Figure 3. Waste-Bearing Concrete Casks Within a Belowground Vault, Oak Ridge National Laboratory, Solid Waste Storage Area No. 5. Source: Photograph courtest of Oak Ridge National Laboratory

controlled manner but is amenable to collection and monitoring procedures. Closure of each bay is accomplished by constructing a masonry wall incorporating two air vents and a man-access hole. Figure 4 is a closer view of the vault structure showing a completed closed bay and an adjacent open bay. No detail of the closure method shown in Figure 4 is recommended for long-term LLW disposal vaults (nor was it the design intent for this storage facility). The cement block closure is not durable nor is it impermeable to water flow to the extent required for satisfaction of the performance objectives. This depicted closure method would possibly be acceptable for temporary closure during disposal operations nearby. A detail of the vault design not indicated in the figures is the existence of two access holes about 2 in. in diameter in the ceiling. These holes allow air venting, interior air sampling, and access by viewing devices after closure. With appropriate appurtenances for security and filtering, access holes like these could be incorporated in an acceptable long-term disposal vault.

A variation of shallow belowground vaults have also been used for LLW storage in Ontario, Canada, at the Chalk River National Laboratory (CRNL) and at Whiteshell Nuclear Research Establishment (WNRE) in Manitoba, Canada (Feraday, 1982; Charlesworth and Carter, 1982; and Morrison, 1974). The structures at each of these sites have evolved over the years from rectangular bunker type concrete trenches (61 m x 4.9 m x 2.4 m deep) to the currently used cylindrical concrete designs (6 m diam x 4 to 5 m deep) with removable weather-proof caps. Major wastes stored in these facilities include ion exchange resins and filters, Cobalt-60 sources, cell wastes, and irradiated piping.

Ontario Hydro has also used the rectangular concrete structures for storage of LLW. However, as used in this report, these structures are more accurately categorized as bunkers rather than vaults.

2.1.2 Performance Capabilities

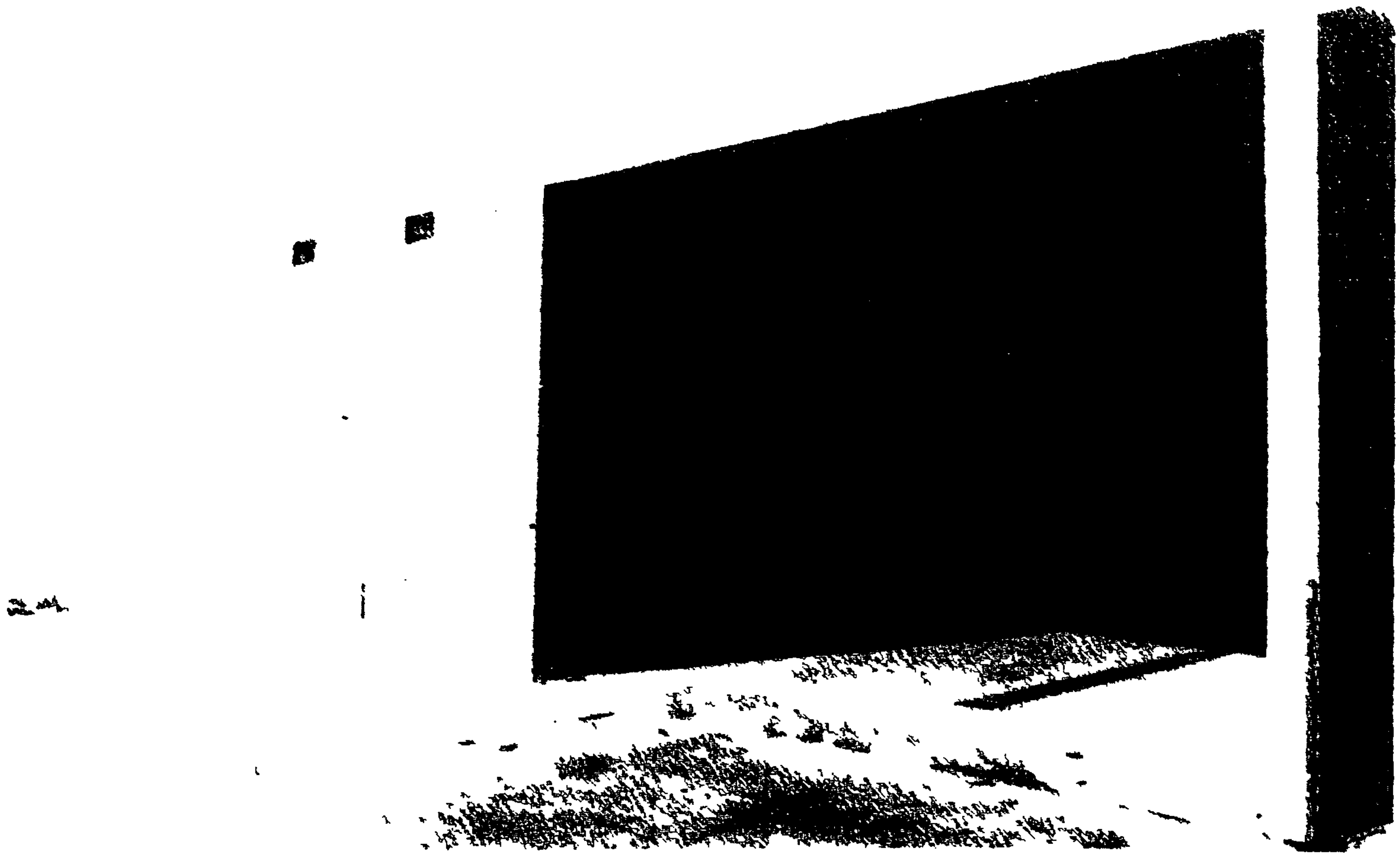
A belowground vault has several performance capabilities that make it an attractive LLW disposal alternative. The vault is visually unobtrusive.

In the event of erosion or mass earth movement, only the vault would be exposed. The waste would still be isolated.

Intrusion of ground water, animals and plants into a belowground vault is unlikely. The belowground vault is itself a barrier to intrusion in addition to the natural barrier of subsurface geologic materials. Inadvertent human intrusion into a vault is highly unlikely both because of its structural competence and its obvious contrast with earth materials.

A vault is self-supporting and can support backfilled earth with negligible subsidence.

Escape of liquid or gaseous matter from the vault is impeded by the vault structure and the surrounding earth cover. Radiation flux to the surface is limited by the engineered roof and by the earth cover.



The chained area shown is a bay of a belowground vault which has been temporarily closed (same bay shown in Figure 3). The closure shown is by means of a masonry wall incorporating two air vents and a man-access hole. This closure method is not recommended for long-term LLW disposal, but may be acceptable for temporary closure during disposal operations in an adjacent bay.

Figure 4. Temporary Closure of a Bay Within a Belowground Vault, Oak Ridge National Laboratory, Solid Waste Storage Area No. 5. Source: Photograph courtesy of Oak Ridge National Laboratory.

An appropriately designed vault should remain intact and sealed through all foreseeable or projected seismic, meteorological, and earth movement events. The vault units would be easy to locate and could be reentered in the event the waste material is to be retrieved.

Design and construction of the vaults could be standardized with potential economic benefits. Standardization of the vaults could lead to standardization of waste handling procedures. Regulatory control of the standardized vaults may be more efficient. Uniformity of facilities and procedures could decrease vulnerability of workers to accidental radiation exposure caused by accidents while performing unfamiliar activities.

Some disadvantages are associated with belowground vaults for LLW disposal. The vaults must be protected from flooding during construction and operations. They cannot be visually inspected or monitored. Also use of remote handling facilities is hampered by the limited access. Consequently, exposure of workers to radiation hazards may be higher than desirable.

Therefore, the basis for design and construction must be structural integrity and low permeability of the vault and its surrounding geological environment over a period of hundreds of years.

Design and construction efforts should verify that the foundation and abutment geological structure is competent to support the vault. Static and dynamic bearing capacity, total and differential settlements, and liquefaction potential are essential design considerations. Soil and ground-water chemistry must be checked to avoid soils that could corrode the structure.

The vault structure itself should provide lateral confinement and overhead cover, and should not depend on its contents for structural stability. The vault should be designed to safely support all dead loads including the vault itself, the wastes, and the earth cover and all operating loads necessary to place the wastes and the earth cover.

The vault design should include provisions for temporary closure during operation and permanent closure afterwards consistent with the performance objectives.

Design features of the vaults and their immediate surroundings must allow monitoring and possible mitigating actions during all phases of the facility life through the institutional control period. Also the facility must be reasonably self-sustaining after the institutional control period ends.

Interfaces between construction stages must incorporate prevention of radionuclide escape and intrusion by biota and ground water. Lasting and durable surface sealants must be used over any permeable materials used to assemble the vault.

Disposal operations within the belowground vaults must not place personnel at unnecessary risk or compromise the ultimate integrity of the closed vaults. These requirements can be met through careful application of existing design methods and conscientious construction quality control.

2.2 Aboveground Vaults

2.2.1 Description and Experience

The aboveground vault alternative disposal unit is an engineered structure or building with floor, walls, roof, and limited access openings with its foundation at or very near the ground surface.

The vault fabrication could be of masonry blocks, fabricated metal shapes, reinforced cast in place or sprayed concrete, or plastic or fluid media molded into various solid shells. All of these materials have been used to construct vaults and no constraints should be placed on material selection or shape of the vault as long as it can be shown that the performance objectives can be achieved.

Aboveground vaults will be readily visible on the landscape. That characteristic may or may not be a detriment in the sociopolitical acceptance of the alternative disposal method or any disposal site incorporating aboveground vaults.

Some possible concepts for aboveground disposal vaults are shown in Figures 5 and 6. Figure 5 shows a multi-bay vault structure that could be constructed in phases as needed to maintain capacity above the demand for disposal space. Figure 6a shows a pyramid-shaped, single-bay vault. This type of vault may be more suitable for sites where level ground is scarce. Its shape and construction would make it able to support heavy loads and resist damage or deterioration caused by tornados, seismic events, or impact from airborne debris.

Figure 6b shows a dome-shaped vault variation. These detached units could also be built on an as-needed basis. One unloading facility could serve several of these units. Dome-shaped vaults offer some savings in construction materials per unit volume of enclosed space but they would not be as space efficient as rectilinear shapes for usable waste disposal volume.

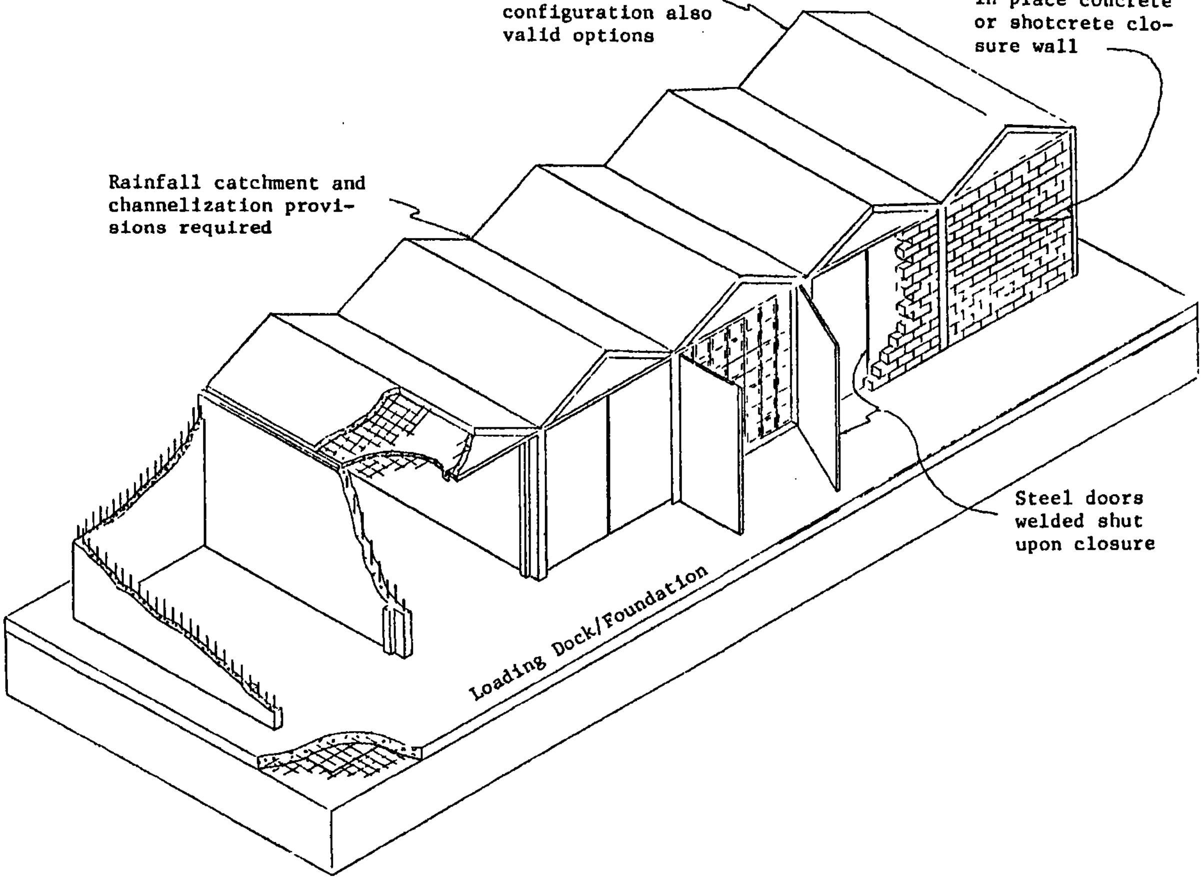
Figure 6c shows another rectilinear vault concept, typical of many vaults currently used for storage of a variety of goods.

Other variations are, of course, possible and may be better suited for particular sites. The concepts shown in Figures 5 and 6 are not to be construed as being favored over any other variation.

Aboveground vaults are used in Canada for storage of LLW. The New Brunswick Electric Power Commission has built storage vaults on bedrock at its Pt Lepreau site completely aboveground. An aboveground storage facility is also being used at Ontario Hydro's Bruce site.

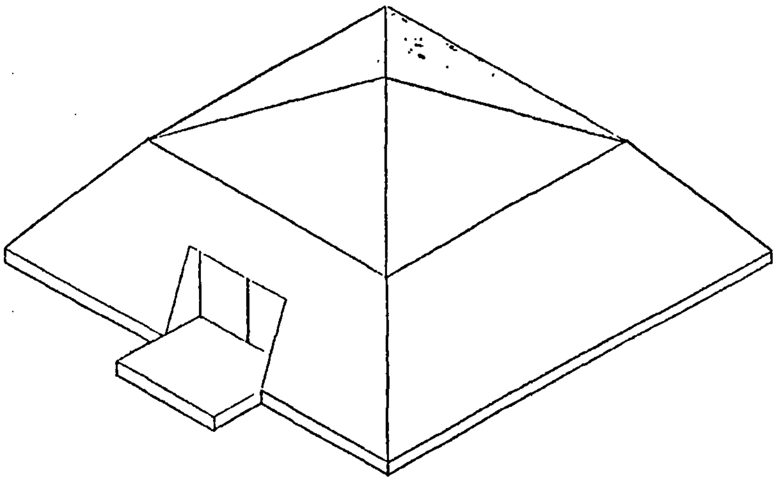
Aboveground vaults are being promoted for LLW disposal by some groups in the U. S.

A wide variety of aboveground vaults have been built and successfully used for warehousing manufactured goods, raw materials, and meat and produce. Their wide acceptance shows that they are economical, durable, and versatile structures.

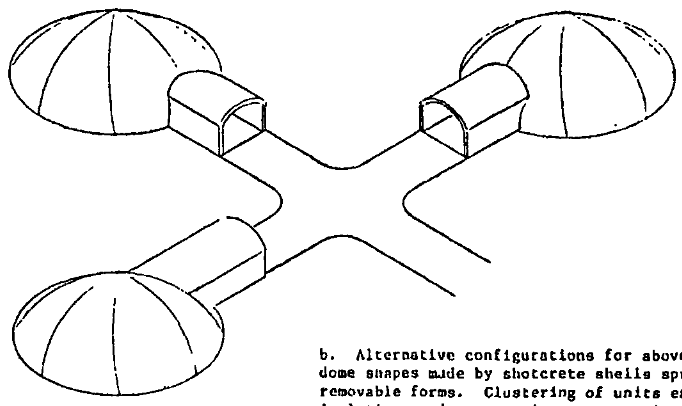


The separate cells of the overall disposal vault structure could be constructed and used progressively as needed. The construction depicted here is primarily of reinforced concrete, cast in-place to minimize leakage-prone joints. As a cell is filled to capacity it is sealed permanently, while neighboring cells are in operation. Cellular disposal reduces quantities of leakage in the case of a single cell failure. Truck unloading docks are included as part of the foundation. Cellular vaults are inherently feasible for waste requiring strict segregation.

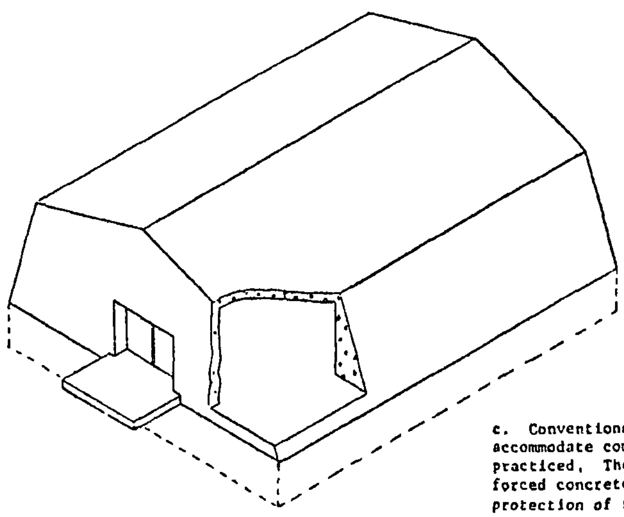
Figure 5. Conceptual Sketch of Cellular Aboveground Vaults for LLW Disposal.



a. The most durable structural alternative of an aboveground vault would be a pyramidal form made of thick monolithically poured reinforced concrete. The expense of such construction would be higher per unit of capacity than other alternatives but it would be most durable in the face of catastrophic hazard.



b. Alternative configurations for aboveground vaults include dome shapes made by shotcrete shells sprayed on inflatable, removable forms. Clustering of units enhances segregation, isolation, and progressive construction sequences. The portal assemblies shown could be moveable and reusable after unit closure.



c. Conventional rectilinear aboveground vaults would accommodate common warehouse operations as presently practiced. The structures could be formed from reinforced concrete incorporating buttressed walls for protection of the disposed waste as well as enhancing structural durability. Metallic or masonry construction would be inherently less stable and offer less leakage prevention than concrete.

Figure 6. Three alternative forms of aboveground LLW disposal vault: Pyramidal, Dome or Igloo, and Rectilinear.

2.2.2 Performance Capabilities

An aboveground vault for low-level radioactive waste disposal is an engineered structure that can stand alone on its foundation, and through its own design features, satisfy the performance objectives.

In the design of vault details considerable architectural freedom may be allowed because this alternative is a totally man-made integral disposal unit that does not depend on geological materials for waste isolation.

Current geotechnical foundation engineering and structural design methods allow aboveground vaults to be built to withstand a large range of natural hazards including seismic events, erosion, and landslides. Aboveground vaults are less vulnerable to flood damage. These qualities may allow more freedom in siting LLW disposal facilities in regions that demonstrate less than ideal characteristics for other alternative disposal methods.

Physical security can be engineered into aboveground vaults. Appropriate design of the vault closure should render the portals at least as secure as the bulk of the structure so accidental or misguided access by that path will be prevented. The high visibility of aboveground vaults is a primary concept advantage for preventing inadvertent human intrusion.

Interfaces between construction materials can be sealed, as well as the bulk of the structure itself, to any degree required to impede radionuclide migration.

Earth overburden loads are not a necessary design consideration nor is ponding or ground-water intrusion. Aboveground vaults are not susceptible to plant or animal intrusion. Standardization of vault design, construction, and operation may enhance safety and efficient operations as a result of worker familiarization with waste handling procedures.

Venting or even eventual retrieval of the waste material can be designed into the original structure or accomplished at some future date without jeopardizing the performance objectives. Monitoring of aboveground vaults is enhanced by their accessibility.

Some disadvantages may also be expected with aboveground vault disposal. There would be no secondary barrier to prevent radionuclide releases to the atmosphere if the vault structure failed after the waste packages deteriorate.

Also there would be less time available to take remedial actions to prevent radioactivity releases to the atmosphere from escaping from the site.

Active maintenance requirements could be extensive. The institutional control period required would be much longer than for any subsurface disposal method. Also, as mentioned for belowground vaults, exposure of workers to radiation hazards of high activity wastes could be higher than desired because of the difficulty in adapting remote handling equipment for use in limited access facilities.

2.3 Earth Mounded Concrete Bunkers

2.3.1 Description and Experience

The development of the earth mounded concrete bunker (EMCB) concept for disposal of radioactive wastes has been an evolutionary process. The use of earth shields for protection from radiation began with the design and construction of bomb shelters in the 1940's. The development of engineered structures and packages for containment of radioactive materials has continued with the increased acceptance and use of nuclear energy and radioactive materials in industrial processes and commercial products. The design of EMCB's includes features of trenches, belowground vaults, and earth mounds, as well as controlled packaging and encapsulation.

EMCB's for the disposal of low-level and intermediate-level wastes were first put in use in France in the 1960's (van Kote, 1981). There, the heavy dependence on nuclear energy, coupled with a lack of suitable shallow land burial sites made it necessary to develop an engineered facility for disposal of the wastes.

The basic design of the French EMCB's requires segregation of wastes according to level of activity. Intermediate-level wastes are embedded in concrete monoliths belowground; and low-level wastes, or intermediate-level wastes with appropriate packaging, are stored aboveground in earthen mounds (tumuli) over the concrete monoliths. Figure 7 is a perspective view of an earth mounded concrete bunker.

Typical construction, operation, and closure of an EMCB follows the sequence shown below in which short-lived wastes are disposed of according to type and activity level (Lavie and Barthoux, 1982).

a. A wide trench is first excavated above the water table. Typical dimensions may be 100 m x 30 m x 6 m (Figure 8a).

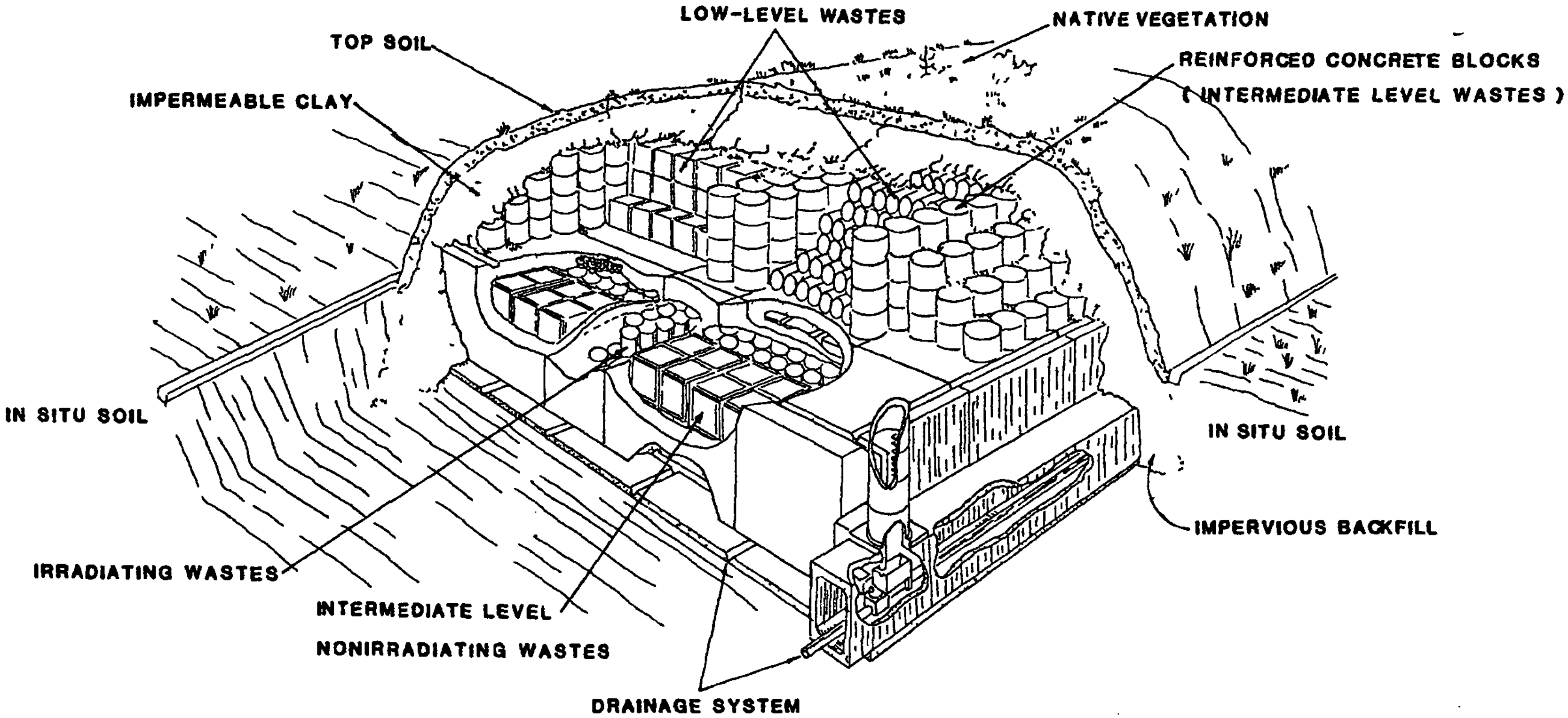
b. The sides of the trench are shaped to form temporarily stable sideslopes and the bottom of the trench is covered with a reinforced concrete pad.

c. A drainage system is provided, on and around the concrete pad to collect any runoff or infiltration which may occur during the construction and initial operation stages.

d. The trench is subdivided into compartments (approximately 6 m x 6 m x 6 m) with reinforced concrete, cast-in-place panels (Figure 8b).

e. Intermediate-level, nonirradiating wastes, which have been packaged and segregated, are lowered by crane into the compartments in successive layers (Figure 9a). (The French definition of nonirradiating wastes are wastes that emit less than 200 mrad/hr).

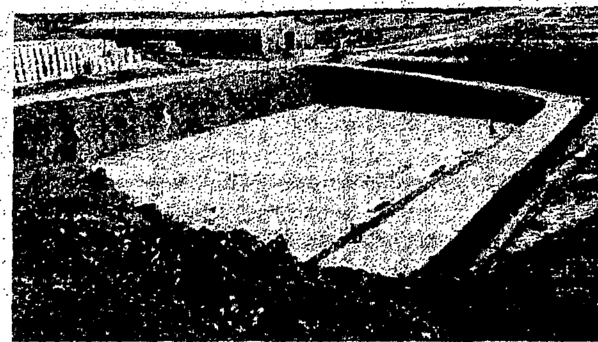
f. After each layer within a compartment is completed, it is backfilled with concrete.

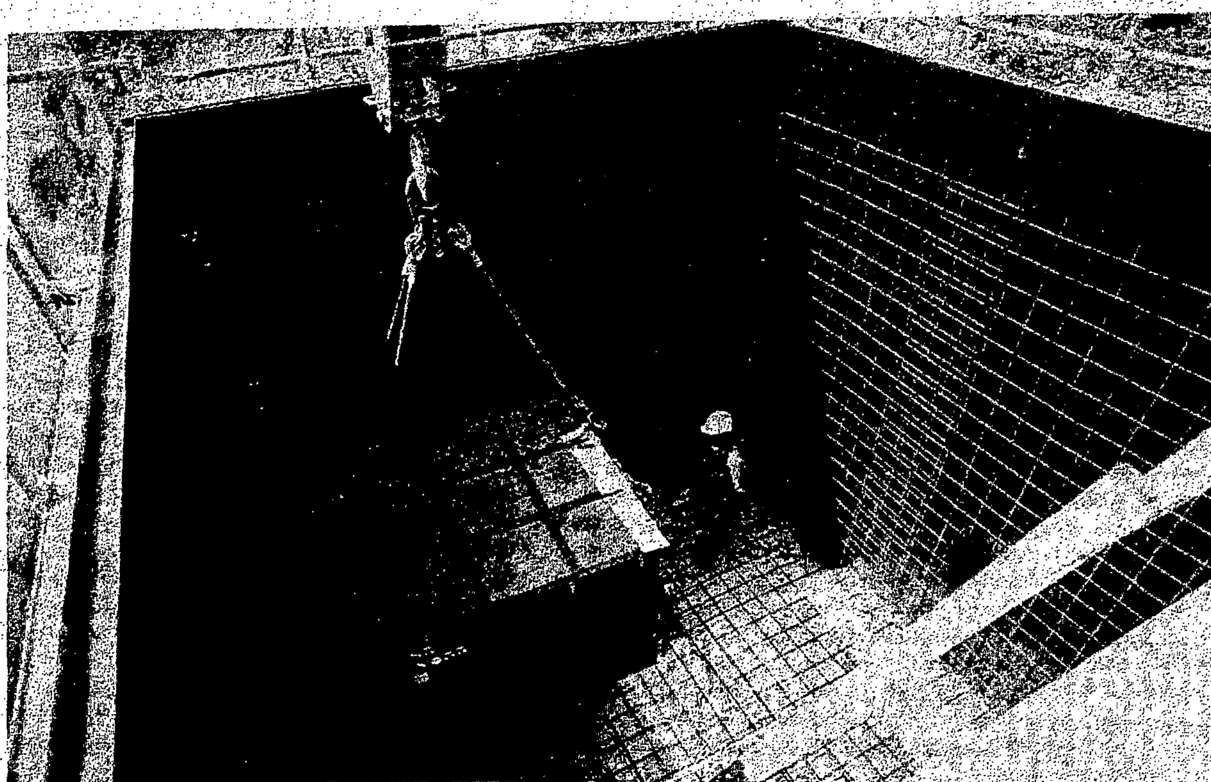


The perspective view of an Earth Mounded Concrete Bunker depicts the approximate locations of wastes which are separated according to level of activity. Intermediate-level wastes are embedded in concrete monoliths belowground: low-level wastes, or intermediate-level wastes with appropriate packaging, are stored aboveground in earthen mounds over the concrete monoliths. A drainage network is provided within and around the structure to prevent contact of water with the wastes and to provide collection and monitoring capabilities.

Figure 7. Perspective View of an Earth Mounded Concrete Bunker. Source: modified from F. Van Kote, "Twelve Years Experience in Low- and Intermediate-Level Waste Disposal."

a. Trench, or pit, excavated for construction of an Earth Mounded Concrete Bunker at the Centre de la Manche in France. The bottom of the trench is covered with a reinforced concrete pad, and a drainage network is provided, on and around the pad to collect runoff or infiltration which may occur during the construction and initial operation stages.



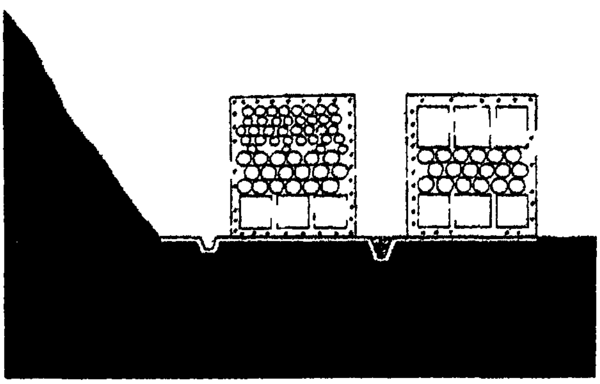


b. Compartment within an Earth Mounded Concrete Bunker trench, used for construction of waste-bearing monoliths. The trench is subdivided into compartments, as shown, by panels. Steel reinforcement is placed on the bottom and sides to provide strength to the monolith.

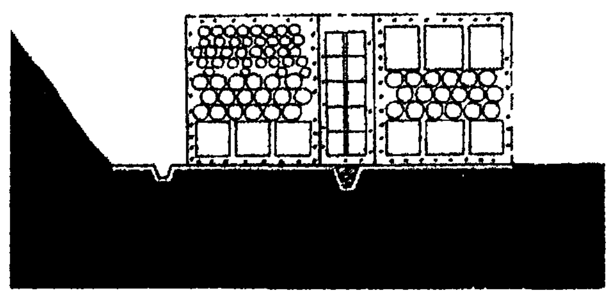
Figure 8. Initial Construction of an Earth Mounded Concrete Bunker. Source: Brochure from Commissarat a L'Energie Atomique, "The Centre De La Manche," 1981, Available from the Agence Nationale Pour La Gestion Des Dechets Radioactifs, Paris, France.

a. Intermediate-level, nonirradiating wastes are lowered by crane into compartments in successive layers. After each layer is placed, it is backfilled with concrete.

b. Upon placement of the last layer of waste in a compartment, reinforcing steel is placed on top of the layer, and the compartment is completely backfilled with concrete, embedding the wastes in a large concrete monolith.



c. Large monoliths are constructed in pairs with a two-meter void between them, reserved for disposal of irradiating waste, which require additional shielding.



d. Upon filling of the void between monoliths with irradiating wastes, concrete is poured, producing a smaller concrete monolith surrounded by two larger ones.

Figure 9. Construction Phases of an Earth Mounded Concrete Bunker. Source: Brochure from Commissarat a L'Energie Atomique, "The Centre De La Manche," 1981, Available from the Agence Nationale Pour La Gestion Des Dechets Radioactifs, Paris, France.

g. When the last layer of waste has been placed in a compartment reinforcing steel is placed on top of the layer, and the compartment is completely backfilled with concrete, embedding the wastes and resulting in one large concrete monolith as shown in Figure 9b.

h. The large monoliths are constructed in pairs wth a two-meter void between them, which is used for disposal of irradiating wastes (Figure 9c). (The French definition of irradiating wastes are wastes that emit more than 200 mrad/hr.)

i. To reduce the hazard of irradiating wastes, the narrow void between monoliths is temporarily covered by a concrete slab in the interim between placement of wastes.

j. Once the void between monoliths is filled with irradiating wastes, concrete is poured, producing a smaller concrete monolith surrounded by two larger ones (Figure 9d).

k. The construction and operation sequence is continued, creating monoliths side by side, until the bunker is filled.

l. Once the last monolith is completed, the large concrete "platform" of monoliths is waterproofed with a layer of asphalt.

m. Impervious backfill material is placed on the trench slopes to the top level of the monoliths, and another drainage system is installed to catch runoff during further construction, and to monitor infiltration at this level in the facility after closure.

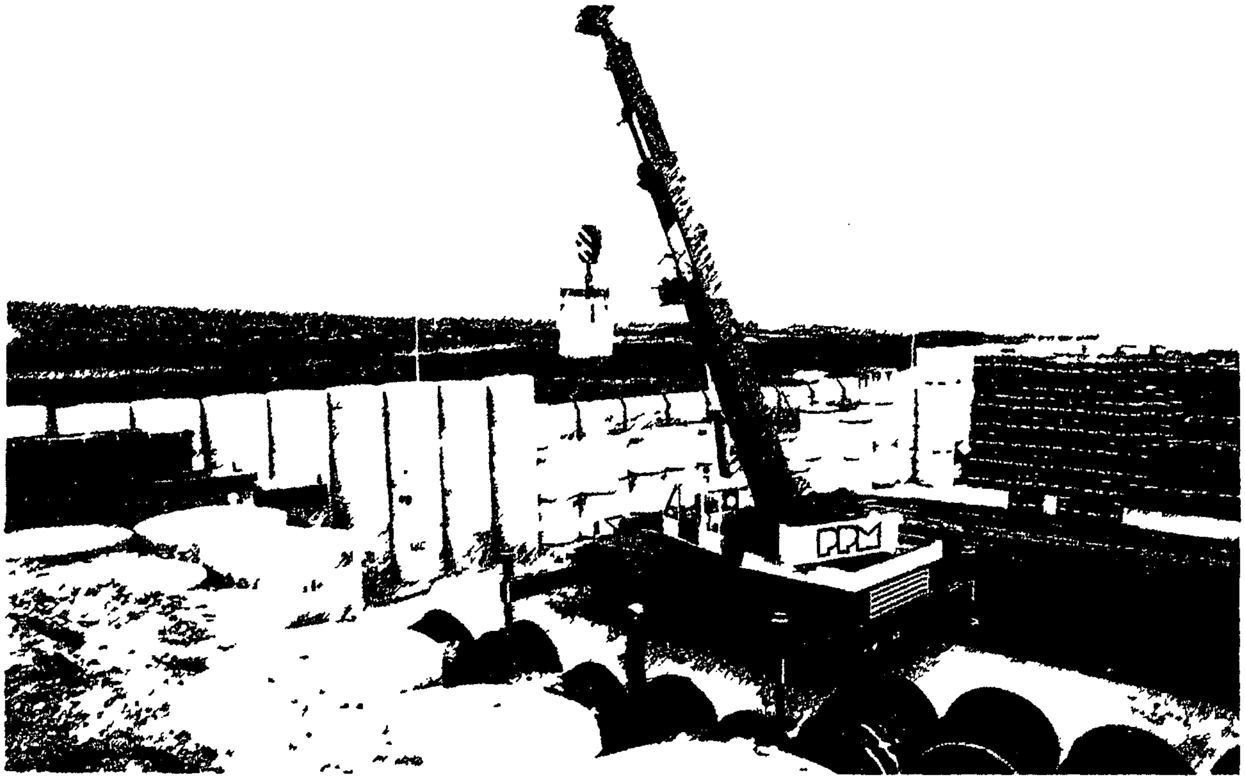
n. Mounds, or tumuli, are constructed on top of the buried monoliths using low-level wastes in metal drums, and intermediate-level wastes in reinforced concrete blocks. The wastes embedded within the concrete blocks are typically packaged in either concrete or polymer containers.

o. The concrete blocks containing intermediate-level wastes provide a structural framework for the mounds and are stacked by crane to a maximum height of about 6 m, in rows across the middle, as well as around the perimeter of the monoliths (Figure 10).

p. Along the perimeter the blocks are stacked in a stepped arrangement to give the final tumulus the shape of a sloping mound (Figure 11a).

q. Metal drums containing low-level wastes are placed inside the "compartments" formed by the rows of concrete blocks (Figure 11b).

r. Periodically during the placement of the metal drums, cohesionless (e.g., sand) backfill material is placed to fill the voids between drums, reducing the possibility of future settlement, and helping insure mound stability (Figure 11c).



Construction of an Earth Mounded Concrete Bunker, mound or tumulus on top of buried monoliths at the Centre de la Manche, France. Concrete blocks containing intermediate-level wastes provide the structural framework of the mound and are stacked by crane in rows across the middle, as well as around the perimeter.

Figure 10. Earth Mounded Concrete Bunker Tumulus Under Construction. Source: Brochure from Commissarat a L'Energie Atomique, "The Centre De La Manche," 1981, Available from the Agence Nationale Pour La Gestion Des Dechets Radioactifs, Paris, France.

a. Along the perimeter of the area, the blocks are stacked in a stepped arrangement to provide stability and to give the final tumulus the shape of a sloping mound.

b. Metal drums containing low-level wastes which have been placed inside the "compartments" formed by rows of concrete blocks at the Centre de la Manche, France.

c. Cohesionless backfill material is placed periodically during construction to fill the voids between drums, thus reducing the potential for future settlement, and increasing the stability of the mound.

d. A completed Earth Mounded Concrete Bunker at the Centre de la Manche, France. Upon completion of backfilling operations, the entire mound is covered with a thick layer of impermeable clay, which in turn is covered by a layer of topsoil. The surface of the mound is stabilized by planting native vegetation which not only stabilizes the soil but encourages drying.

Figure 11. Final Construction Phases of an Earth Mounded Concrete Bunker. Source: Brochure from Commissarat a L'Energie Atomique, "The Centre De La Manche," 1981, Available from the Agence Nationale Pour La Gestion Des Dechets Radioactifs, Paris, France.

s. When all concrete blocks and metal drums have been emplaced, the backfill material is placed over the entire stock, to fill all voids between the packages, and to increase the stability of the completed earthen mound.

t. The entire mound is then covered with a thick layer of impermeable clay, which in turn is covered with a layer of topsoil.

u. The facility, which now forms a tumulus or earthen mound, is then surrounded by a final drainage system designed to collect rainwater flowing over the clay layer.

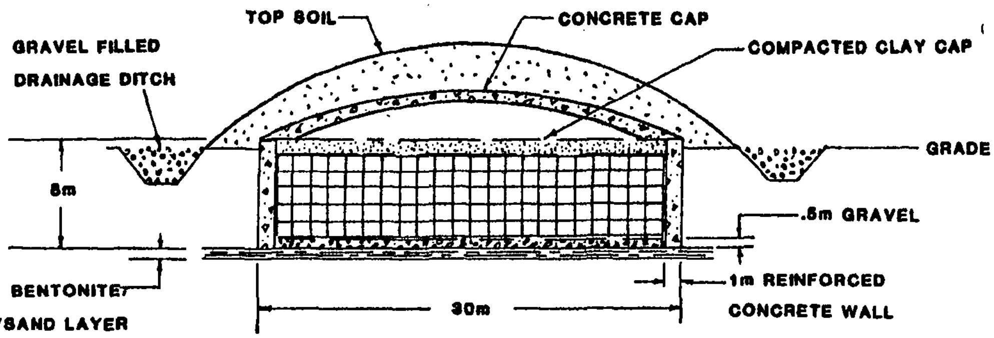
v. The EMCB is completed by planting the newly formed tumulus with native vegetation to stabilize the surface soil and encourage drying (Figure 11d).

The monitoring program for EMCB's includes analysis of water collected in the drainage network, monitoring and periodic checks on the ground water, a meteorological station for monitoring and collecting rainfall for analysis, measurements of radioactivity in the air, dosimeters at strategic locations to monitor radiation levels, and a strict monthly reporting procedure. Additional technical requirements for EMCB's include that the locations of waste packages and their contents, in both the tumuli and the monoliths, be recorded on a disposal plan and stored on microfilm in several different places.

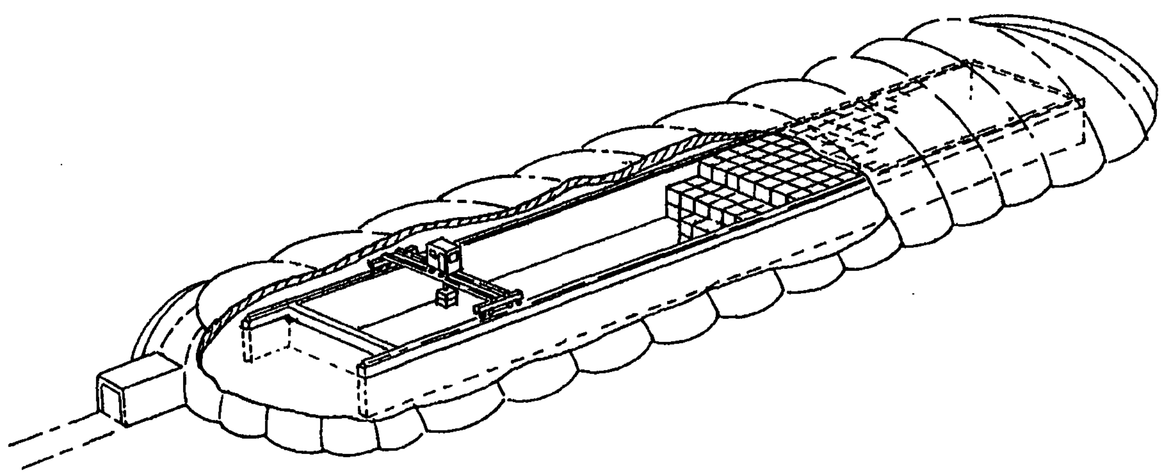
Since the EMCB alternative is a "hybrid" concept involving aboveground and belowground construction, encapsulation, and backfilling, with both concrete and earth, many variations have been suggested. For example, to reduce operating problems during cold or rainy weather, and to reduce subsequent drainage problems within the structure, it has been proposed (Feraday, 1982) that an air supported weather shield be installed over the facilities during filling (Figure 12). Such a concept has potential application to most of the alternative disposal methods considered.

Experience gained in France since 1969 with EMCB's has shown the concept to be an effective and attractive disposal method. The performance objectives of protection of the general population, protection of individuals from inadvertent intrusion, and protection of individuals during operation appear to have been satisfactorily met and public acceptance has been satisfactory. An extensive monitoring network in and around completed concrete earth mounded bunkers at France's disposal site, the Centre de la Manche, has detected no problems after closure of these units. A governmental organization, the Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA), was established in 1979 to maintain access control to the repository for a period of 200 to 300 years after closure of the site, to prevent inadvertent intrusion, and to assure that the site remains stable after closure.

The successful operating experience with EMCB's in France is documented by the volume of wastes stored between 1969 and 1982. A total of over 170,000 m^3 of waste has been stored in the Centre de la Manche facilities (Lavie and Barthoux, 1982), which represents about one-half the capacity of the facility.



TYPICAL CROSS-SECTION
thru
FACILITY AFTER CLOSURE



The conceptual drawing of a concrete walled disposal vault depicts an air supported weather shield which is used during the operational stage. The facility represents only one of many possible variations to the Earth Mounded Concrete Bunker concept. The use of an air supported weather shield has potential application to most of the alternative disposal methods considered in this report.

Figure 12. Earth Mounded Concrete Bunker with an Air Supported Weather Shield. Source: modified from M. A. Feraday, "Canadian Experience with the Storage and Disposal of Low- and Intermediate-Level Waste," pp 411-429 in Proceedings of the Symposium on Low-Level Waste Disposal, Washington, DC, 1982.

It is projected (van Kote, 1981) that over 800,000 m^3 of the low- and intermediate-level wastes will be generated in France by the year 2000.

A variation of the EMCB concept has been tested by the Energy Research and Development Administration (ERDA) for the disposal of transuranic-bearing solid waste (Gilmore, 1977). The ERDA concept places steel drums containing wastes within trenches which are subsequently backfilled to form an earth mound (Figures 13 and 14).

2.3.2 Performance Capabilities

The use of EMCB's, which constitute a multiple barrier system, may reduce some of the technical siting requirements for the repository because of the inherent stability of the packaged waste form and constructed facility.

The advantages of this alternative result from positive control and containment of the wastes. The encapsulation and multiple barrier approach allows flexibility in siting the facilities and decreases the possibility of inadvertent intrusion. Stability of the wastes within EMCB's may be confirmed from examination of data available from extensive drainage and monitoring networks. Such networks are easily incorporated into the design of EMCB's.

Structural considerations for EMCB's include the design and construction of stable trenches, waterproof barriers, drainage and monitoring networks, and concrete slabs and panels. Technical requirements unique to this disposal method during operation and closure are waste-form management, construction sequencing, and backfilling with concrete.

The disadvantages of EMCB's are primarily economic and operational. Because of the design and construction, EMCB's are obviously more expensive than conventional trench disposal. Operational disadvantages involve stricter packaging requirements and planned disposal sequencing with segregated wastes. EMCB's would not be amenable for intermittent or low volume operations because of the sequencing requirements and economical reasons.

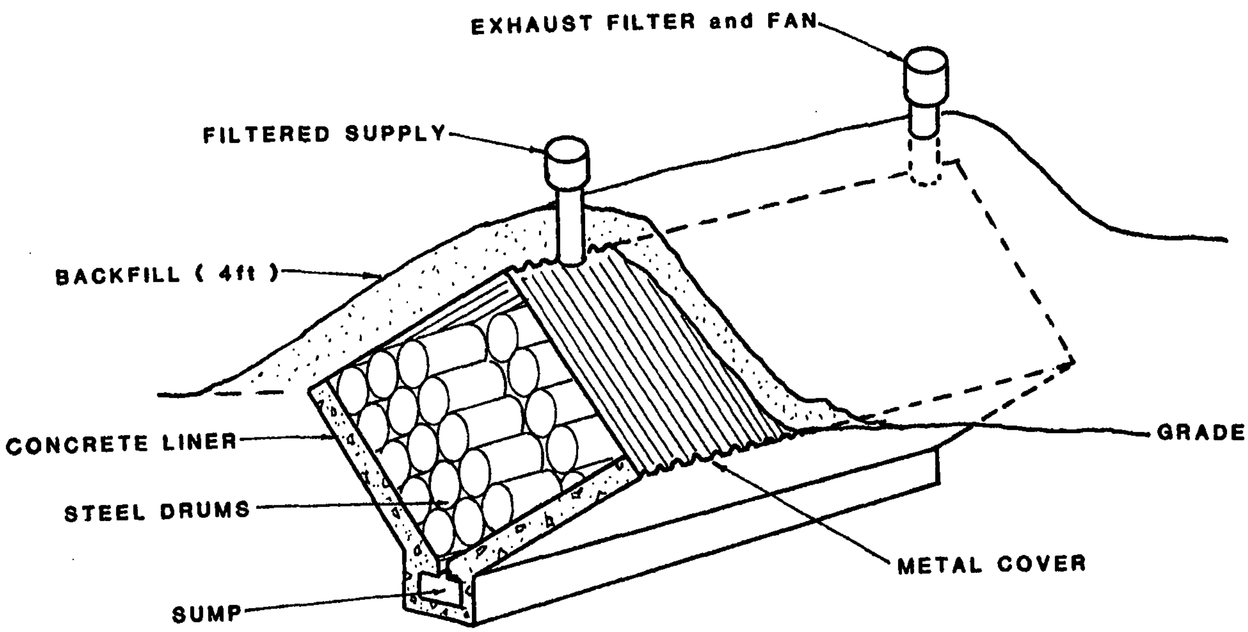
2.4 Mined Cavities

2.4.1 Description and Experience

Mines vary greatly in geologic setting, type of excavation and manner of resource extraction.

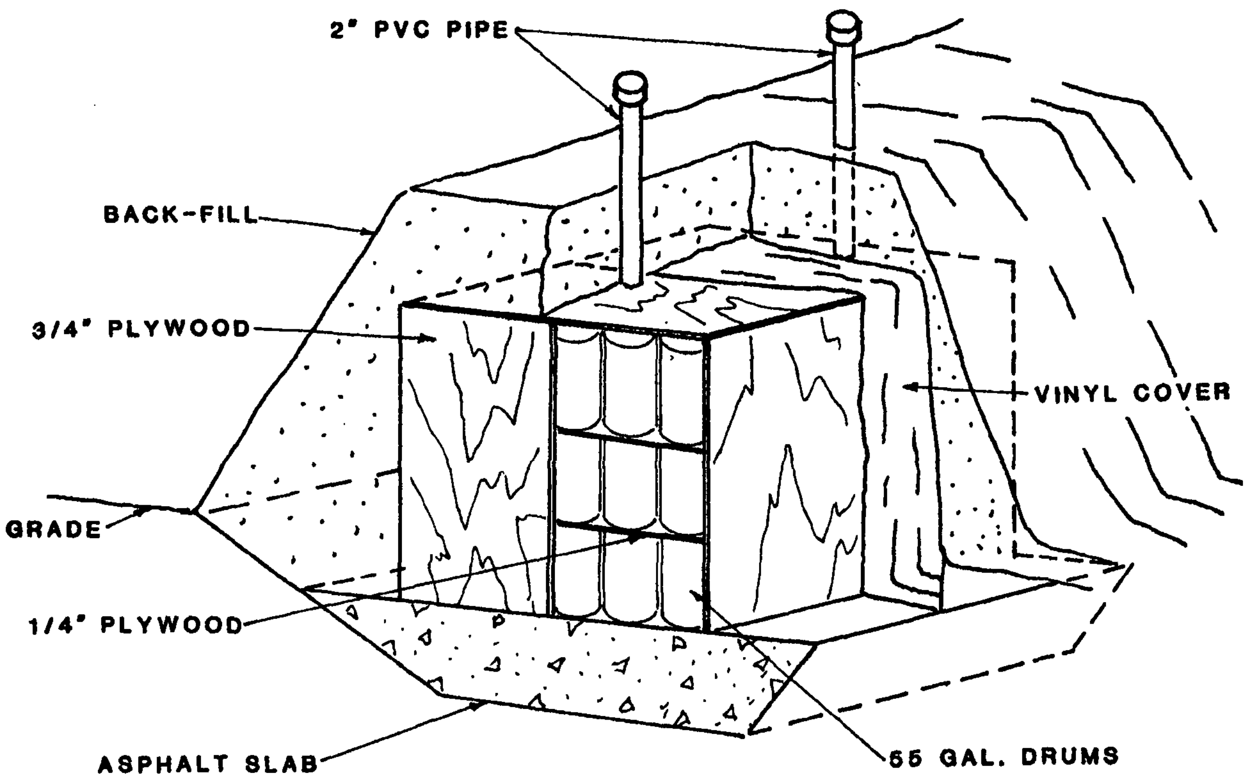
Mined cavities for the purpose of this discussion include enclosed cavities developed in the removal of natural resources. Open-pit mines or surface mines are excluded from consideration because they are similar in concept to trenches.

Most underground mines in the U. S. are developed to recover coal, limestone, salt (halite or gypsum), copper, iron, lead or zinc. Coal mining produces the greatest volume of new underground space. Total coal production in the U. S.



This variation of the Earth Mounded Concrete Bunker concept has been tested by the Energy Research and Development Administration. Steel drums containing transuranic wastes are placed in concrete lined trenches which are subsequently covered and then backfilled with earth.

Figure 13. Variation of the Earth Mounded Concrete Bunker Concept. Source: modified from W. R. Gilmore, Radioactive Waste Disposal, Low and High Level, p. 273, Noyes Data Corp., Park Ridge, NJ, 1977.



The variation of the Earth Mounded Concrete Bunker concept shown has been tested by the Energy Research and Development Administration. Drums containing transuranic wastes are stacked on top of a below-grade asphalt slab. A plywood housing provides lateral stability to the stacked drums. The bunkers are backfilled with earth after a waterproof cover is placed covering the wastes.

Figure 14. Earth Mounded Bunker on an Asphalt Slab. Source: modified from W. R. Gilmore, Radioactive Waste Disposal, Low and High Level, p. 274, Noyes Data Corp., Park Ridge, NJ, 1977.

is approximately 0.5 billion tons per year. Approximately 50 percent of the total coal production in the U. S. is from underground mines. Metallic mineral mining produces approximately 0.5 billion tons of ore per year, but only 12 percent comes from underground operations. Nonmetallic minerals, including salt and limestone, account for the excavation of over 2 billion tons of material per year but only 2.5 percent of the production is from underground mines. In considering the underground space produced, coal mining activities account for most space with metallic mining and nonmetallic mining each accounting for space equal to approximately 20 percent of that of coal mining (Lunt and others, 1977).

2.4.1.1 Coal Mines

Underground coal mines for the most part involve removal of relatively thin coal seams in rock sequences of alternating shales, limestones and sandstones. Thin units with alternating lithologies generally produce unstable roof conditions. Mine roof collapses are a major concern in extracting coal. Newer mining methods (longwall mining and shortwall mining) depend on using temporary roof support and allowing the mine roof to collapse after the coal is extracted. Roof stability problems are often compounded by ground water and drainage problems because of local zones of high permeability in the alternating lithologic sequences.

Water in coal mines reacts with fine-grained pyrite (FeS_2) in coal to produce iron oxide and sulfuric acid (Barnes and Romberger, 1968). The high acid content in coal mine water could present problems for waste disposal because acid mine water can accelerate the corrosion of steel containers and can attack any waste forms solidified with cement or lime-based materials. Therefore, wet coal mines are unacceptable for low-level radioactive waste burial because of the incompatibility of the mine water and the usual waste forms.

Coal that remains in mine pillars can continue to give off methane (coal gas or blackdamp) after mining has ceased. Operating coal mines require constant ventilation to prevent the accumulation of explosive mixtures of air and methane. The coal left in mine pillars can also present problems for secondary use because the pillars can support combustion. Underground mine fires are difficult to extinguish and usually result in progressive roof failure. Any risks of fire or explosion are unacceptable and coal mines that have these potential problems are not deemed suitable for disposal of radioactive wastes.

Consequently, although space is available in coal mines, these mines are generally not suitable for low-level radioactive waste disposal because of poor roof stability, the presence of acidic drainage water and the problem of explosions and/or fires from coal and methane given off from coal in the pillars. Only unusual geologic situations or extensive engineered adaptations would permit coal mines to be used.

2.4.1.2 Metal Mines

Mined openings developed in exploiting metallic mineral deposits often cover extensive areas, but are generally irregular in layout. The direction of

mining is changed frequently to follow the richest mineralization. Passages through nonorebearing intervals are kept as small as practical to avoid unnecessary expense. Transport into and out of metal mines is often complicated by the irregular mine development.

The major metal mining operations in the U. S. are developed in areas of sulfide mineralization. The drainage from metal sulfide mines is usually quite corrosive because of acid production from sulfide oxidation (Krauskopf, 1967). Moisture in mines where sulfide minerals are extracted would corrode steel drums or concrete-based solidified wastes. Therefore, mines associated with metal extraction are generally not suitable for LLW disposal.

2.4.1.3 Limestone Mines

Underground mining for nonmetallic bedded mineral deposits such as limestone produces cavities that are generally very regular in layout with uniformly-spaced rooms and pillars. The sizes of access passages (adits and shafts) are kept uniform throughout the mine since all of the material excavated is equally valuable. Limestone is a low-value material and must occur in large quantities to be economically mined. Mine plans usually involve broad passages and regular development of rooms and pillars.

Limestone mines are usually developed in such a way as to avoid intercepting water-bearing rock units. Limestone mine drainage water is slightly alkaline and carbonate salts in solution do not significantly accelerate corrosion of steel or concrete. Moisture in limestone cavities would be of only minor consequence, as long as the drainage system prevented significant accumulations.

Dry, stable limestone mines have been used in the U. S. for storage or warehousing of manufactured products (Stauffer, 1973, 1975). Figure 15 indicates areas where limestone is mined belowground and where storage areas have been developed. Completed limestone mines have been proposed but never used for hazardous waste storage or disposal (Samelson and Zordan, 1982). Underground storage facilities in mined space in limestone have been in operation in Kansas City since 1944. In 1975, the Kansas City area had 13 million square meters of mined space being used at 13 commercial sites in the metropolitan area. No major instability or safety problems have occurred.

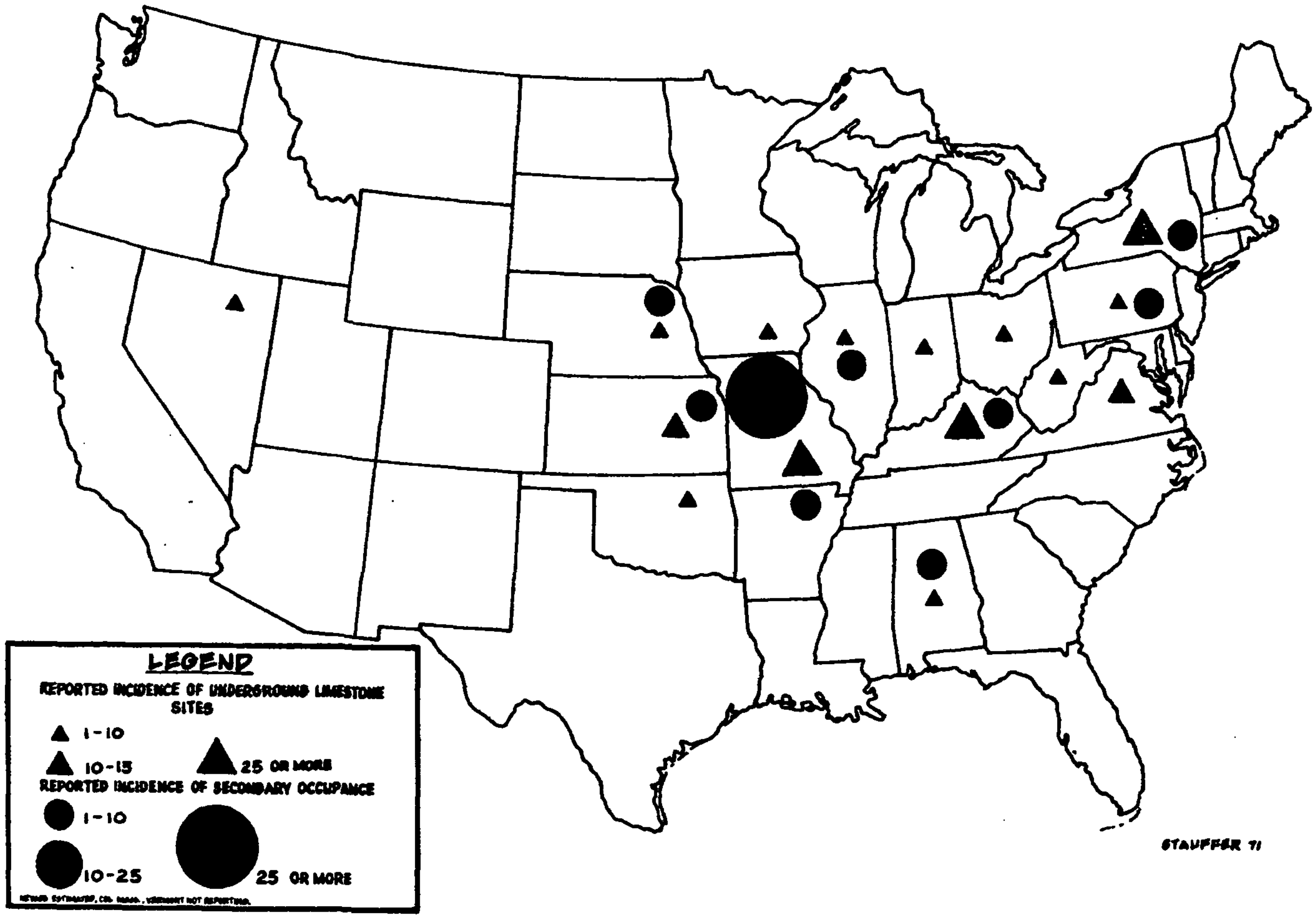
Characteristics of a typical underground limestone mine storage facility used for vital records and cold storage and office space in the Kansas City area are described below:

a. Roof span of 12 meters or less.

b. Pillars 6 meters or more in diameter.

c. A mine roof that consists of 2 or more meters of competent, massively bedded limestone.

d. Thick overburden that will prevent weathering of the roof rock.



Numerous limestone mining operations have been developed for storage areas. In addition to the number and location of underground mines, locations where storage areas have been developed are also shown. Completed limestone mines such as these have been proposed but never used for storage or disposal of LLW materials in the United States.

Figure 15. Major Limestone Mines in the United States. Source: T. P. Stauffer, "Kansas City: A Model of Underground Development," pp 29-38 in Proceedings of the Symposium on the Development and Utilization of Underground Space, Univ. of Missouri, Kansas City, MO. 1975.

e. A mine entrance that is down the natural rock dip from mine passages.

f. Limestone layers left as floor material (Williams, 1975).

2.4.1.4 Salt Mines

Major salt deposits occur in the U. S. both as bedded units or diapiric (intruded) salt units (Figure 16). Diapiric salt deposits are salt masses that have been forced upward into or through overlying geologic units. The deformation of the surrounding units forms a domelike structure. Methane may occur in salt mines developed in diapiric salt in sufficient quantities to be explosive. Therefore equipment must be provided for detecting and controlling methane gas.

Faults and folds in the bedded salts do occur but more rarely than in structurally deformed salt (Stone and others, 1975). Also, methane gas generally occurs less frequently and in smaller concentrations.

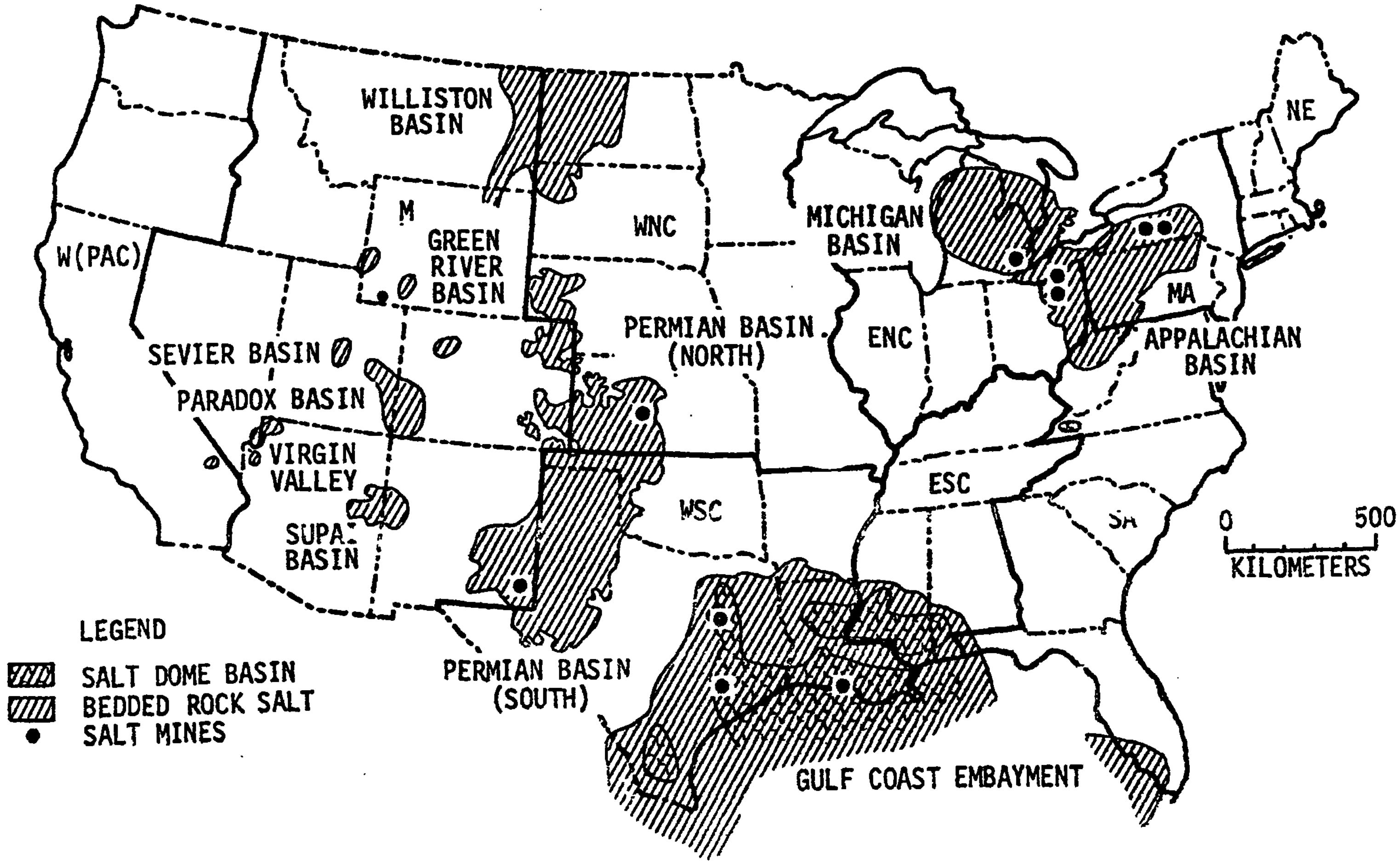
Underground mining of bedded salt (halite and gypsum) is similar in many respects to limestone mining. The salt must occur in large quantities and be relatively pure to be economically exploitable. Since all the material is equally valuable the rooms and pillars are laid out in a uniform rectangular pattern. Pillars are kept to the minimum size and maximum spacing that can safely support the roof. Access tunnels are straight and of constant cross section. Salt mine water is corrosive to steel drums but dry salt presents no special problems with regard to its compatibility with steel drums or concrete encased wastes.

The Asse Salt Mine in the Federal Republic of Germany has been used for low- and high-level radioactive waste disposal and is currently being used as a research facility. The mine is in a domed Permian salt unit. The evaporite sequences have a relatively complex chemistry with some hydrated chlorides and sulfates present. The best disposal sites within the mine are those units that are high purity (over 98 percent) halite (NaCl). While some water problems have been anticipated due to inclusions in the salt crystals and hydrated salt, disposal operations and research have proceeded satisfactorily (Westinghouse Electric Corp., 1983).

A completed potash mine at Herfa-Neurode near Bad Hersfeld, West Germany, is being used for nonradioactive hazardous waste disposal. The mine is in bedded salt and was developed to a depth of 700 meters. The mine uses classic room-and-pillar mining system with 12-14 meter wide square rooms and 3 to 4 meter square pillars. The mine is dry and requires no engineered drainage. The room heights range from 2 to 3 meters.

Wastes in standard steel or plastic drums are placed in the mine for indefinite storage or disposal. The mine received 100,000 tons of waste from 1972 to 1976. The mine is projected to take 36,000 to 38,000 tons per year. Space is being filled at the rate of 150,000 m^3 per year.

No major operational problems have been noted. Although the deposits are mixed hydrated and nonhydrated salts, no significant corrosion problems have been observed (Kown and others, 1977).



Bedded salt deposits occur at various locations throughout the United States while intruded salt units (salt Domes) are generally restricted to the Gulf coastal regions.

Figure 16. Major Salt Deposits and Salt Mines in the United States. Source: EPA-600/2-75-040, "Evaluation of Hazardous Wastes Emplacement in Mined Openings."

2.4.2 Performance Capabilities

Properly selected and operated existing mined cavities in limestone or bedded salt offer the best potential within this alternative for low-level radioactive waste disposal in that the mines can offer:

a. Isolation from the surface environment and human contact.

b. Reduction in the likelihood of inadvertent intrusion.

c. Shielding adequate for radiation problems associated with all classes of low-level radioactive waste.

d. Surroundings that are chemically compatible with and will not corrode the waste forms or containers.

e. Disposal areas which can be stable over the long period of time required for the waste to become harmless.

While each mine is unique with respect to its geologic setting, dry mines with stable roofs have a demonstrated record for successful storage of valuable materials (Stauffer, 1973; 1975). Many mines are located in seismically stable areas and are well isolated from the surrounding water-bearing units.

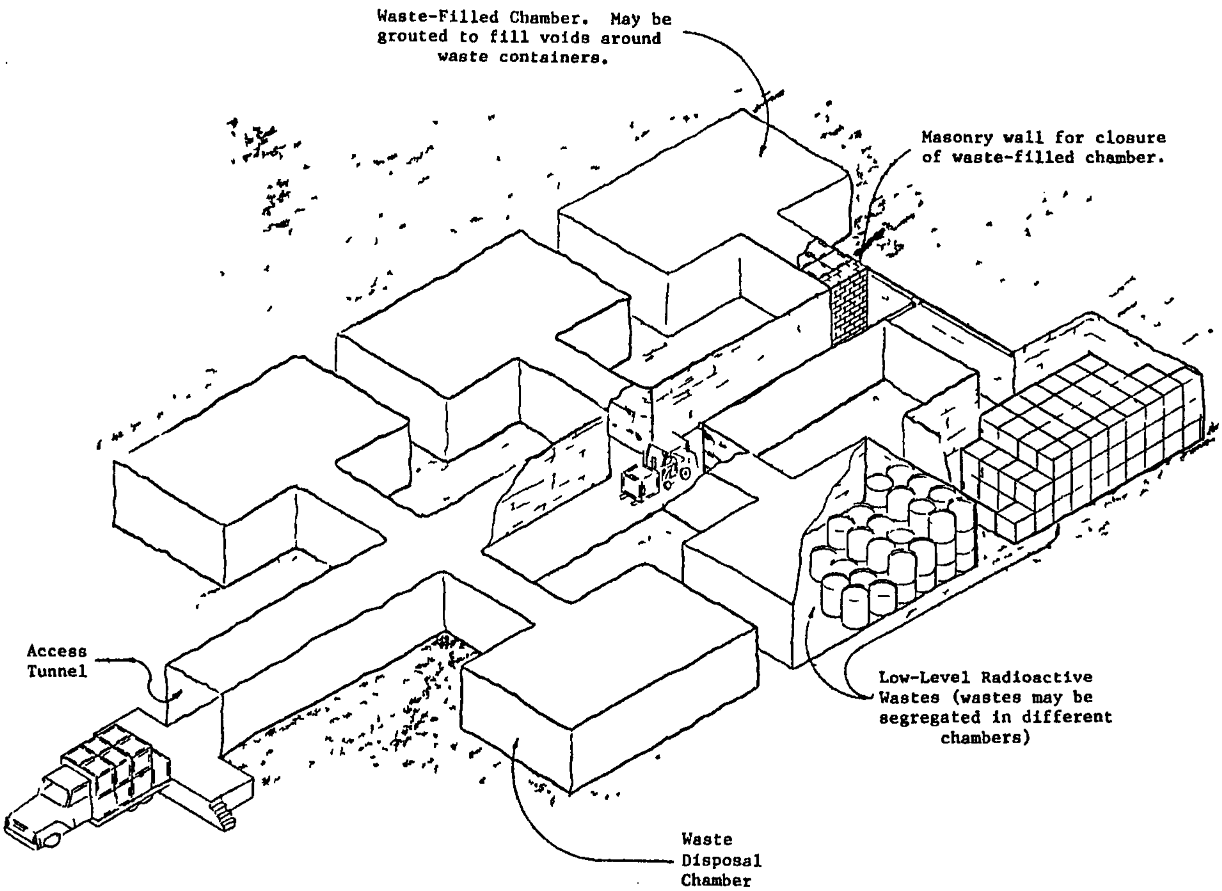
Limestone mines offer some advantages over salt mines in that the carbonate rocks in the walls and floor are less soluble in water and will act to neutralize any corrosive activity that may degrade the containment characteristics of the waste forms. Limestone units are less prone to flowage under stress than salt units and are generally more easily strengthened (or maintained) using conventional mining and tunnelling techniques such as grouting and roof bolting.

However, as mentioned previously, salt mines have been successfully used for low-level radioactive waste disposal on a pilot scale at the Asse Salt Mine and hazardous wastes are being placed in indefinite long-term storage in a worked out salt mine at Herfe-Neurode in the Federal Republic of Germany. Both installations have excellent safety records.

Vital records and movie films are being stored at the Carey rock salt mine in Hutchinson, Kansas.

In all the above cases, mined cavities selected for storage were dry and structurally stable. The security, safety, and resistance to inadvertent intrusion in the mined cavity storage is superior to that available in most land burial sites. Properly chosen mines may be effective options for future low-level radioactive waste disposal.

Figure 17 shows one concept of a mined cavity LLW disposal facility. In this concept, mined cavity disposal could proceed with the orderly filling of existing cavities. Wastes could be segregated, if desired, by designating different rooms or chambers for different waste classes. The chambers used for disposal of structurally unstable wastes could then be grouted to ensure



Modified Room and Pillar Mine in Bedded Limestone or Salt. Wastes may be segregated by chamber if required. If retreat method of filling chambers is used, the connecting passage ways may be filled with wastes and grouted to fill voids. Individual chambers may be sealed off when full by masonry or cast in place concrete walls. Instrumentation such as extenseometers could be installed from the main access tunnel.

Figure 17. Mined Cavity Concept for LLW Disposal

long-term roof stability. This treatment could also be applied to rooms used for disposal of stable wastes, if desired, to enhance long-term performance.

The existing mined cavities that would be available for LLW disposal were mined on the basis of profitable resource exploitation, and not suitability for waste disposal. The locations and characteristics of the existing cavities cannot be altered in any major way to improve waste containment or site safety. Excavation of new mines for the sole purpose of LLW disposal would be quite expensive. However, construction has just begun on a purpose built disposal facility in Sweden.

Disposal site suitability criteria for mined cavities are appreciably different from those needed for shallow land burial. Simple disposal sites are still the best selections from the viewpoint of predictability and adequacy of present physical and hydrologic models. For mined cavities, this requirement will eliminate many mines and may limit consideration to room-and-pillar mines in horizontal or near-horizontal rock units that have well-documented characteristics with regard to stability and hydrologic conditions.

Considerations such as future population growth and future mineral exploration are of importance but the isolation afforded by mined cavities makes surface development of reduced importance. Most mined cavity disposal sites will require some surface control, but not to the degree required for shallow land burial.

Surface drainage is also of reduced importance if the mine portals or shafts are above projected flood levels. The occurrence of water-bearing geological units is an important consideration in mine selection. The most obvious requirement is that the mined area selected for waste disposal must not be subjected to flooding.

Mines and tunnels can survive earthquakes with little damage unless the fault crosses the tunnel. Mined cavities are not likely to be exposed by normal weathering or slumping and landsliding. Of course, stable slopes near portal areas are an important consideration.

Other design features in mine-cavity operation differ significantly from those required in shallow burial. The overburden above most cavities is usually far thicker and less permeable than compacted soils used in shallow burial. Water infiltration can be prevented if mines are selected that have aquacludes above and below the mined horizon rather than depending on artificial cover materials.

Most mines are sufficiently deep that minimum burial depth and prevention of inadvertent intrusion requirements would be easily achieved.

Tight packing of waste forms would be desirable, but not necessary for stability. Waste can be segregated by room with each room closed separately. Radiation hazards at the surface would be negligible in most mined cavity operations.

The locations of shafts and drifts could be recorded using standard surface and mine surveying techniques. Surface monuments could be used to mark underground waste locations.

A mined cavity would have a three-dimensional buffer zone around the waste placement area, much like the buffer zone required for shallow land burial. Separate room closures would reduce the potential for personnel exposure to radiation hazards.

Monitoring activities at mined cavity disposal areas could proceed as monitoring would in shallow land burial, but the placement of monitoring wells would require deeper drilling or access to the mine level. Additional instrumentation such as extensometers and load cells would be required to monitor stability of the mined openings.

Remedial action planning would be complicated by depth and lack of accessibility, but could still be factored into the design and operation of the facility. A monitoring program that could be phased out as confidence is gained in the facility's operation would be preferred because of the access problem in replacing malfunctioning instruments.

In summary, while underground coal mines are the most abundant type of enclosed mined cavities, this type of mine is unsuitable for radioactive waste burial. Metallic mineral mines generally are developed in an irregular plan to follow zones of mineralization. This development makes these mines less accessible for placement of waste, and drainage from mines exploiting sulfide ores is corrosive and would be incompatible with most drummed or concrete-encased, low-level radioactive waste. The nonmetallic mineral mines developed in bedded materials (such as limestone, halite and gypsum) offer the best potential for disposal of radioactive wastes in mined cavities.

Discussion in the following section on criteria applicability to mined cavities will be restricted to nonmetallic mined cavities. No further consideration will be given to coal and metal mines in this study.

2.5 Augered Holes

2.5.1 Description and Experience

Although the strict definition of the term augered hole is a hole sunk into the ground using an auger, the term has been used in the literature to refer to holes sunk by any conventional method, including the use of multileaf backhoe digger attachments or roller bits. Therefore, in this report the term refers to a shallow land burial alternative in which the wastes would be disposed of in holes bored, augered, or sunk by any other conventional method that resulted in the same end product.

Holes may be augered or bored to practically any depth and diameter as long as the rig used can excavate through the soil or rock and the walls are supported or can stand unsupported. However, there are certain practical size and depth constraints for augered holes. The larger the diameter of the hole the larger

is the drill rig required. The rig must have sufficient power to turn the auger and must have sufficient power and reach to pull the drill string from the hole. For deep holes in the 10-ft-diam range, these rigs are very large and expensive. Hard ground slows the drilling rate; auger rigs work best in soft to firm consistency cohesive soils. Boulders also slow progress and these must be removed by jackhammering and hand loading, a dangerous and time-consuming task.

The use of augered holes for storage or disposal of low- or intermediate-level radioactive waste has been studied by the US Department of Energy (Dickman and Boland, 1982; Hooker, 1983; Card and others, 1981; Cohen and others, 1982), the Atomic Energy of Canada, Ltd (AECL) (Morrison, 1974; Beamer and others, 1982; Harmon and others, 1983) and by the NRC and other agencies (MacBeth and others, 1978 and 1979) as an alternative to shallow land burial of these wastes.

At the Nevada Test Site (NTS), the US Department of Energy (DOE) is currently evaluating the use of large-diameter augered holes for disposal of high specific activity low-level radioactive wastes. The objectives of this test are to define the tritium diffusion rate in soil and to achieve greater confinement and isolation of wastes and reduce risks of exposure at the ground surface.

The DOE Greater Confinement Disposal Test (GCDT) study began in 1981 and waste emplacement was scheduled to begin in November 1983. The basic design of the experiment calls for a central waste shaft, surrounded by nine smaller holes for instrumentation. The waste disposal shaft is 10 ft diameter and 120 ft deep.

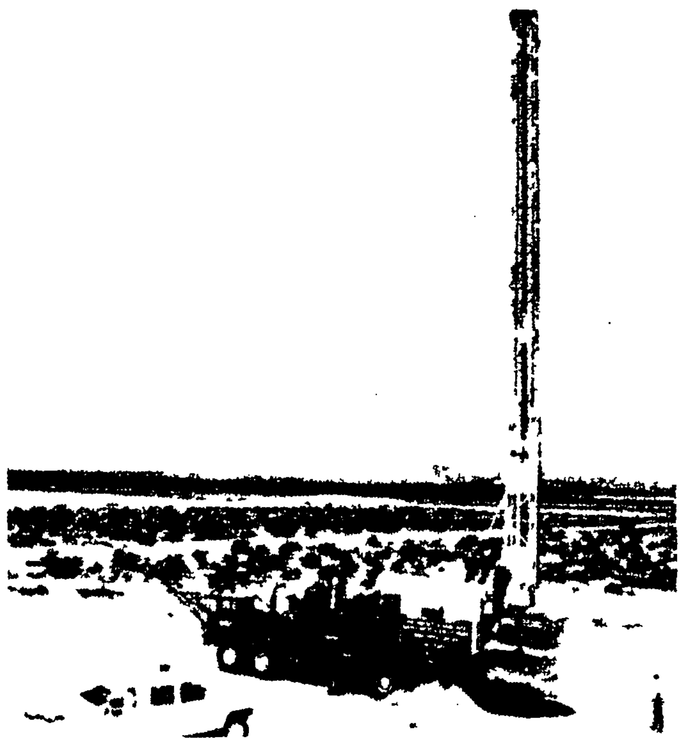
The main hole was sunk with an auger rig as shown in Figure 18. Figure 19 is a schematic of the sequential boring operations.

Figure 20 is a schematic of the waste shaft and instrument holes. The central shaft was also instrumented.

Only 30 ft of the waste shaft is to be used for waste disposal. The bottom 20 ft was backfilled over the emplaced instruments. After the wastes are emplaced, the waste shaft will be backfilled to slightly above the ground surface and the monitoring phase will begin.

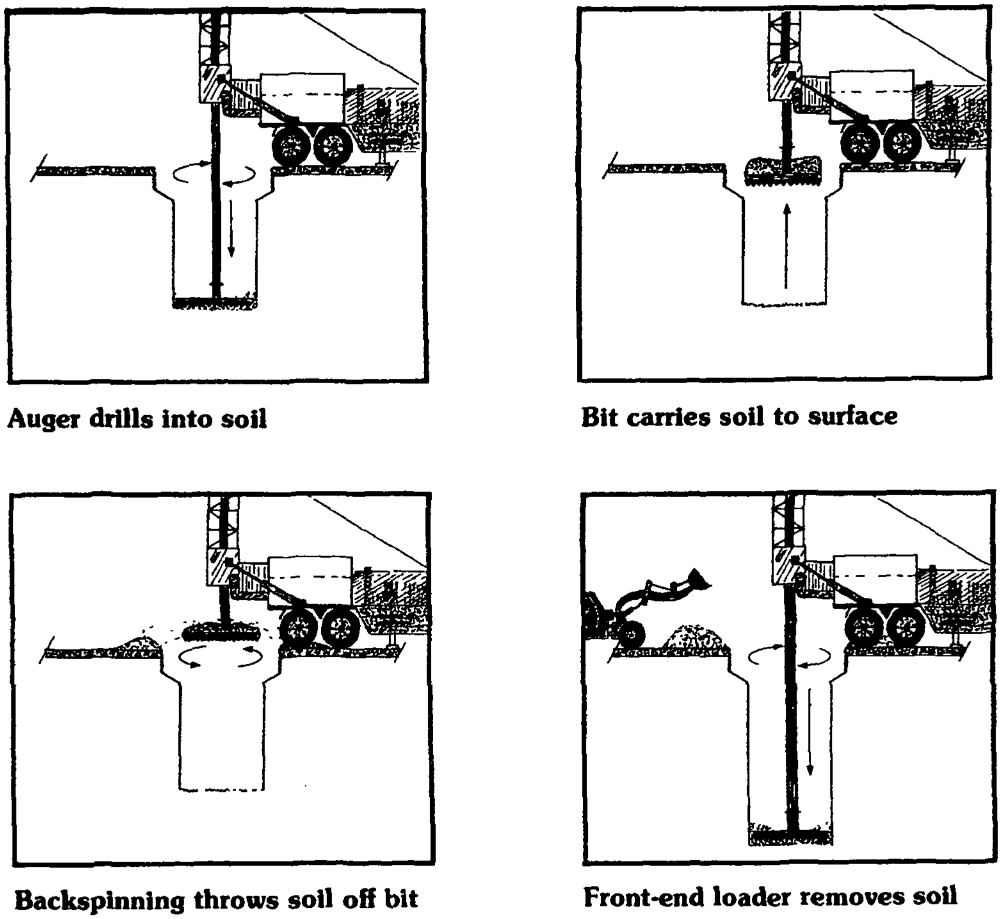
It should be noted that this test is being conducted under closely supervised conditions in an area almost ideally suited to construction of large augered holes and that much experience has been gained at NTS with this construction method from the extensive weapons testing programs conducted there.

A similar study is also being conducted at NTS under DOE funding (Dickman and Boland, 1983). In this experiment, 10-ft-diam holes were augered 30 ft deep from the bottom of previously excavated trenches 18 ft deep. A 6-ft-diam casing was then lowered into the hole. Holes were cut into the casing at 5-ft vertical spacing, and horizontal borings were drilled into the soil at these locations to install soil atmospheric samplers.



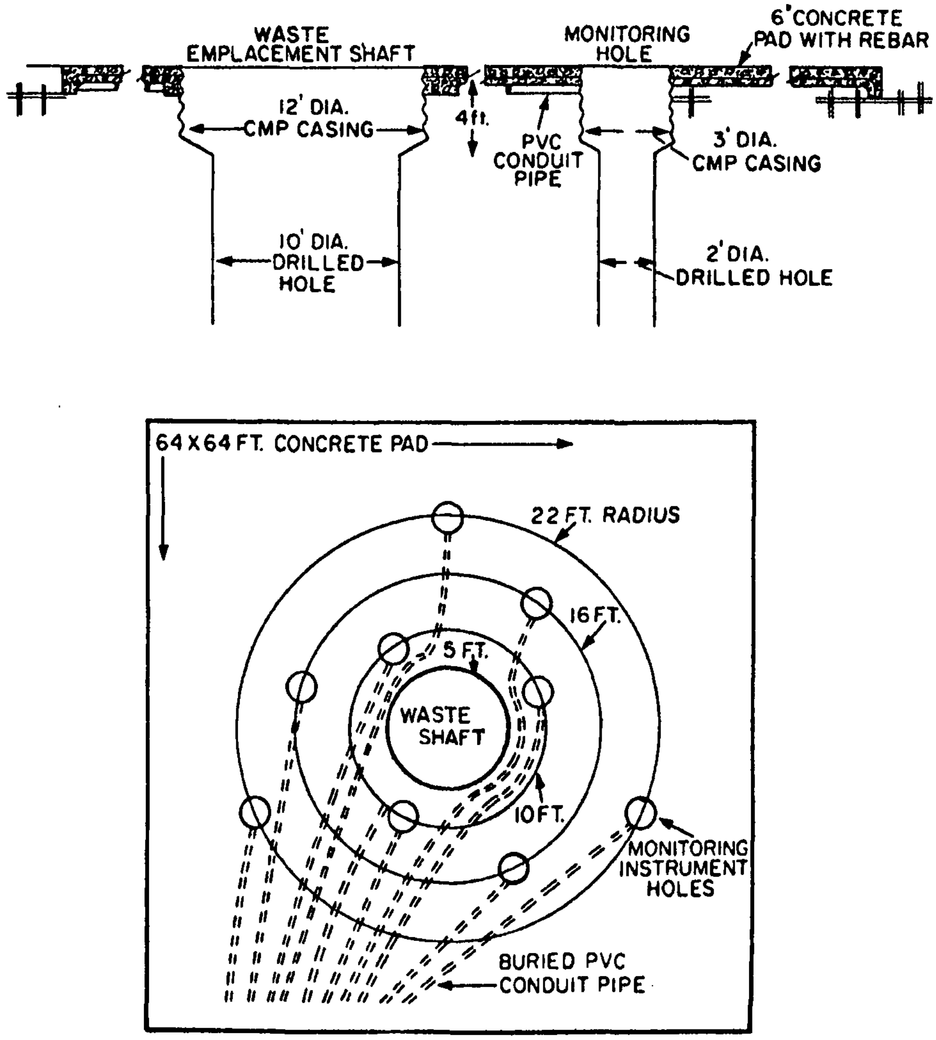
A truck-mounted drilling rig used by the DOE for the Greater Confinement Disposal Test at the Nevada Test Site. The auger rig drilled a 10-ft-diam, 120-ft deep waste disposal shaft and the surrounding instrument shafts.

Figure 18. Auger Drill Rig, Greater Confinement Disposal Test. Source: Reynolds Electrical and Engineering Co., "Greater Confinement Disposal Test at the Nevada Test Site, June 1983," DOE/NV/00410-79.



The schematic presents the sequential auger boring operations for the Greater Confinement Disposal Test at the Nevada Test Site. The auger was rotated into the soil until the loose material was above the auger. The auger was then raised above the collar and spun backwards to throw the cuttings to the side of the hole. The auger was then lowered back into the hole and the process repeated until the desired depth was reached.

Figure 19. Sequential Drilling Operations, Greater Confinement Disposal Test. Source: Reynolds Electrical and Engineering Co., "Greater Confinement Disposal Test at the Nevada Test Site, June 1983," DOE/NV/00410-79.



Shown are plan and elevation views of the waste shaft and instrumentation holes used for the Greater Confinement Disposal Test at the Nevada Test Site. The basic design consists of a centrally located waste emplacement shaft surrounded by nine instrumentation holes for assessing the potential for radionuclide migration.

Figure 20. Waste Shaft and Instrumentation Holes, Greater Confinement Disposal Test. Source: Reynolds Electrical and Engineering Co., "Greater Confinement Disposal Test at the Nevada Test Site, June 1983," DOE/NV/00410-79.

A 250,000 curie tritium source is to be emplaced in the holes. Besides the subsurface instrumentation and air samples, plant uptake and tritium migration through the cover will be measured. As of November 1983, the hole had been dug and the instrumentation and casing had been installed but the tritium source had not been emplaced.

In Canada, "tileholes" or concrete pipes set vertically on concrete foundations with the tops set flush with the ground surface have been used for storage of ion exchange resins and filter cannisters at Ontario Hydro's Bruce site and at Chalk River National Laboratory, Ontario, Canada (Morrison, 1974; Feraday, 1982). The tileholes are well above the water table and an underdrainage system was installed which led to a monitored and controlled discharge. Figure 21 is a schematic of the tilehole system.

At Oak Ridge National Laboratory (ORNL) in Tennessee, transuranic (TRU) wastes are being stored in shallow holes at Solid Waste Storage Area No. 6. The geology of this area may be characterized as a steeply dipping, faulted, weathered shale forming the ridges bounded by incised tributaries of White Oak Creek.

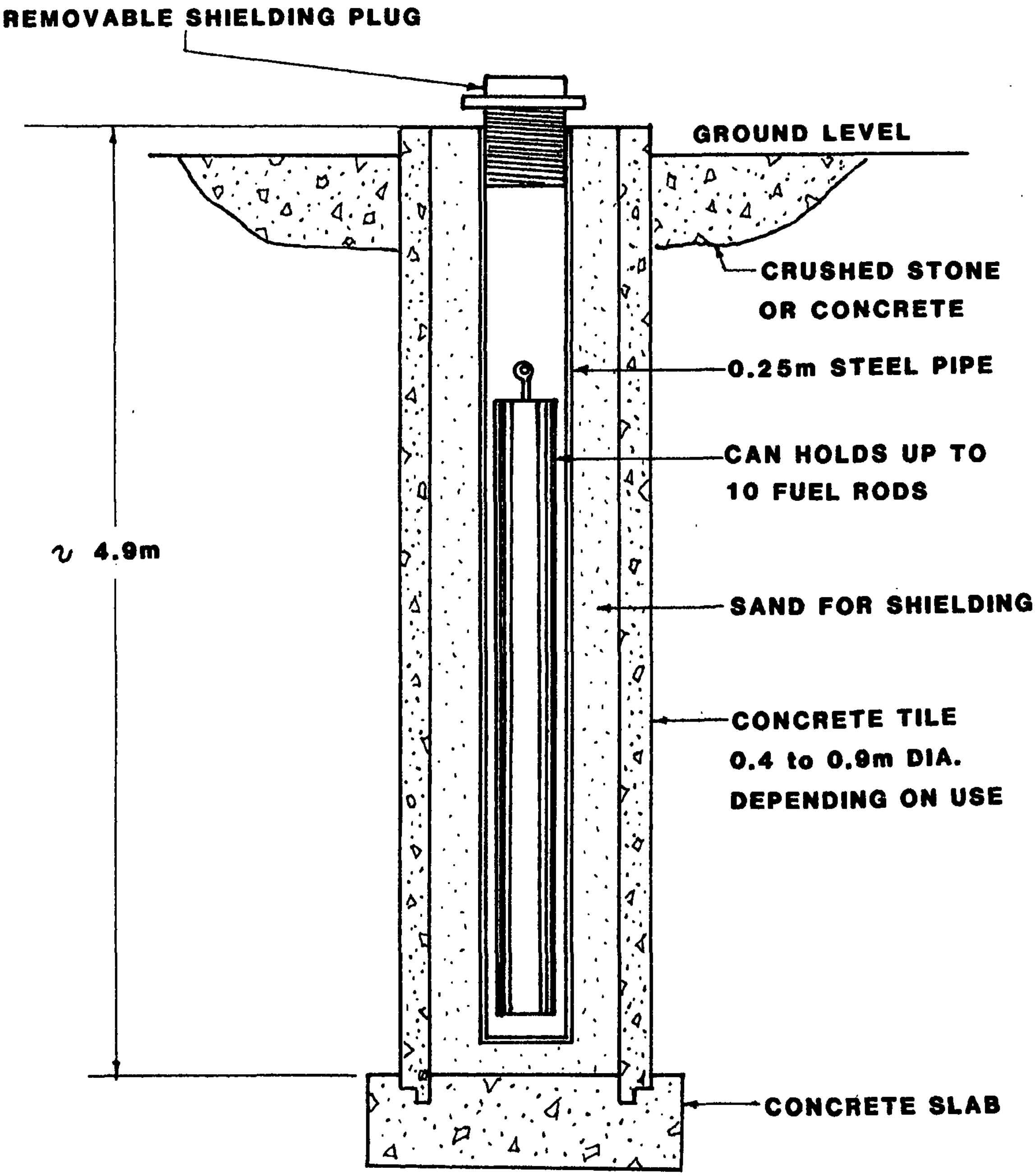
Only the upper portions of the ridges are used for storage to take advantage of greater depths to the ground-water table. The average hole depth is less than 21 ft, with a minimum of 2 ft of undisturbed shale maintained between the bottom of the hole and the water table. The holes are spaced on 6-ft centers, and are excavated on an as-needed schedule.

Radioactive waste is transported to the site in reusable shielded containers on flatbed trailers. The containers are lifted by hoist from the trailer and lowered onto a template over the open hole. A trap door is then opened and the waste is lowered down the hole with a cable and hoist system, or for the lower activity waste, it is simply allowed to fall to the bottom of the hole. The waste is then covered with 1 to 2 ft of soil or until the measured radiation level is verified to be below safe standards. No compaction is applied to the backfill.

The hole may be left open for short periods during fair weather but is covered by a conical sheet metal weather cap during rainy periods. When wastes and backfill reach to within about 4 ft of the ground surface the hole is topped out with loosely placed backfill to within 1-1/2 ft of the surface, 6 in. of concrete is poured into the hole, allowed to set, and the hole is then backfilled to the surface with soil.

Upon completion of a grid of these holes, a surface treatment is applied. About 4 lb per square foot of dry bentonite clay is broadcast and disked into the soil and the area is seeded with grass. When subsidence over the holes has been observed, more soil was added and these areas were reseeded.

Piezometers and sampling wells are located around the disposal area. Water samples are taken and water table depths are measured from these holes. No radionuclide migration from augered holes at Storage Area 6 has been detected over the last decade of use. However, mitigation of migration through lateral ground-water pathways from a nearby trench disposal area has been necessary.



This schematic presents a typical concrete tile hole for storage of low-level radioactive wastes at Ontario Hydro's Bruce site and at the Chalk River National Laboratory, Ontario, Canada.

Figure 21. Concrete Tile Hole. Source: modified from J. A. Morrison, "AECL Experience in Managing Radioactive Wastes from Canadian Nuclear Reactors," Atomic Energy of Canada Limited, AECL-4707.

Augered holes have also been used at Los Alamos National Laboratory (LANL) in New Mexico for disposal of solid wastes that required shielding (National Research Council, 1976). Tritium wastes and TRU wastes were first encased in asphalt before placement in these drilled shafts. Contaminated oils were placed in 55 gal drums and stacked in the shafts.

The holes were approximately 2.5 ft diam and up to 65 ft deep. Some were concrete lined. A rounded surface concrete sealing plug 3 ft thick was poured when each hole was filled. The regional water table depth ranges from 850 to 1050 ft. There is some perched water in the stream connected alluvial aquifers in the canyons but wastes were disposed of only along the tops of the mesas or plateaus.

The precipitation is sparse at this site and infiltration is limited to the upper 10 ft of soil. Purtymun (1973) reported that some tritium was migrating from these shafts in the vapor phase through open joints in the tuff.

2.5.2 Performance Capabilities

The design, construction, operation, closure, and monitoring of augered holes can be accomplished with proven technology and equipment. Augered holes share several common features at each of the sites where they are used. At all sites the holes are fairly shallow and are above the water table. However, in some instances the holes may not have been above the zone of fluctuation of the water table.

Protection of the general population from releases of radioactivity should be satisfactory. Hole caps must be carefully designed to insure this protection and the literature suggests that several types of seals and plugs have been used to achieve this objective.

Slow diffusion of radioactive ions through surrounding soils is probably the dominant mode of radionuclide migration. This slow diffusion will help reduce the concentrations of radioactive materials released to the atmosphere at the surface or to the ground water.

Protection of individuals from inadvertent intrusion and prevention of plant and animal intrusion can be achieved through the use of greater disposal depth, the use of sealing plugs and caps, and through the use of long lasting labels identifying the disposal shafts. Because of their discrete point locations and surface markings the risk of inadvertently punching through the disposal shafts with near vertical boreholes or wells should be very low, even after the institutional period ends.

Protection of individuals during operations is achievable through the use of shielded transport casks. No workers must enter the disposal shafts. The transfer of the wastes from the transport vehicle to the hole must be carefully executed with the proper equipment, but this operation is routinely and safely done at several existing storage sites and presents no significant problems.

If the backfill is reasonably compacted, settlement and hole side wall stability should not be a problem. The top of the holes can be capped slightly above the original grade to minimize infiltration of surface runoff. Surface contours and vegetation could be established to minimize erosion from runoff. If these practices are followed, stability of the disposal site after closure should be achievable and active maintenance should be minimal.

The practical dimensions of an augered hole facility are dependent on projected waste volumes, land availability, site characteristics, container sizes, safety, and costs. The limits on depth of burial should be based on analysis of soil hydraulic conductivity, the depth to the water table and the bedrock. The minimum cover thickness allowed should minimize the possibilities of exposure to humans and animals, either from inadvertent intrusion, radionuclide migration through the cover, or root penetration and plant uptake.

In summary, the augered hole disposal alternative offers the possibility of satisfactory isolation of the wastes from the ground surface, and hence satisfactory protection of humans, and barriers to animals and plants.

The increased depth of disposal in augered holes would reduce the amount of water infiltrating the wastes from the surface if backfill is compacted to prevent cracks from forming. Such cracks could short circuit the backfill's protection and provide preferential flow paths if they occurred.

Stable temperatures at greater depths may reduce the rate of formation of gases and thus reduce their rate of transport to the ground surface.

A high degree of protection from erosion and flooding may be achieved with augered holes.

To achieve the desired performance and minimize active maintenance, quality control of waste emplacement and backfilling must ensure that void spaces have been minimized and filled and that backfill is compacted. Also, water must be prevented from entering the hole during construction and operations.

3. CRITERIA APPLICABILITY

Each of the 10 CFR Part 61 Subpart D criteria related to site suitability, design, operations, closure, and monitoring have been assessed for applicability to each alternative method of disposal of low-level radioactive wastes considered in this report. The alternative methods under consideration ranged from surface disposal methods (aboveground vaults) to deep disposal methods (mined cavities). Thus, the existing criteria required examination to determine whether they were applicable and adequate for complete evaluation of each alternative. The general requirement for meeting the long-term performance objectives of Subpart C is implicit for each disposal alternative and the criteria specifying the goals of waste isolation are directly applicable in all cases. An assessment of each specific criterion versus each alternative is summarized in Figure 22, and the applicability of each is discussed below.

3.1 Assessment of 10 CFR 61.50, Disposal Site Suitability Requirements for Near-Surface Disposal

The criteria for assessment of disposal site suitability are contained in 10 CFR 61 Subpart D, paragraph 61.50. As stated in 61.50 (a)(1), "The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis in disposal site suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits." The criteria are restated below and are assessed with respect to the alternative methods discussed previously.

Criterion 10 CFR 61.50 (a)(2)

"The disposal site shall be capable of being characterized, modeled, analyzed, and monitored."

This criterion is directly applicable to each alternative disposal method. However, many mines are located in geologically complex areas where accurate characterization and modeling would be extremely difficult. Mined cavities in such areas may be excluded, while mines in bedded units such as salt and limestone would fit the criterion of geologically characterizable (predictable) sites.

Criterion 10 CFR 61.50 (a)(3)

"Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part. Reference 10 CFR Part 61 Subpart C - Performance Objectives." (These performance objectives are listed in Section 2 of this report.)

ALTERNATIVE DISPOSAL METHOD	10 CFR 61.D.50: Site Suitability (1) Acceptability	(2) Capable of Being Characterized	(3) Population Development	(4) Resource Exploitation	(5) Flooding	(6) Surface Runoff	(7) Ground-Water Intrusion	(8) Ground-Water Discharge	(9) Tectonic Hazards	(10) Surface Wasting Hazards	(11) Other Facility Impacts
Belowground Vaults									*	▨	
Aboveground Vaults					*	*	NA	NA ▨	*	▨	
Earth Mounded Concrete Bunkers						*	*		*	▨	
Mined Cavities		*	*	*	NA ▨	*	NA ▨		*	▨	▨
Augered Holes									*	▨	
Report Sec. Ref. Criteria	3.1 & 4.3										

ALTERNATIVE DISPOSAL METHOD	51: Site Design (1) Satisfy Performance Objectives	(2) Closure Capability	(3) Enhance Natural Characteristics	(4) Infiltration and Degradation	(5) Surface Runoff Control	(6) Minimize Contact with Water
Belowground Vaults		*		▨		
Aboveground Vaults	*	*		▨		
Earth Mounded Concrete Bunkers		*		▨		
Mined Cavities		*		▨	▨	*
Augered Holes		*				
Report Sec. Ref. Criteria	3.2 & 4.3					

ALTERNATIVE DISPOSAL METHOD	52: Site Operation and Closure (1) Waste Segregation	(2) Depth and Stability Standards	(3) Satisfy 52(a)(4)-(a)(11)	(4) Waste Packing Methods	(5) Subsidence Prevention	(6) Surface Radiation Limits	(7) Locate Units by Surveys	(8) Maintain Buffer Zones	(9) Close Units and Stabilize	(10) Maintain Closure During Disposal	(11) Limit Contents to LLW
Belowground Vaults	*			*	NA	▨					*
Aboveground Vaults	*			*	NA	▨			*		*
Earth Mounded Concrete Bunkers				*	▨	▨			▨		*
Mined Cavities	*			*	▨	▨			*		*
Augered Holes						▨					*
Report Sec. Ref. Criteria	3.3 & 4.3										

ALTERNATIVE DISPOSAL METHOD	53: Site Monitoring (a) Preoperation Monitoring	(b) Mitigation Plan	(c) Operational Monitoring	(d) Surveillance Monitoring
Belowground Vaults			▨	
Aboveground Vaults			▨	▨
Earth Mounded Concrete Bunkers			▨	
Mined Cavities			▨	*
Augered Holes			▨	
Report Sec. Ref. Criteria	3.4 & 4.3			

KEY: NA "Not applicable as Written"
▨ "Additional or Modified Criterion Identified"
blank space "Criterion Applicable as Written"
* "Qualifying Statement in Text"

Figure 22. Matrix of Criteria Applicability to Alternative Disposal Methods

This criterion is also directly applicable to each alternative disposal method. However, surface development would not necessarily compromise the waste isolation afforded by mined cavities, if intrusion by drilling and future mining are prohibited. If the minerals mined (for example, limestone or salt) are of low value there would be little incentive in future development to reopen a mine. Also, if the mine is dry, the possibility of contaminating surface or ground water would be remote. Thus, the disposal operations would be unlikely to have any adverse effects on the surface development.

Criterion 10 CFR 61.50 (a)(4)

"Areas must be avoided having known natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part."

Again, the criterion is directly applicable to each alternative disposal method. However, all existing mines were developed in areas having known natural resources; but if the valuable minerals in the specific area have been completely mined out this requirement may be met. The major consideration is the determination of the amount of the surrounding area or buffer zone that must be controlled to guarantee that no future activities impact upon the isolation of the buried wastes.

Criterion 10 CFR 61.50 (a)(5)

"The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year floodplain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines.""

This criterion is directly applicable to each alternative except mined cavities. However, since aboveground vaults do not represent a burial technique, their design facilitates the construction of base levels and underlying barriers above ponding elevations observed at specific sites. The flooding addressed in this criterion refers exclusively to surface flooding or ponding, whereas many mines are constantly wet and require pumping to avoid flooding from within. Such mines would thus be excluded. Dry mines would have to be assessed as to the likelihood of future flooding from surface or subsurface sources. The mines used for disposal would have to be well isolated from water-bearing geological units and all surface openings and unloading facilities and administrative buildings would have to be in nonflooding areas.

Criterion 10 CFR 61.50 (a)(6)

"Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units."

This criterion is directly applicable to belowground vaults and augered holes. Inundation of properly sited aboveground vaults or earth mounded concrete

bunkers is highly unlikely. However, overland flows must be controlled to minimize the potential for surface erosion and foundation erosion as suggested in the criterion. The criterion only applies to portals and shafts and surface facilities of mined cavities which could be inundated.

Criterion 10 CFR 61.50 (a)(7)

"The disposal site must provide sufficient depth to the water table that ground-water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of this part being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table."

This criterion is directly applicable to belowground vaults and augered holes. By definition, aboveground vaults are constructed on the surface and, therefore, are above the ground-water table. Earth mounded concrete bunkers are constructed both above and below ground level, thus any contact with the water table would place at least part of the facility in the zone of fluctuation. Earth-mounded concrete bunkers should, therefore, be placed entirely above the water table and the exception noted in the criterion is not applicable. Many mines are below the water table and some mines are below significant aquifers. To use any mine for waste disposal, it is necessary to prove that ground water will not move through the mined area. The exception allowed for molecular diffusion may be of use in demonstrating containment of wastes in the event of flooding of some mines. It may be necessary to control the water table at mines to a far greater extent than in trenches.

Criterion 10 CFR 61.50 (a)(8)

"The hydrogeologic unit used for disposal shall not discharge ground water to the surface within the disposal site."

This criterion is directly applicable to each disposal alternative except aboveground vaults. By strict application of the criterion terminology, an aboveground vault is not a "hydrogeologic unit used for disposal" and so the criterion, as written, does not apply to use of the aboveground vault concept. However, siting of aboveground vaults on a hydrogeologic unit that discharges ground water within the disposal site should be discouraged.

Criterion 10 CFR 61.50 (a)(9)

"Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

This criterion is directly applicable to each disposal alternative. However, the vulnerability of properly engineered structures, i.e., structures that are designed to resist damage from foreseeable seismic events (specifically earthquake-generated forces) is substantially less than any disposal concept relying heavily on subsurface placement of earth materials for satisfaction of performance objectives.

Criterion 10 CFR 61.50 (a)(10)

"Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

The criterion is applicable to each disposal alternative. However, only the portals and shafts and other surface facilities of mined cavities would be vulnerable to damage from surface geologic processes. While the criterion is applicable to each alternative, modifications are appropriate. For all the disposal methods, the criterion should be expanded to include the avoidance of areas where dispersive soils, liquefiable soils, or soils possessing corrosive geochemistry, and karstic or cavernous strata occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives.

Criterion 10 CFR 61.50 (a)(11)

"The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program."

This criterion is directly applicable to each disposal alternative. However, the criterion may need to be expanded for application to mined cavities. Many mines are located near other mines simply because of the local occurrence of a specific resource. Nearby mines and mining activities would have to be examined critically to determine that their future development will not adversely impact containment in mines selected for waste disposal. The requirement for monitoring may eliminate areas that have high background radioactivity, such as uranium or phosphate mines or areas where radioactive tailings have been placed.

3.2 Disposal Site Design Requirements for Near-Surface Disposal

Criterion 10 CFR 61.51 (a)(1)

"Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure."

This criterion is directly applicable to each of the five alternative disposal methods. The criterion may be difficult to satisfy in the long term with aboveground vaults. Because of their exposure to adverse climatic conditions they may require periodic maintenance throughout the institutional control period.

Criterion 10 CFR 61.51 (a)(2)

"The disposal site design and operation must be compatible with the disposal site closure and stabilization plan and lead to disposal site closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met."

The criterion is directly applicable to each method. Since each alternative contains multiple individual disposal units associated with a facility, the operations and closure of individual disposal units must be compatible with the site closure and stabilization plan.

Criterion 10 CFR 61.51 (a)(3)

"The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met."

This criterion is directly applicable to each alternative disposal method considered. In fact, the primary reason for considering any engineered facility for LLW disposal is that they may complement and improve the ability of the disposal site to meet the performance objectives.

Criterion 10 CFR 61.51 (a)(4)

"Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the disposed waste, and to resist degradation by surface geologic processes and biotic activity."

This criterion is applicable to each alternative, and is directly applicable to the augered hole disposal alternative. Additional criteria may be required for the other methods. For both belowground vaults and earth mounded concrete bunkers, additional criteria may be required specifying resistance of covers to degradation and corrosion from the soil geochemistry. Meteorological processes should be included in consideration of aboveground vault design. For mined cavities this requirement should be altered to require that infiltration into the disposal chamber through the roof, walls, or floor be minimized.

Criterion 10 CFR 61.51 (a)(5)

"Surface features must direct surface-water drainage away from disposal units at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future."

This criterion is directly applicable to each alternative disposal method except mined cavities. For mined cavities the criterion should require that surface-water drainage be directed away from all openings (portals and shafts) to the mined areas and away from unloading facilities and administrative buildings. For the depths of most mines, the potential problem of uncovering the waste from natural weathering and erosion would be negligible.

Criterion 10 CFR 61.51 (a)(6)

"The disposal site must be designed to minimize to the extent practicable the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal."

This criterion is directly applicable to each alternative. This criterion may be the most important consideration in selecting mines to be used for low-level radioactive waste disposal.

3.3 Near-Surface Disposal Facility Operation and Disposal Site Closure Requirements

Criterion 10 CFR 61.52 (a)(1)

"Wastes designated as Class A pursuant to 10 CFR 61.55, must be segregated from other wastes by placing in disposal units which are sufficiently separated from disposal units for the other waste classes so that any interaction between Class A wastes and other wastes will not result in the failure to meet the performance objectives in Subpart C of this Part. This segregation is not necessary for Class A wastes if they meet the stability requirements in 10 CFR 61.56(b) of this part."

This criterion is applicable to each alternative and is directly applicable to earth mounded concrete bunkers and augered holes. For belowground and aboveground vaults and mined cavities, Class A wastes may be segregated for disposal but segregation is not a necessary requirement for structural stability if the waste complies with the waste characteristics requirements in 10 CFR 61.56 (a)(1)-(8). (Waste decomposition with the generation of even small quantities of explosive gases such as hydrogen or methane would be very dangerous in these confined disposal units.) Segregation of unstable Class A wastes may be desirable so that any shifting or settling of these wastes will not affect adjacent Class B and C wastes.

Criterion 10 CFR 61.52 (a)(2)

"Wastes designated as Class C pursuant to 10 CFR 61.55, must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years."

This criterion is directly applicable to each alternative disposal method.

Criterion 10 CFR 61.52 (a)(3)

"All wastes shall be disposed of in accordance with the requirements of paragraphs (a)(4) through (11) of this section."

This general criterion is directly applicable to each alternative considered, except for the changes, or additions, which are noted below.

Criterion 10 CFR 61.52 (a)(4)

"Wastes must be emplaced in a manner that maintains the package integrity during emplacement, minimizes the void spaces between packages, and permits the void spaces to be filled."

This criterion is directly applicable to augered holes.

Package integrity is important and thus is directly applicable to each alternative disposal method. However, minimization of void spaces is not necessary for structural stability of vaults, bunkers or mined cavities. It is, however, desirable from the standpoint of efficient and economical operations.

Criterion 10 CFR 61.52 (a)(5)

"Void spaces between waste packages must be filled with earth or other solid material to reduce future subsidence within the fill."

This criterion is directly applicable to augered holes. The criterion is not applicable to belowground and aboveground vaults. Inherent within the concept of vault disposal units is an integrated structure capable of physical stability as it stands empty. Backfill material within void spaces between waste components in a vault is, therefore, not relevant to earth subsidence outside the vault. Earth subsidence is controllable by appropriate construction techniques prior to operation of the belowground vault. Backfilling of internal void spaces in a vault may, however, provide one more barrier to radionuclide migration and so should be encouraged.

For earth mounded concrete bunkers, the criterion should be expanded to require that the void spaces between wastes designated as Class B and Class C pursuant to 10 CFR 61.55, must be backfilled with concrete or otherwise stabilized, and that the void spaces within the tumulus of each unit be filled with soil or other solid material to minimize subsidence.

Within mined cavities, void spaces should be filled by grouting in horizontal cavities. Conventional trench packing systems could be employed if vertical shafts are used. Subsidence would not be a problem unless roof collapse occurred and this would be an important long-term consideration.

Grouting of void spaces in the disposal chambers would be an added barrier to radionuclide migration and ground-water intrusion and would minimize the possibility of roof collapse. The wording of the criterion should be altered to remove the reference to subsidence "within the fill."

Criterion 10 CFR 61.52 (a)(6)

"Waste must be placed and covered in a manner that limits the radiation dose rate at the surface of the cover to levels that at a minimum will permit the licensee to comply with all provisions of 10 CFR 20.105 of this chapter at the time the license is transferred pursuant to 10 CFR 61.30 of this part."

This criterion is directly applicable to all of the alternative disposal methods. Additionally, during the "operational" period of each unit, radiation dosages must also be limited at the surface, and temporary covers should be provided over high activity wastes during the interim between placement and closure.

Criterion 10 CFR 61.52 (a)(7)

"The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGS or NGS record files."

This criterion is directly applicable to all the alternative methods.

Criterion 10 CFR 61.52 (a)(8)

"A buffer zone of land must be maintained between any buried waste and the disposal site boundary and beneath the disposed waste. The buffer zone shall be of adequate dimensions to carry out environmental monitoring activities specified in 10 CFR 61.53(d) of this part and take mitigative measures if needed."

This criterion is directly applicable to each alternative.

Criterion 10 CFR 61.52 (a)(9)

"Closure and stabilization measures as set forth in the approved site closure plan must be carried out as each disposal unit (e.g., each trench) is filled and covered."

This criterion is directly applicable to each alternative disposal method except for the requirement for covering, which is not appropriate for aboveground vaults and mined cavities. They are, by definition, covered. For earth mounded concrete bunkers, closure plans should address the belowground monoliths and the aboveground tumuli separately. To assure closures within a reasonable time frame, a construction sequencing plan with projected future waste quantities should be submitted to demonstrate facility operation and closure time period for each alternative method.

Criterion 10 CFR 61.52 (a)(10)

"Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures."

This criterion is directly applicable to all of the alternative disposal methods considered.

Criterion 10 CFR 61.52 (a)(11)

"Only wastes containing or contaminated with radioactive materials shall be disposed of at the disposal site."

This criterion is also directly applicable to all of the disposal alternatives. However, it may not go far enough in stating what may not be disposed of, with respect to the various alternatives, e.g., hazardous or toxic wastes that are slightly radioactive.

3.4 Environmental Monitoring Requirements for Near-Surface Disposal

Criterion 10 CFR 61.53 (a)

"At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a twelve month period."

This criterion is directly applicable to each alternative disposal method.

Criterion 10 CFR 61.53 (b)

"The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of Subpart C may not be met."

This criterion is also directly applicable to all disposal methods.

Criterion 10 CFR 61.53 (c)

"During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early

warning of releases of radionuclides from the disposal site before they leave the site boundary."

This criterion is directly applicable to each alternative disposal method. The criterion should, however, be expanded to include specific reporting requirements demonstrating biotic, ecologic, and surface stability, including data on drainage water, ground water, meteorological factors (rainfall and air) and dose rates. In addition, a disposal plan should be submitted for surface drainage water and ground water that has been sampled and tested. Plans for mitigative measures should also be developed and submitted for approval prior to operation. Insufficient time may be available to develop plans for mitigation after a release of radiation has occurred, especially for the aboveground vaults.

Criterion 10 CFR 61.53 (d)

"After the disposal site is closed, the licensee responsible for postoperational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

This criterion is directly applicable to belowground vaults, earth mounded concrete bunkers, mined cavities, and augered holes. For aboveground vaults, the criterion is applicable, but should be expanded. The surveillance and early warning systems should be designed to detect releases of radionuclides as they approach the vault envelope as well as passage out of the structure. This requirement is deemed necessary because there is no secondary barrier to prevent radionuclide release and escape from the site. For mined cavities postoperational surveillance may be difficult to establish due to the lack of access to filled and closed chambers.

Consideration should be given to a site characterization program, design and operations, closure and a short-term, high technology monitoring system that would allow a high degree of confidence in the alternative's performance to be established in a relatively short time period. The monitoring program may then be phased out as the disposal facility's satisfactory performance is documented.

4. CONCLUSIONS AND RECOMMENDATIONS

In this section the suitability of each of the alternative disposal methods is briefly summarized. The applicability of the 10 CFR 61 Subpart D criteria are discussed and recommended modifications and supplemental criteria are outlined.

It should be noted that each of the methods studied offers some advantages such as enhanced waste isolation, enhanced protection of the general population and individuals, and increased stability of the disposal facility and site.

These advantages are accompanied in some cases by some disadvantages such as increased potential for exposure of workers during operations and more complex operations and monitoring requirements. Although costs were not developed for these disposal methods, their use would probably result in higher disposal costs than shallow land burial.

The suitability of each method is discussed in section 4.1 below, followed by the criteria assessment in section 4.2.

4.1 Suitability of Alternative Methods

4.1.1 Belowground Vaults

Use of belowground vaults is considered to be a satisfactory method for disposal of low-level radioactive wastes. Advantages and disadvantages of belowground vaults are highlighted below. More detailed discussion is given in section 2.1.

The advantages are:

a. Belowground vaults are visually unobtrusive.

b. They are not susceptible to damage or exposure of the waste packages from erosion, weathering, predictable seismic events, surface disturbances, or soil settlement.

c. They provide an effective extra barrier to plant or animal intrusion.

d. They provide an effective barrier to inadvertent human intrusion.

e. They provide an effective barrier to ground-water infiltration.

f. They provide an effective barrier to radionuclide migration.

g. They are structurally stable. They can support backfilled earth and do not depend on the waste packages for support.

h. Long-term active maintenance requirements should be minimal.

i. Belowground vaults may be easily relocated, if required.

j. Design and construction could be standardized for safe, efficient operations.

The disadvantages are:

a. Belowground vaults must be protected against flooding during construction and operations.

b. They are not amenable to visual inspection and monitoring after closure of the unit.

c. They are not amenable to the use of remote handling equipment.

d. Exposure of workers to radiation hazards could be high unless temporary covers or shields are used.

e. Belowground vaults must be protected from degradation caused by corrosive soils.

4.1.2 Aboveground Vaults

Aboveground vaults present a valid alternative for LLW disposal. Advantages and disadvantages are listed below and are discussed in more detail in section 2.2.

The advantages are:

a. Aboveground vaults do not depend on variable geological materials for waste isolation.

b. They do not rely on the waste packages for structural support.

c. They can be designed and constructed to resist damage or degradation from most foreseeable hazards.

d. Because of their high visibility and physical security, inadvertent human intrusion is highly unlikely.

e. They are not susceptible to ground-water infiltration.

f. They are not susceptible to plant and animal intrusion.

g. Design and construction could be standardized for safe, efficient operations.

h. Aboveground vaults can be inspected visually and are easily monitored.

The disadvantages are:

- a. Aboveground vaults possess no secondary barrier to radionuclide release. Insufficient time may be available for remedial actions, if required, before radionuclides leave site.

- b. The institutional control period is likely to be substantially longer than for other disposal options.

- c. Active maintenance requirements are likely to be more extensive than for other methods because of their exposure to the elements.

- d. They are not amenable to the use of remote handling equipment.

- e. Exposure of workers to radiation hazards may be high unless temporary waste covers or shields are used.

4.1.3 Earth Mounded Concrete Bunkers (EMCB's)

The feasibility of the earth mounded concrete bunker concept for LLW disposal is substantiated by 14 years operating experience in France. Again, the advantages and disadvantages of their use are listed below and are discussed in more detail in section 2.3.

The advantages are:

- a. Prior successful experience in France supports satisfactory performance.

- b. EMCB's are resistant to infiltration of surface and ground water.

- c. Inadvertent human intrusion is highly unlikely due to their visibility and physical barriers.

- d. EMCB's are easy to relocate, if required.

- e. Long-term active maintenance should be minimal.

- f. Remote handling of high activity wastes can be used to minimize exposure of workers to radiation hazards.

The disadvantages are:

- a. EMCB's must be protected from flooding during construction and operation.

- b. Strict packaging requirements and waste disposal sequencing requirements must be followed during operations.

- c. EMCB's are not amenable to low volume or intermittent operations.

4.1.4 Mined Cavities

Existing mined cavities in bedded limestone or salt may provide satisfactory waste isolation over the long periods required. To do so, they must be dry and structurally stable. Advantages and disadvantages of this alternative are listed below. Section 2.4 provides a more detailed discussion.

The advantages are:

a. Suitable dry, structurally stable mined cavities in geologically characterizable sites exist.

b. Mined cavities offer the potential for very good long-term waste isolation.

c. Inadvertent intrusion is highly unlikely.

d. Plant and animal intrusion is highly unlikely.

e. Long-term structural stability of mines is well documented.

f. Surface drainage or flooding are unlikely to adversely affect performance.

g. Surface developments are not likely to adversely impact performance.

h. Operation and closure of individual disposal chambers would not adversely affect other closed chambers or closure of facility.

The disadvantages are:

a. Not much can be done to enhance performance capabilities of marginally suitable existing mines.

b. Construction of new mined space for LLW disposal would be quite expensive.

c. Remedial action planning is complicated by lack of access.

d. Monitoring is complicated by remote location and limited access.

e. Mined cavity disposal is not amenable to the use of remote handling equipment for high activity wastes. Thus worker exposure to radiation hazards may be high.

4.1.5 Augered Holes

Disposal of LLW in augered holes is capable of providing at least as much, and perhaps greater waste isolation and protection of the general population and individuals than present shallow land burial practices.

Some of the advantages and disadvantages of augered hole disposal are listed below. They are discussed in more detail in section 2.5.

The advantages are:

a. Augered holes offer the potential for good long-term isolation of wastes.

b. Inadvertent human intrusion is unlikely.

c. Plant and animal intrusion is unlikely.

d. Remote handling equipment may be used for high activity wastes to enhance worker safety.

e. Augered holes are amenable to intermittent or low volume operations.

f. The operating period for individual holes is relatively short.

g. Closure of individual holes does not adversely affect nearby holes or closure of the site.

The disadvantages are:

a. Minimization of void spaces, backfilling, and compaction are necessary to minimize settlement and long-term maintenance.

b. The disposal area cannot be exploited as fully as other methods because of the relatively low volume capacity of the holes and the much higher volume of unused space surrounding each hole.

4.2 Applicability of Criteria and Recommended Modifications and Supplemental Criteria

4.2.1 Belowground Vaults

All of the 10 CFR 61.D Technical Requirements are directly applicable to the belowground vault disposal alternative with one exception. This variation is within Section 61.52 (a) on site operation and closure. Subsection 61.52 (a)(5) explicitly requires that void spaces between waste packages be filled with soil or other engineering material to reduce future subsidence. Vault structures, belowground and aboveground, are entirely self-supporting and do not rely on the contained waste packages for structural stability. This criterion is necessary for shallow land burial but it is not necessary for vault disposal. Backfilling of voids may be desirable, however, to provide an extra buffer or barrier to radionuclide migration.

Additional or modified criteria are suggested in the following areas:

Criterion 61.50 (a)(10) should be expanded to include the avoidance of areas where dispersive soils, expansive soils, liquefiable soils, corrosive soils,

and karstic areas occur with such frequency and extent as to significantly affect the ability of the disposal site to meet the performance objectives.

It is recognized that engineering modifications to site soils or specific design features can sometimes be used to overcome these problems. These factors can be taken into consideration during the normal review process if proposed by the license applicant.

Criterion 61.51 (a)(4) requires maintenance of waste package integrity, minimization of void spaces, and filling of the voids.

Package integrity should be maintained for any disposal method.

However, minimization of void spaces is not necessary for structural stability of belowground vaults. Similarly, filling of these voids is unnecessary for minimization of fill subsidence or structural stability.

Filling of these voids may provide an extra barrier to radionuclide migration and is desirable for this reason.

The potential for corrosion caused by incompatible soil chemistry should also be examined.

Criterion 61.52 (a)(6) should be expanded to require temporary wastes covers or shielding be used for high activity wastes in the interim between waste emplacement and vault closure.

Supplemental environmental monitoring criteria are suggested for specific reporting requirements for major parameters of concern. A plan for remedial actions should also be submitted prior to operations.

4.2.2 Aboveground Vaults

All of the technical requirements of 10 CFR 61 Subpart D (61.50-61.53) are applicable to aboveground vaults except 61.50 (a)(7), 61.50 (a)(8), and 61.52 (a)(5).

61.52 (a)(5) is not applicable for the same reasons as specified in the preceding discussion of belowground vaults. However, backfilling of voids between waste packages should be encouraged to provide an extra barrier to radionuclide migration.

61.50 (a)(7) and (8) concern ground-water intrusion and ground-water discharge from the hydrogeological unit used for disposal, respectively.

Because the aboveground vault is constructed entirely aboveground, ground-water intrusion is not a valid concern. Thus the criterion (a)(7) is unnecessary.

The waste packages placed in an aboveground vault are not within a hydrogeological unit. Thus the criterion, as written, is not applicable. However,

the vault should not be founded on a hydrogeological unit that discharges ground water to the surface. Therefore, it is suggested that the criterion be restated in more applicable terms.

Suggested modifications or supplemental criteria are discussed in the following paragraphs.

Criterion 61.50 (a)(10) should be expanded to include the avoidance of areas where dispersive soils, liquefiable soils, or corrosive soils, and karstic areas occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives.

Additional or modified site design criteria may be needed dealing with cover infiltration and degradation problems addressed in 61.51 (a)(4). Meteorological processes should be included in consideration of aboveground vault design.

Site operation and closure criterion 61.52 (a)(1) outlines waste segregation requirements. As noted in 3.3.1 of this report, waste segregation is not necessary for assurance of structural stability of vaults. However, segregation of unstable Class A wastes may be desirable so that any settlement or shifting of unstable Class A wastes does not affect adjacent Class B and Class C wastes.

The criteria in 61.52 (a)(4) and 61.52 (a)(5) require waste package integrity to be maintained, require minimization of void spaces, and filling of void spaces. As discussed for belowground vaults, maintenance of package integrity is important for safe operation of any disposal alternative. However, minimization of void spaces is not necessary for structural stability of aboveground vaults. Likewise, filling of these voids is not necessary for minimization of fill subsidence or for structural stability, but is desirable because of the backfill's extra buffer to radionuclide migration.

Also, as mentioned for belowground vaults, the criterion limiting radiation dose at the surface of the cover (61.52 (a)(6)) should be expanded to require temporary waste covers or shields for use in vaults.

The environmental monitoring criteria of 61.53 are applicable to aboveground vaults, but suggested supplemental criteria are recommended for operational monitoring (61.53 (c)). The suggested supplemental criteria are for specific reporting requirements, submittal of a disposal plan for collected surface and ground water, and submittal of plans for mitigative measures or remedial actions. This last requirement is considered as quite important for aboveground vaults because of the lack of a secondary barrier preventing radionuclide escape from the site, if the vault is breached or otherwise fails to perform as required.

Mainly because of this potential risk, additional surveillance monitoring requirements are recommended for aboveground vaults, so that radionuclide migration may be detected as they approach the vault envelope before passing out of the vault structure.

4.2.3 Earth Mounded Concrete Bunkers

All of the criteria set forth in 10 CFR 61 Subpart D are applicable, either directly or indirectly, to earth mounded concrete bunkers. The alternative represents a variation of shallow land burial methods which the criteria specifically address and thus the requirements inherent in siting, design, operations, closure, and monitoring are applicable. Since the design and subsequent operation of earth mounded concrete bunkers are somewhat more sophisticated than shallow land burial, some of the specified criteria may be too general and may require expansion to address specific features of this alternative. Suggested modifications are discussed below.

The site suitability criteria are applicable to evaluation of earth mounded concrete bunkers with little modification. The exception noted in 61.50 (a)(7) whereby disposal below the water table may be considered is not applicable. EMCB's are constructed both below and above the ground surface, thus any contact with the water table would place part of the facility within the zone of fluctuation. Therefore, earth mounded concrete bunkers should be placed entirely above the water table.

Criterion 61.50 (a)(10) should be expanded to include avoidance of areas where liquefiable soils, dispersive soils, or soils of corrosive geochemistry occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives.

The site design criteria are applicable as written with one minor exception. It is recommended that 61.51 (a)(4) be expanded to specify resistance of the cover to degradation from corrosive soil chemistry. This requirement may imply the use of sulfate resistant or other special concrete mixes where appropriate.

Additional or modified site operation and closure criteria are suggested for 61.52 (a)(5), (6), and (9). Backfill placed in voids in the monoliths should be concrete. Backfill in the tumulus may be soil or other solid material.

Temporary covers for high activity wastes should be specified for use during operations within the belowground monoliths before the concrete backfill is placed.

It is recommended that closure plans for disposal units should separately address the monoliths and tumulus because of the difference in operations and materials.

Environmental monitoring requirements are applicable as written. As discussed earlier, it is recommended that specific reporting requirements be developed for parameters of importance and that a remedial action plan be developed and submitted, prior to operating the facility.

4.2.4 Mined Cavities

Most of the criteria set forth in 10 CFR 61 Subpart D are applicable to mined cavities. The greater isolation afforded by mined cavities may allow some

exceptions to be made with regard to 61.50 (a)(3) population growth and development. An exception to the requirement regarding proximity to known natural resources (61.50 (a)(4)) may be allowable in some cases. The provisions in 61.50 (a)(5) and 61.50 (a)(7) regarding flooding and ground-water intrusion may need modification to cover the possibility of seepage from surrounding water-bearing units.

Criterion 61.50 (a)(10) applies only to the surface features of a mined cavity disposal facility. The criterion should be expanded to include avoidance of areas where dispersive soils, liquefiable soils, corrosive soils, and karstic or cavernous strata occur with such frequency and extent to significantly affect the ability of the site to meet the performance objectives or to preclude defensible modelling and prediction of long-term impacts.

While criterion 61.50 (a)(11) is applicable to mined cavities, it should be expanded to require that nearby mines and mining activities be examined to determine whether existing and future operations will affect the selected mine's waste isolation capabilities, or the environmental monitoring program.

The design criterion 61.51 (a)(4) should be modified to require that infiltration or seepage through the roof, walls, and sides of the disposal chamber be minimized.

Criterion 61.51 (a)(5) again applies only to surface features of the disposal facility. The criterion should be restated to require that all surface water drainage be directed away from these facilities.

The 61.52 (a)(4) and (a)(5) operations and closure criteria may need modification. As in the case of vaults, minimization and backfilling of void spaces is not necessary for structural stability. However, grouting of voids is recommended as an added barrier to radionuclide migration and ground-water intrusion. Grouting of voids would also provide added protection against roof collapse. The criterion should also be restated to remove the reference to subsidence within the fill.

Criterion 61.52 (a)(6) should be restated to require temporary covers or shielding for high activity wastes in the interim between emplacement and closure of the chamber.

The environmental monitoring criteria are applicable as written. However, additional criteria are suggested to require submittal of a plan for disposal of collected drainage water and submittal of a plan for remedial actions. A plan for remedial actions is especially important because of the limited access to the disposal chambers. Specific reporting requirements should also be specified for the major parameters of concern.

For surveillance monitoring addressed in 61.53 (d), consideration should be given to development of a highly reliable short-term monitoring system that would allow the facility's performance to be established in a relatively short time. The monitoring program could then be phased out as the facility's satisfactory performance is established and documented.

4.2.5 Augered Holes

The augered hole disposal concept is not radically different from present shallow land burial practices. In both cases, wastes are disposed of in shallow excavations in unconsolidated materials. The site suitability requirements would be similar for both, and in fact, may be more easily met with augered hole disposal. Augered hole disposal at greater depths than is practiced for shallow land burial could enhance the site's ability to meet the performance objectives.

Three areas were noted in section 3 of this report where additional or modified criteria may be required. These criteria were also targeted for modification in the discussion of each of the other methods and the same modifications are appropriate.

The criteria and modifications are: 61.50 (a)(10) should be expanded, as noted previously to include avoidance of dispersive, liquefiable, and corrosive soils, and consideration of karstic or cavernous strata that occur with such frequency and extent as to significantly affect the ability of the disposal facility to meet the performance objectives.

61.52 (a)(6) should be expanded to require high activity wastes be covered in the interim between placement and closure of the hole.

61.53 (c) should be expanded to include specific reporting requirements for parameters of concern, and to require submittal of a plan for remedial actions.

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GLOSSARY

ACTIVE MAINTENANCE: Any significant remedial activity needed during the period of institutional control to maintain a reasonable assurance that the performance objectives in 10 CFR 61.41 and 61.42 are met. Such active maintenance includes ongoing activities such as the pumping and treatment of water from a disposal unit or one-time measures such as replacement of a disposal unit cover. Active maintenance does not include custodial activities such as repair of fencing, repair or replacement of monitoring equipment, revegetation, minor additions to soil cover, minor repair of disposal unit covers, and general disposal site upkeep such as mowing grass.

ACTIVITY: A measure of the rate at which a material is emitting nuclear radiations; usually given in terms of the number of nuclear disintegrations occurring in a given quantity of material over a unit of time; the standard unit of activity is the curie (Ci), which is equal to 3.7×10^{10} disintegrations per second.

ADIT: A nearly horizontal tunnel through which an underground mine is entered, drained, or ventilated.

AGREEMENT STATES: Any States with which the Commission or the AEC has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954. A Nonagreement State is any other State. (10 CFR 150.3)

AQUICLUDE: A formation which, although porous and capable of absorbing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring. (ASTM STP 746)

AQUIFER: Geologic stratum or set of beds with relatively high transmissivity and carrying ground water in quantities to make exploitation for consumption economically feasible.

AUGERED HOLES: Cylindrical, near-vertical holes or shafts excavated by spiral augers or other methods.

BACKGROUND RADIATION: Radiation in the environment from naturally occurring radioactive elements, cosmic radiation, and fallout from man's activities such as nuclear weapons testing.

BUFFER ZONE: A portion of the disposal site that is controlled by the licensee and that lies under the disposal units and between the disposal units and the boundary of the site.

BUNKER: A protective embankment or dugout; especially a chamber mostly below-ground of reinforced construction.

CURIE (Ci): A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second (d/s); millicurie (mCi) = 10^{-3} curie; microcurie (Ci) = 10^{-6} curie; nanocurie (nCi) = 10^{-9} curie; picocurie (pCi) = 10^{-12} curie; femtocurie (fCi) = 10^{-15} curie.

DECONTAMINATION: The selective removal of radioactive material from a surface or from within another material.

DIAPIR: A convex upward fold in which a mobile core has broken through the more brittle overlying rocks; a piercement fold structure. Commonly associated with salt domes.

DISPOSAL SITE: That portion of a land disposal facility which is used for disposal of waste. It consists of disposal units and a buffer zone.

DISPOSAL UNIT: A discrete portion of the disposal site into which waste is placed for disposal. For current near-surface disposal the unit is usually a trench.

ENGINEERED BARRIER: A man-made structure or device that is intended to improve a land disposal facility's ability to meet the performance objectives in 10 CFR Part 61, Subpart C.

ENGINEERED DISPOSAL: As used in this report, the disposal of radioactive wastes, usually in suitable sealed containers, in any of a variety of structures especially designed to protect them from water and weather and to prevent leakage to the biosphere by accident or sabotage.

ENVIRONMENTAL SURVEILLANCE: Monitoring of the impact on the surrounding region of the discharges from industrial operations, forest fires, storm runoff, or other natural or man-induced events.

EXPOSURE: A measure of the ionization produced in air by X or gamma radiation. It is the quotient of (1) 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 (2) the mass of the air in the volume element. The special unit of exposure is the Roentgen. (Radiological Health Handbook, U. S. Dept. of HEW). Acute exposure generally refers to a high level of exposure of short duration; chronic exposure is lower-level exposure of long duration.

GROUND WATER: Water that exists or flows below the ground surface (within the zone of saturation).

GROUT: Fluid or semifluid material, often containing Portland cement, which may be pumped or poured into earth strata and by setting up into a solid state, provides mechanical stabilization or water flow control.

HALF-LIFE: The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billons of years. After a period of time equal to 10 half-lives, the radioactivity of a radionuclide has decreased to 0.1 percent of its original level.

HAZARDOUS WASTE: Those wastes designated as hazardous by Environmental Protection Agency regulations in 40 CFR Part 261.

HYDROGEOLOGY: The study of ground water, with particular emphasis on its chemistry, mode of migration, and relation to the geologic environment. (Davis and De Wiest, 1966).

HYDROGEOLOGIC UNIT: Any soil or rock unit or zone which by virtue of its porosity or permeability, or lack thereof, has a distinct influence on the storage or movement of ground water.

IN SITU: In the natural or original position; used to refer to inplace experiments at a storage or disposal site.

INADVERTENT INTRUDER: A person who might occupy a disposal site after closure and engage in normal activities, such as agriculture, dwelling construction, or other pursuits, in which the person might be unknowingly exposed to radiation from the waste.

INTRUDER BARRIER: A sufficient containment of the waste that inhibits human contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in 10 CFR 61; or engineered structures that provide equivalent protection to the inadvertent intruder.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

ION EXCHANGE: A reversible interchange that takes place between ions of like charge, usually between ions present on an insoluble solid and ions in a solution surrounding the solid. An important process in both fundamental and industrial chemistry.

ION-EXCHANGE RESIN: An insoluble polymerized electrolyte that contains either acidic groups for exchanging cations or basic groups for exchanging anions. It contains large, high-molecular-weight ions of one charge and small, simple ions of the opposite charge. The small ions undergo exchange with ions in solution.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

ISOTOPES: Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Identical chemical properties exist between isotopes of a particular element.

KARST: Surface or subsurface rock mass conditions characterized by solution-formed caverns, cavities, open joints, pinnacles, and depressions of a highly irregular form. Almost exclusively applied to carbonate lithologies, e.g., limestone.

LAND DISPOSAL FACILITY: Land, buildings, and equipment intended to be used for the disposal of radioactive wastes into the subsurface of the land. A geologic repository as defined in 10 CFR 60 is not considered a land disposal facility. (10 CFR 61.2)

LEACHING: The process of extracting a soluble component from a solid by the percolation of a solvent (e.g., water) through the solid.

LIQUEFIABLE: Susceptible to near-total loss of shear strength and bearing capacity duing seismic disturbances; used with reference to soils.

LITHOLOGY: The character of a rock formation or of the rock found in a geological area or stratum expressed in terms of its structure, mineral composition, color, and texture.

LOW-LEVEL RADIOACTIVE WASTE (LLW): Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined in section 11e. (2) of the Atomic Energy Act of 1954. (P.L. 96-573) Radioactive wastes containing source, special nuclear, or by-product material that are acceptable for disposal in a land disposal facility (10 CFR 61.2) For explanation of Class A, Class B, and Class C LLW, see 10 CFR 61.55 and 61.56.

NEAR-SURFACE DISPOSAL FACILITY: A land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth's surface.

PERMEABILITY: The capacity of a porous medium to conduct liquids or gases.

PIEZOMETER: An instrument for measuring pressure head in ground water. In an unconfined aquifer with a free water table a piezometer is frequently an open-bottomed monitor well extending below that water table.

PSYCHROMETER: Device used for measuring the amount of water vapor in air; e.g., a hygrometer.

PYROPHORIC: Igniting spontaneously. A pyrophoric liquid is any liquid that ignites spontaneously in dry or moist air at or below 130°F (54.5°C). A pyrophoric solid is any solid material, other than one classed as an explosive, which under normal conditions is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation, handling, or disposal hazard. Included are spontaneously combustible and water-reactive materials.

RAD: The unit of absorbed dose equal to 100 ergs per gram or 0.01 joule per kilogram.

RADIOACTIVITY: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emitting X radiation following orbital electron capture, or of undergoing spontaneous fission. (Radiological Health Handbook, U. S. Dept. of HEW)

REM: A special unit of dose equivalent. The dose equivalent 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. (Radiological Health Handbook, U. S. Dept. of HEW) The dosage of any ionizing radiation that will cause the same amount of biological injury to human tissue

as one roentgen of X-ray or gamma-ray dosage. (Webster's Third New International Dictionary) (1 millirem = 0.001 REM)

REPOSITORY: A term generally applied to a facility for the disposal of radioactive wastes, particularly high-level waste and spent fuel.

ROENTGEN: The special unit of exposure. One roentgen equals 2.58×10^{-4} coulomb per kilogram of air. (Radiological Health Handbook, U. S. Dept. of HEW) The international unit of X radiation or gamma radiation that is the amount of radiation producing, under ideal conditions in one cubic centimeter of air at 0°C and 760 mm Hg pressure, ionization of either sign equal to one electrostatic unit of charge. (Webster's Third New International Dictionary)

SEISMIC: Of, pertaining to, of the nature of, subject to, or caused by an earthquake.

SITE CLOSURE AND STABILIZATION: Those actions that are taken upon completion of operations that prepare the disposal site for custodial care and that assure that the disposal site will remain stable and will not need ongoing active maintenance.

SUBSIDENCE: Sinking or depression of the ground surface; generally due to loss of subsurface support.

SURVEILLANCE: Observation of the disposal site for purposes of visual detection of need for maintenance, custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.

TECTONIC: Of or relating to the deformation of the earth's crust, the forces involved in or producing such deformation, and the resulting rock structures and external forms.

TILEHOLE: A form of augered hole which is lined with ceramic, concrete, or metal fabrications and may be used for retrievable radioactive waste storage.

TRANSMISSIVITY: A property of an aquifer; the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

UNSATURATED ZONE: The zone of soil or rock between the ground surface and the water table; also termed the vadose zone.

VAULT: An artificial enclosed space covered by an overhead structure; especially a passage or room used for storage or safekeeping.

VULCANISM: The processes by which magma (molten rock material within the earth) and its associated gases rise into the earth's crust and are extruded onto the earth's surface and into the atmosphere.

WATER TABLE: The surface within an unconfined aquifer between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to atmospheric pressure.

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13 ABSTRACT (200 words or less)

The study reported herein contains the results of Task 1 of a four-task study entitled "Criteria for Evaluating Engineered Facilities." The overall objective of this study is to ensure that the criteria needed to evaluate five alternative low-level radioactive waste (LLW) disposal methods are available to the Nuclear Regulatory Commission (NRC) and the Agreement States. The alternative methods considered are belowground vaults, aboveground vaults, earth mounded concrete bunkers, mined cavities, and augered holes. Each of these alternatives is either being used by other countries for low-level radioactive waste (LLW) disposal or is being considered by other countries or U.S. agencies.

In this report the performance requirements are listed, each alternative is described, the experience gained with its use is discussed, and the performance capabilities of each method are addressed. Next, the existing 10 CFR Part 61 Subpart D criteria with respect to paragraphs 61.50 through 61.53, pertaining to site suitability, design, operations and closure, and monitoring are assessed for applicability to evaluation of each alternative. Preliminary conclusions and recommendations are offered on each method's suitability as an LLW disposal alternative, the applicability of the criteria, and the need for supplemental or modified criteria.

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