[DNFSB LETTERHEAD]

October 13, 1994

The Honorable Hazel R. O'Leary
Secretary of Energy
Washington, DC 20585

Dear Secretary O'Leary:

By letter dated September 8, 1994, the Defense Nuclear Facilities Safety Board (Board) submitted to you Recommendation 94-2, concerning the Low-Level Waste Disposal Policy for the Department of Energy's (DOE's) Defense Nuclear Facilities. In preparing it's Recommendation, the Board had the benefit of a report prepared by it's staff. Since this report may be of use to you and your associates in evaluating the Board's Recommendation, I am enclosing it for you.

The Board has designated Mr. Steven Stokes of our technical staff to be available to provide any additional information DOE personnel may require.

Sincerely,

John T. Conway
Chairman

c: The Honorable Charles B. Curtis, Under Secretary
The Honorable Thomas Grumbly, EM-1
The Honorable Tara O'Toole, EH-1
Mr. Mark Whitaker, EH-6

Enclosure

DNFSB/TECH-2

Low-Level Waste Disposal Policy
for
Department of Energy Defense Nuclear Facilities

Defense Nuclear Facilities Safety Board

Technical Report

September 14, 1994

Low-Level Waste Disposal Policy for Department of Energy Defense Nuclear Facilities

This paper was prepared for the DNFSB by the following staff members:

Dominic S. Napolitano
Mark T. Sautman
Monique V. Helfrich
Steven A. Stokes

September 14, 1994

Low-Level Waste Disposal Policy for Department of Energy
Defense Nuclear Facilities

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I. Overview

This report is the result of Defense Nuclear Facilities Safety Board (DNFSB) staff reviews of Department of Energy (DOE) radioactive waste management policy and of staff visits to three DOE sites - Hanford, the Los Alamos National Laboratory (LANL), and the Savannah River Site (SRS). The review team consisted of Monique V. Helfrich, Dominic S. Napolitano, Mark T. Sautman, and Steven A. Stokes. Additional assistance was provided by J. Timothy Arcano. This effort and its results are summarized below.

A. Purpose/Methodology

The DNFSB staff reviewed Department of Energy low-level waste (LLW) policy to determine if it ensures that defense nuclear sites incorporate defense-in-depth practices in the design and operation of LLW facilities. The staff focused on buried waste since waste in temporary above ground storage is usually later emplaced in burial pits.

The DNFSB staff attempted to identify the strengths and weaknesses of DOE's LLW guidelines. A comprehensive review of the DOE Order 5820.2A, *Radioactive Waste Management*, and the DOE Performance Assessment Peer Review process was undertaken.

Once the team had identified the positive and negative elements of DOE's policy, low-level waste management practices at three DOE sites (Savannah River, Los Alamos, and Hanford) were examined to see if any site was adversely impacted by the Order's deficiencies, or if the Order's strengths compensated for possible detrimental impacts. In reviewing the three sites, commercial standards were also used as a minimum frame of reference since they provide a basic defense-in-depth approach to low-level waste disposition.

The defense-in-depth concept is well developed in the nuclear power industry and incorporates by design, construction, and operation the concept that radioactive materials are contained within a succession of physical barriers[1]. As used in this paper, the defense-in-depth approach is illustrated in commercial standards[2] for site suitability, facility design, facility operation, and waste form which when taken together represent a systems approach for low-level waste disposition.

B. Department of Energy Low-Level Waste Policy

DOE's low-level waste inventory (see appendix A) is subject to Order 5820.2A, *Radioactive Waste Management*. The Order requires that a site's disposal system meet certain performance objectives. These include allowable dose and release limits. The Order also prohibits disposal of certain wastes and states which factors should be considered when developing and executing a waste management program[3].

The Order requires DOE sites to develop performance assessments (PA), comprehensive reports that estimate the dose consequences of low-level waste disposal. PA's are used to show compliance with the performance objectives and are required by the DOE Order to be used in the development of facility designs and waste acceptance criteria. PA's apply only to individual facilities on a site rather than to a site as a whole.

As described in DOE guidance for their preparation, PA's are useful tools that should determine which designs and criteria will comply with performance objectives[4]. Because many of the radionuclides involved have long half-lives, PA's rely heavily on predictive models. However, predictive models can introduce significant uncertainties. For example, DOE sites are not required to consider their entire inventory of disposed radionuclides in performance assessments; therefore, a significant amount of uncertainty concerning a site's capability, as a whole, to meet performance objectives is interjected into the analysis. The validity of a DOE performance assessment would be compromised by the high level of uncertainty resulting from the exclusion of a significant volume of waste from a site or facility.

Commercial industry has developed defense-in-depth designs and practices to help lessen the impact of uncertainties on disposal criteria. However, DOE has not established a set of required standards which identify similar defense-in-depth principles, and its Order addresses implementation of good practices in only a general manner[5]. Consequently, DOE guidelines allow sites to base their programs on modeling efforts which may possibly have significant uncertainty or unknowns associated with them.

C. Implementation of DOE Policy - Practices Developed at DOE Sites

Many DOE sites are still in the preliminary stages of developing performance assessments. Without these completed efforts and in the absence of DOE standards for low-level waste disposition, the DNFSB staff has observed that some DOE sites have developed disposal programs characterized by minimal engineered covers, operational practices not geared toward ensuring the integrity of waste forms and disposal trenches, and a lack of requirements for both intruder barriers and waste stabilization.

II. Department of Energy Low-Level Waste Disposal Policy and its Deficiencies

Traditionally, DOE's low-level waste has been disposed of using shallow land burial. Criteria for this practice have evolved significantly over the nuclear industry's nearly half century of existence. Initially, shallow land burial consisted of pit excavation, random waste emplacement, and construction of a thin earth cover. Current commercial standards (see appendix B) include provisions for engineered infiltration barriers, waste stabilization, systematic emplacement, and technically justified closure programs. In addition, some recently designed disposal facilities for both commercial and DOE sites, utilize engineered structures that provide more defense-in-depth than shallow land burial. This is illustrated in the conceptual designs completed by state compacts (see appendix C), as well as the vault system at the Savannah River Site.

A. Disposal Objectives

DOE Order 5820.2A, *Radioactive Waste Management*, forms the defense nuclear complex's basis for low-level waste management. The Order describes, in general terms, disposal practices that site operators should use[6]. The primary focus of the Order is the establishment of performance objectives for facilities. These objectives are public protection goals which disposal facilities are required to meet. Each site operator is required to develop specific criteria which would realize these goals. DOE's objectives are[7]:

1. "Protect public health and safety in accordance with standards specified in applicable EH Orders and other DOE Orders."

2. "Assure that external exposure to the waste and concentrations of radioactive material which may be released into surface water, ground water, soil, plants, and animals result in an effective dose equivalent that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR 61. Reasonable effort should be made to maintain releases to the general environment as low as reasonably achievable."

3. "Assure that the committed effective dose equivalents received by individuals who may inadvertently intrude into the facility after the loss of active institutional control (100 years) will not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure."

4. "Protect groundwater resources, consistent with Federal, State, and local requirements."

DOE applies the Order's objectives only to waste disposed of after 1988 (the year the Order was issued). DOE Order 5820.2A does not require that waste disposed of before 1988 achieve these performance criteria. In addition, performance objectives apply only to individual disposal facilities, not the combination of all low-level waste disposal facilities at a given site[8].

Consequently, the DOE system relies on the sites to develop their own standards for disposal programs by preparing performance assessments. DOE has not established standards identifying which practices should be used to ensure the performance objectives are met. The ramifications of DOE's interpretation of the Order and the lack of a standards-based approach are discussed below.

B. Performance Assessment and Standards

A performance assessment is an in-depth technical analysis which contains a logical description of the source term and potential contaminant transport pathways that can impact the public's health and safety and the environment. Calculational models used to determine compliance with performance objectives typically require various simplifying assumptions to facilitate this analysis[9]. Additionally, all assumptions used should be realistic, yet conservative and the use of site-specific data is strongly recommended[10].

The use of simplifying assumptions can result in the introduction of error and uncertainty into the technical analysis. There are three sources of uncertainty which may effect performance assessments: input parameters, scenarios for exposure to the general public and intruders, and models[11]. The uncertainty in such input parameters as geology, hydrology, source term, waste form degradation rates, and erosion rates is often due to the limited site-specific information available. Uncertainties in radionuclide release scenarios, such as human and biotic intrusion and natural phenomenon, are due to the long time periods which need to be examined because of the safety threats posed by long-lived radionuclides. Lastly, predictive models may not be able to sufficiently simulate the complexity of site characteristics or radionuclide transport mechanisms due to the approximations used to solve transport equations and/or the assumptions used in the model's formulation.

The sources of uncertainty listed above can be reduced with varying degrees of difficulty. For example, input parameter uncertainty can be minimized, but extensive site characterization efforts may be required to fully resolve issues associated with unknown source terms and complex hydrogeologies. Elements of significant uncertainty may also be present in both model and scenario development[12]. For example, predictive models must make approximations and assumptions in order to solve transport equations. Since scenario selection is dependant upon patterns of future human behavior, assumptions must be made about that behavior. These approximations and assumptions are sources of uncertainty that can not be reduced. While the error introduced by equation solution can be determined through experiment, it is difficult to estimate how much uncertainty is introduced by scenario development. A modeler can attempt to conservatively estimate the data for a scenario, e.g., the type and quantities of food intake, water usage, damage from natural phenomena; however, the long-time frames modeled preclude consideration of every possible event that is dependent upon future human behavior.

Guidelines have been developed that attempt to address through sensitivity and uncertainty analysis the ability of the performance assessment to predict the performance of any system[13,14]. However, these analytical tools do not eliminate all uncertainty. They can only be used to assess the degree to which the predicted systems or sub-systems behavior depends on particular assumptions or parameters (sensitivity analysis) or to determine the extent that the predicted performance may differ from actual performance (uncertainty analysis)[15].

The Savannah River E-Area Vault Performance Assessment demonstrates how uncertainties can affect efforts to model this type of disposal system[16]. Through a sensitivity analysis, the assessment identifies its key unknowns: partition coefficients, hydraulic conductivities, recharge rates, and the service life of the vault. However, the performance assessment notes that many of the largest uncertainties are associated with assumptions for intruder scenarios. For the most part, these uncertainties are essentially irreducible because they cannot be better quantified through site characterization, and because they depend on future human behavior patterns (i.e., future site use). In the SRS E-Area Vault assessment, the intruder scenario is an important basis for establishing radionuclide inventory limits, and its credibility is very important to the model's conclusions.

Standards developed for shallow land burial can help compensate for errors and uncertainties in modeling. For example, the U.S. Nuclear Regulatory Commission's criteria (described in appendix B) aim to provide a defense-in-depth approach. The extent to which a model's shortcomings influence disposal criteria development can be reduced by increasing the conservatism, consistent with NRC's criteria or similar standards. The relationship between NRC's standards and modeling is summarized below.

1. Siting criteria - Increasing conservatism in standards for groundwater depth, site homogeneity, location of discharges, and allowable geologic processes can reduce the effect of hydrogeologic uncertainties.

2. Design - Stiffer standards for covers, biotic and intruder barriers, and drainage systems, reduce the impact of scenario assumptions and infiltration modeling uncertainties.

3. Operations - Improved standards for waste segregation, stabilization, and backfilling help extend the service life of the cover system and lessen the effects of unknowns resulting from an inadequate description of the site's hydrogeology, scenario selection, and modeling approximations for container integrity, and radionuclide distribution.

DOE does not require site operators to use a standards-based approach to achieve defense-in-depth. Rather, DOE has site operators use the performance assessment process to hopefully develop a set of criteria that can achieve the performance objectives. Consequently, DOE contractors may not necessarily develop conservative disposal criteria which employs the defense-in-depth approach.

C. Performance Assessment and Source Term

The operator of a site with many disposal facilities can design its waste management system so that all of its waste, past and future, meets performance objectives. For example, a site may have two contiguous disposal facilities: one for waste disposed of long ago and one for current waste. The site operator may also be planning to construct a new facility nearby for future waste. Each of these facilities will have a distinct source term. However, it is possible that releases from adjacent facilities share common environmental pathways and contaminant plumes from the facilities might combine and result in a cumulative dose.

A comprehensive approach to design would be to apply a single performance objective to all facilities combined, so that the total release from the system would not exceed allowable limits. Clearly, the design of one facility should affect disposal criteria for the other two. For example, if the old facility was poorly designed, then the new facility may need to compensate by including more infiltration barriers.

DOE sites are not required to ensure that waste disposed of prior to 1988 will meet the performance objectives[17]. For example, the performance objectives for facilities containing waste disposed of before 1988 at the Savannah River Site are being determined using the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) process[18]. Therefore, the Savannah River Site is not required to consider older facilities in the design of current and future facilities. The SRS Vault system is designed and will be operated to meet DOE performance objectives. However, this facility has a finite capacity which may not last for the entire site mission. Consequently, SRS may need to construct new disposal facilities. However, if new facilities are designed and operated in compliance with the same performance objectives as the Vaults, the cumulative impact of all the facilities may exceed the public protection goals for which the DOE Order is intended.

Given that contaminant plumes may overlap, there is no technical justification for allowing DOE to ignore components of its disposal system's source term based on arbitrary time frames or facility boundaries. If performance assessments included the site's entire low-level waste source term, with each component's associated pathway, a more accurate description of a site's total dose consequence could be predicted, and more robust facilities could be designed.

D. Summary

Performance assessments are useful tools to determine compliance with performance objectives. DOE policy requires site operators to rely upon PA's to help develop site-specific low-level waste disposal designs and criteria. However, if any of the following are true, DOE's reliance on this analytical tool could result in an unconservative approach to waste disposition: (1) a completed performance assessment does not exist; (2) the performance assessment does not address waste disposition using a systems approach; (3) an assessment has an extremely high degree of uncertainty. Moreover, continued waste emplacement without a detailed technical basis and without imposing other requirements will result in a fundamentally flawed approach to waste management. In contrast, defense-in-depth designs and practices, consistent with commercial standards, provide, at a minimum, a basis to eliminate weaknesses inherent in performance assessments.

III. Implementation of Department of Energy Policy

A. Structure and Status of Performance Assessment Process

The Department of Energy and the Nuclear Regulatory Commission have adopted the performance assessment process to analyze disposal facilities. DOE Order 5820.2A states, "Field organizations shall prepare and maintain a site-specific radiological performance assessment for the disposal of waste and for demonstrating compliance with the performance objectives stated in paragraph 3a [see above]."[19] The performance assessment addresses how the characteristics of the region, facility, and waste, as well as the disposal practices, interact to minimize human exposure to the disposed radioactive material.

1. Structure of Radiological Performance Assessment Approval Process

There are three components in the performance assessment approval process as established by DOE Order 5820.2A and related documents[20,21]. First, during the development of a performance assessment, a Peer Review Panel (the Panel), whose members are chosen by the Deputy Assistant Secretary for Waste Management (EM-30), conducts a preliminary review. Second, once a field organization completes a performance assessment, it is sent to EM-30. EM-30 tasks the Panel with executing a final review to judge the technical adequacy of the document. Third, Panel recommendations are transmitted to EM-30, where they are used to approve the document. In addition, DOE Order 5820.2A (8)(e) requires the Office of Environment, Safety, and Health (DOE-EH) to provide independent oversight for radioactive waste management programs and to determine compliance with the Order requirements.

The Panel's function is integral to the approval of a performance assessment. The Panel's charter states that it "shall ensure consistency and technical quality in the development and application of radiological performance assessments of DOE low-level waste disposal systems and shall provide EM-30 an auditable record of reviews."[22] The Panel's technical judgement on the defensibility of a performance assessment is a key link in the approval chain.

Consistent with its mission, the Panel has prepared the *Performance Assessment Review Guide for DOE Low-Level Radioactive Waste Disposal Facilities, DOE/LLW-93*. This document outlines the general content of a performance assessment review, but it does not establish specific technical criteria for reviews. Technical issues are dealt with on a case by case basis using the professional judgement of Panel members.

EM-30 has two principal criteria for Panel membership: (1) member must be employed by either DOE or one of its contractors, and (2) member must have broad knowledge in either mathematical modeling or the pragmatic aspects of low-level waste disposal[23]. There are eight Panel members, all of whom represent some interest within the DOE complex. Six members represent the sites with major disposal facilities (Hanford, Idaho National Engineering Laboratory (INEL), LANL, Nevada Test Site (NTS), Oak Ridge National Laboratory (ORNL), and SRS). One individual represents sites which generate, but do not dispose of low-level waste. Lastly, one Panel member represents DOE-EH. With the exception of the DOE-EH member, the Panel is composed of individuals who have strong organizational ties to DOE contractor disposal operations. In addition, the DOE-EH seat has presently been delegated to a contractor from Battelle Pacific Northwest Laboratory (Washington, DC Office).

The Panel has recognized that there are potential conflicts of interest in its deliberations and has adopted a recusal process. Any member of the Panel employed by a contractor whose site's work is under review, does not have a vote on whether the performance assessment should be deemed technically adequate. However, the recused member may be present at Panel meetings and provide additional information to the Panel during its deliberations.

Approval by EM-30 and independent reviews by DOE-EH could provide a check on the Panel's activities. However, EM-30 has not clearly defined its part in the approval process. It has no formal procedures or criteria for approval of a performance assessment. Although DOE-EH is required by DOE Order 5820.2A to provide independent oversight for waste management programs, it has not conducted formal reviews for any performance assessment nor does it have procedures to carry out its oversight function in this area.

2. History of DOE Radiological Performance Assessments

DOE Order 5820.2A was issued in 1988. During the nearly six years since its promulgation, the Panel has conducted a number of reviews. However, during this time only two performance assessments (SRS Saltstone and SRS E-Area Vaults) have received Panel approval. Further, neither the SRS Saltstone PA nor the E-Area Vault PA have been reviewed and approved by DOE.

The Panel has conducted eight preliminary reviews and four final reviews. These are:

Preliminary

ORNL Solid Waste Storage Area 6
INEL Radioactive Waste Management Complex
Hanford 200-W Burial Ground
LANL Area G (withdrawn after review)
Hanford Grout
SRS Saltstone
SRS E-Area Vaults
NTS Area 5

Final

Hanford Grout (rejected by Panel as inadequate; new version is currently under review)
NTS Area 5 (withdrawn at suggestion of Panel)
SRS Saltstone (approved by Panel)
SRS E-Area Vaults (approved by Panel)

The preliminary performance assessment for LANL Area G and the final performance assessment for NTS Area 5 were withdrawn after the Panel discovered technical inadequacies. Both are currently being revised. LANL has not set a date for completion of its revised PA, but NTS expects its revision to be delivered to the Panel by December 1994 or January 1995. The Hanford Grout final performance assessment was initially rejected by the Panel, but has since been submitted for another review. The SRS Saltstone final performance assessment was conditionally approved by the Panel, contingent upon gathering more information regarding material properties and calculations. The SRS E-Area Vault performance assessment was recently accepted by the Panel and is currently under review by DOE.

In addition to the above performance assessments, there are seven PA's under development, none of which have undergone any review by the Panel. These are:

ORNL Solid Waste Storage Area 7
SRS Hazardous/Mixed Waste Facility
Hanford 200 E-Burial Ground
Hanford Environmental Restoration Disposal

LANL Environmental Restoration Disposal Facility
Hanford Vitrified Low-Level Waste Facility
NTS Area 3

3. Summary

Although DOE Order 5820.2A was issued in 1988, DOE has not yet approved a single performance assessment, and most PA's are still in the preliminary stages of development.

B. Summary of Department of Energy Site Practices

Many sites in the DOE complex are still in the preliminary stages of drafting performance assessments. The U.S. Nuclear Regulatory Commission (NRC) has established disposal standards (appendix B), which identify good practices based on experience and sound engineering principles. Given the absence of performance assessments and specific DOE standards, the DNFSB staff has used the NRC standards as criteria to evaluate DOE disposal sites.

A summary of DNFSB staff observations at each site is given below, with a comparison of the sites to the five functional areas of waste disposal (siting, design, operation, closure, and waste form) shown in Table 1. More detailed descriptions are provided in appendix D.

1. Hanford

The Hanford Site is characterized by a deep water table and has the advantage of a large buffer zone between its burial grounds and the public. The DNFSB staff has observed that Hanford disposal facilities appear to be well sited and operated in accordance with some sound operational procedures.

The Hanford Site employs shallow land burial for the disposal of low-level waste. Burial trenches are 20-23 feet deep, 82 feet wide, and have lengths up to 1640 feet. Trench covers consist of roughly 8 feet of soil. There are no engineered drainage systems. Additionally, the Hanford design does not include layers, such as coarse stones, or engineered barriers to prevent intrusion by humans, animals, or plants. The design of Hanford's shallow land disposal facility does not meet commercial standards.

Operationally, many Hanford waste disposal practices have been upgraded to meet commercial standards. Recently, Hanford has adopted two important commercial practices. Long-lived radioactive waste, equivalent to the NRC's B or C class, is treated or repackaged to ensure that the waste form meets

NRC structural stability criteria. In addition, stabilized waste is segregated from other radioactive waste. As described in appendix B, these practices help prevent the disposal unit cover from subsiding.

In the past, Hanford used heavy machinery to compact waste and backfill disposal trenches. This practice decreased void space between packages and reduced the volume of waste which would otherwise naturally degrade. Thus, compaction helped inhibit future subsidence of disposal unit covers. However, crushing waste had disadvantages as well. By damaging waste packages, Hanford lessened the ability of waste forms to mitigate releases and increased the surface area available for contaminant leaching. Thus, although compaction lessened the quantity of water entering a trench, it simultaneously increased the chance of radionuclide transport by water reaching the waste.

Hanford waste now undergoes less post-emplacement compaction than in the past. Although backfill is still compacted with heavy machinery, more stable waste containers (steel and wood rather than cardboard) are now used, and waste is stacked in an ordered manner. Since stronger waste packages withstand more stress, and ordered stacking evenly distributes applied forces, waste packages are expected to experience less damage during backfill compaction.

2. Los Alamos National Laboratory

LANL's program exhibits deficiencies in all five functional areas of radioactive waste disposal. In terms of site suitability, LANL is in a semi-arid region with a deep water table, but the area is prone to erosion and LANL's disposal pits are located near the site boundary. As a result, lateral migration of contaminants and cliff erosion are potential concerns.

LANL uses both trench and shaft disposal for low-level waste. Trenches are approximately 60 feet deep, 80 feet wide, and 700 feet long. They are unlined and the floors slope to a french drain. Presently, LANL's cover design consists of three feet of crushed tuff below six inches of soil, and does not incorporate plant and animal intrusion barriers. However, LANL currently provides inadvertent intruder protection for certain wastes by using deep burial.

Shaft disposal differs somewhat from trench disposal. Shafts have been used to dispose of some high specific activity waste packages. Their design incorporates remote waste handling techniques to reduce worker dose and includes a concrete cap.

Operations at LANL do not generally maintain the integrity of the disposal unit or waste form. LANL compacts its waste in trenches, does not structurally stabilize waste forms, and does not segregate long-lived stable waste from unstable waste. Since natural degradation of waste facilitates subsidence, NRC standards require long-lived waste to be structurally stabilized and segregated from short lived waste in order to inhibit system failure[24,25]. As a result, commercial trenches with long-lived waste should have a longer service life than those for shorter lived wastes. By not structurally stabilizing and segregating its waste, LANL increases the probability that its units will fail. Compaction does provide some compensation for not using these procedures. However, as discussed in the previous section (Hanford), compaction may have deleterious effects.

3. Savannah River Site

Traditionally, SRS has used shallow land burial. SRS has recently completed a new Vault system for low-level waste disposal. The SRS design and planned operations are improvements over previous shallow land burial program at the Burial Grounds.

The SRS region is humid and has a shallow water table. Additionally, there is a direct link between the water table and local surface water. These factors suggest that the groundwater pathway is an important scenario for the design of SRS facilities.

The Burial Grounds have employed two types of trenches; the slit trench and the engineered low-level trench (ELLT). The slit trench is a long narrow unit (20 feet x 15 feet x 150-400 feet) and is used for waste that requires remote handling. The ELLT is generally 18 feet x 150-400 feet x 900-1200 feet and is used for the remaining wastes. Both trench designs include trench covers with at least four feet of earth. There are no inadvertent or biologic intrusion barriers. In contrast, the new Vault structure serves as both an intruder and infiltration barrier. Final closure plans for both of these facilities are not yet developed.

Not only in design but operationally, the Vaults are also an improvement over the Burial Grounds. Each vault acts as a stable container for low-level waste. As such, neither waste segregation nor stabilization in the Vaults seems necessary to comply with commercial standards. In comparison, the Burial Ground design does not provide a similar degree of stability, nor have Burial Ground procedures included good practices such as waste segregation and stabilization.

4. Summary

In the absence of DOE standards and finalized performance assessments for low-level waste disposition, sites have incorporated some components of a defense-in-depth approach consistent with commercial standards. However, the sites' burial grounds have not adopted all the principal components of this approach. The burial grounds at all three sites reviewed by the DNFSB staff (Hanford, LANL and SRS) would not meet the standards in at least two of the areas of design, operation, closure, and waste form.

site\area	Siting	Design	Operations	Closure	Waste Form
Hanford positive aspects	• deep water table • dry climate • far from public		• stacks waste • separates LLW classes	• plants used to stabilize units	• stabilizes waste • does not bury DOE banned wastes
negative aspects		• no engineered cover • no drainage system • no intruder barriers		• no final plan	
LANL positive	• deep water table • dry climate	• french drain • intruder protection	• stacks waste	• plants used to stabilize units	• does not bury DOE banned wastes
negative	• near site boundary • on-top narrow mesa	• no engineered cover	• compacts waste in trenches • no separation of LLW classes	• no final plan	• does not stabilize waste • uses cardboard packages
SRS positive(BG)	• far from public	• french drain	• stacks waste	• plants used to stabilize units	• does not bury DOE banned wastes
negative(BG)	• shallow water table • wet climate	• no engineered cover • no intruder barriers	• no separation of LLW classes	• no final plan	• does not stabilize waste
positive(vault)	• far from public	• man-made interim rain cover • intruder protection • drainage system	• separation of waste (see waste form)		• vaults designed to be structurally stable container for waste • will not accept DOE banned wastes
negative(vault)	• shallow water table • wet climate			• no final plan	

Table 1: This table shows the five functional areas of waste disposal and the positive and negative practices each site exhibits relative to these functional areas. This is a summary of the preceding discussion and the detail in appendix D.

Appendix A - Department of Energy Low-Level Waste Inventory

The quantities and characteristics of low-level waste are important elements for predicting the long-term public health consequences of disposal. Discussed below are the locations, volumes, and types of waste that the defense nuclear complex has disposed of and what the Department of Energy (DOE) expects to dispose of in the future. This information is summarized from DOE's *Integrated Database for 1993.*

Eighty-four percent of DOE's low-level waste volume is located at six defense nuclear sites with operating shallow land burial facilities. Listed in order of decreasing volumetric inventory, these are: the Savannah River Site (SRS), Hanford, Nevada Test Site (NTS), Y-12 and the Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), and the Idaho National Engineering Laboratory (INEL). The Fernald Environmental Management Project does not have an operating shallow land burial facility, however, the volume of its low-level waste stored on site represents 12 percent of the DOE total. This waste mostly consists of material contaminated with uranium/thorium. The remainder of the waste volume is located at a number of smaller DOE (both defense and non-defense) sites. This geographical distribution is displayed in Figure A-1.[26]

The volume of waste buried at each site is shown in Figure A-2. The graph includes each site's total inventory and its annual inventory addition for 1992. The Department and its predecessors have disposed of more than 2.8 million cubic meters of low-level waste[27]. As shown in the figure, SRS is a focal point for DOE disposal operations. It has the single largest volume of buried waste, 23 percent of the total volume in the complex[28], and its burial operations account for approximately 32 percent of all DOE annual additions[29].

With regard to the radioactive content of DOE's low-level waste, the defense nuclear complex has disposed of more than 43 million curies[30]. At present, it is estimated that radioactive decay has lessened this inventory to nearly 12 million curies[31]. Figure A-3 illustrates the total activity of waste buried at the time of emplacement. Also shown is the average curie content per cubic meter. INEL has the largest radioactive inventory, and its waste has the largest average curie concentration (Ci/m^3).

DOE low-level waste can be divided into six groups to describe radioactive content. Figure A-4 uses groups of fission products, uranium/thorium, alpha emitting-waste, activation products, tritium, and other (unknown or mixtures of the above groups). Waste contaminated with uranium/thorium is the most prominent category of low-level waste with an estimated volume of 1.1 million cubic meters[32]. Fission product waste totals approximately 992 thousand cubic meters[33]. Taken together, fission products, uranium/thorium, and alpha wastes represent eighty-five percent of DOE's total waste volume[34]. Wastes falling into the activation products, tritium, and other categories represent fifteen percent of the volume.

There are many uncertainties associated with the future generation of low-level waste by defense nuclear facilities. The *Integrated Data Base for 1993* assumes that in the future, the annual amount of waste disposed of will be the same as that projected in 1993[35]. It is not clear what the technical basis for this projection is or if this assumption is meant to incorporate low-level waste generated by D&D and environmental restoration activities. According to the *Integrated Data Base for 1993*, there are presently no reliable estimates for the future generation rates of these two waste streams[36].

In summary, the Department of Energy is responsible for large quantities of low-level waste. Its waste is located in three different regions of the nation (Southeast, Southwest, and Northwest), and it does not constitute a homogenous inventory. DOE waste is mostly material contaminated by fission products and uranium/thorium. Finally, it is not clear how the quantities and characteristics of DOE waste will change as the Department shifts its mission.

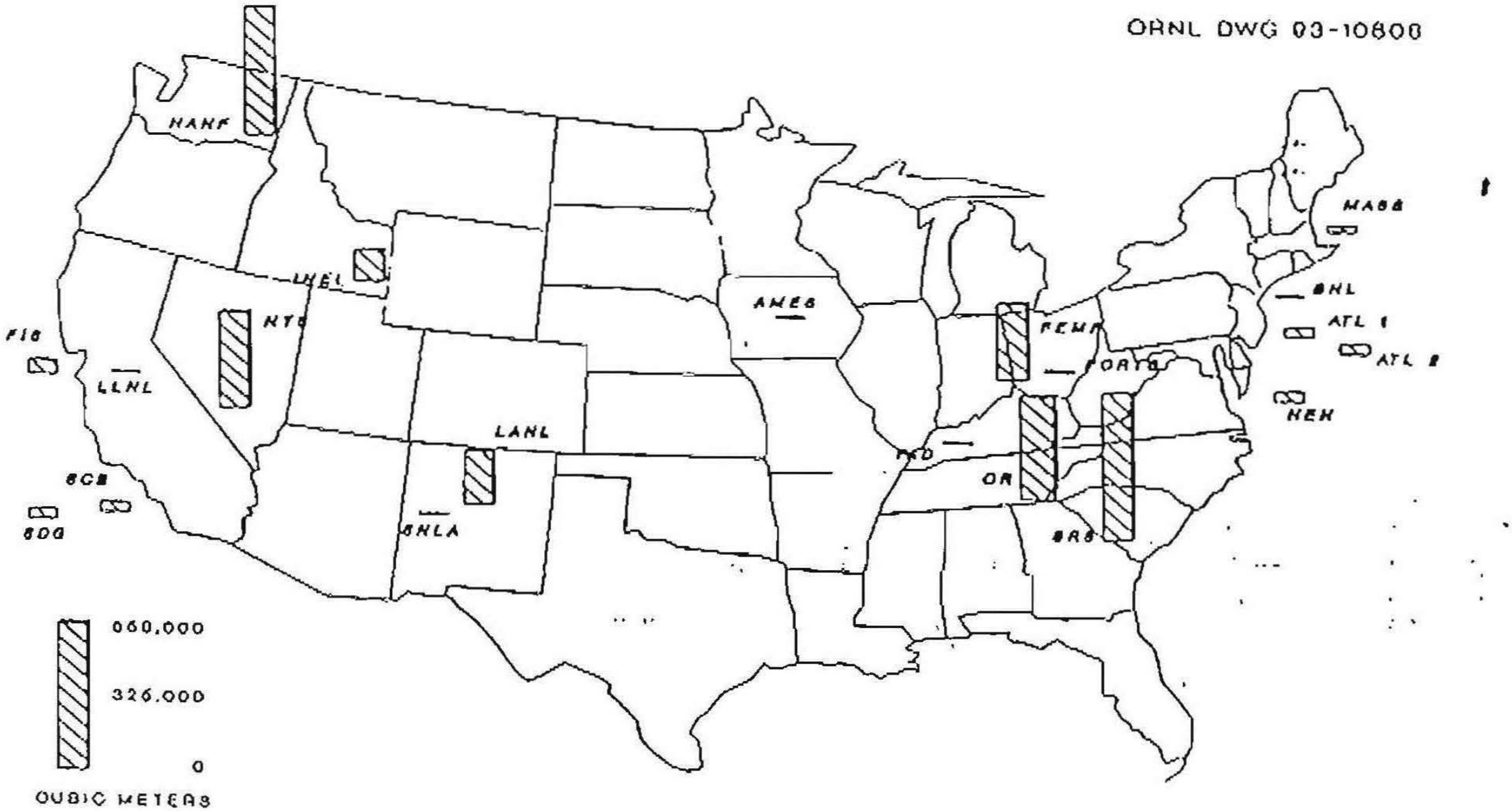


Figure A-1. Locations and total volumes of DOE LLW disposed through 1992

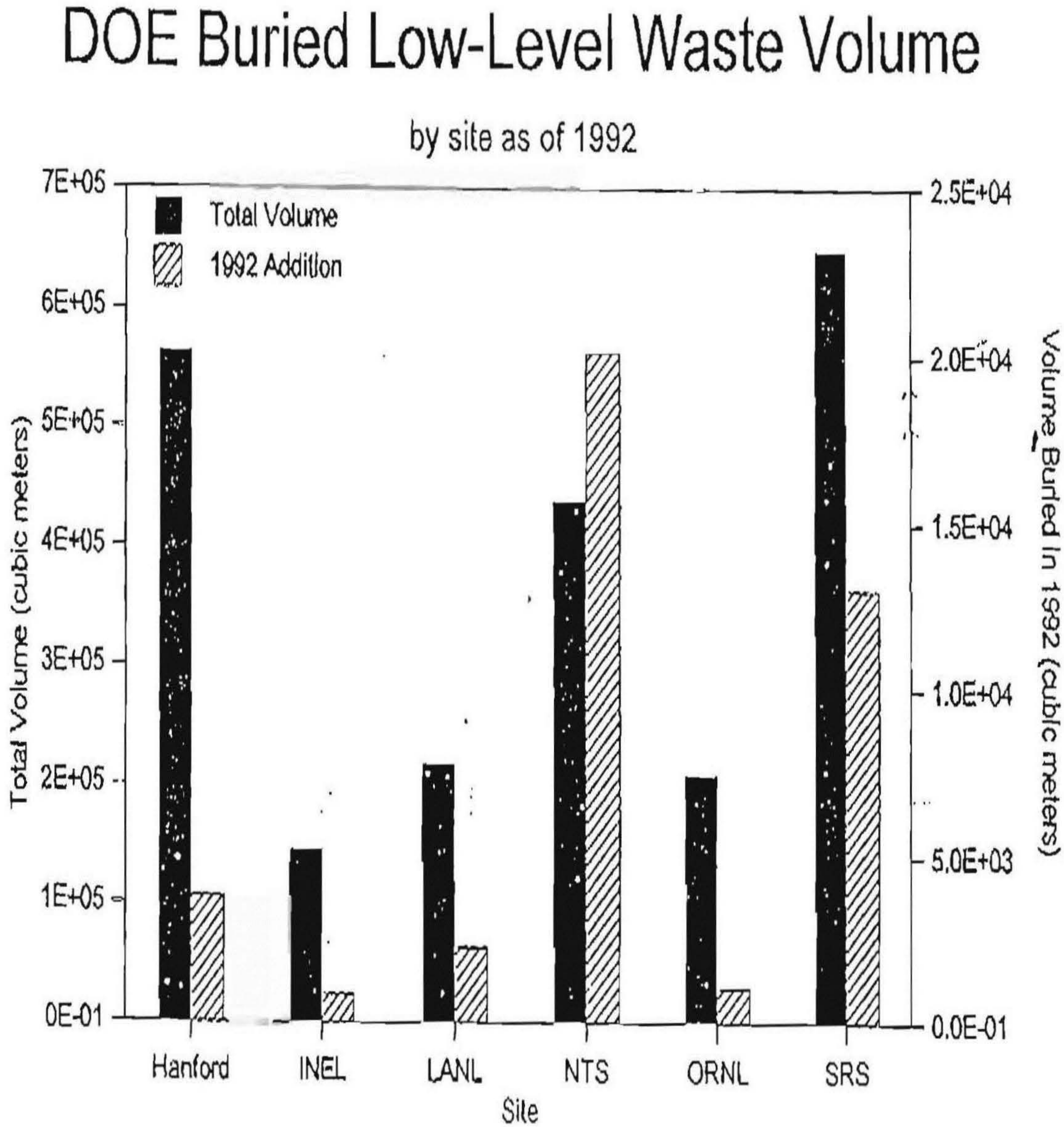


Figure A-2: This graph shows the total volume of low-level waste buried at each of the major DOE sites. Also shown is the volume of waste these sites buried in 1992. Source: *Integrated Database for 1993.*

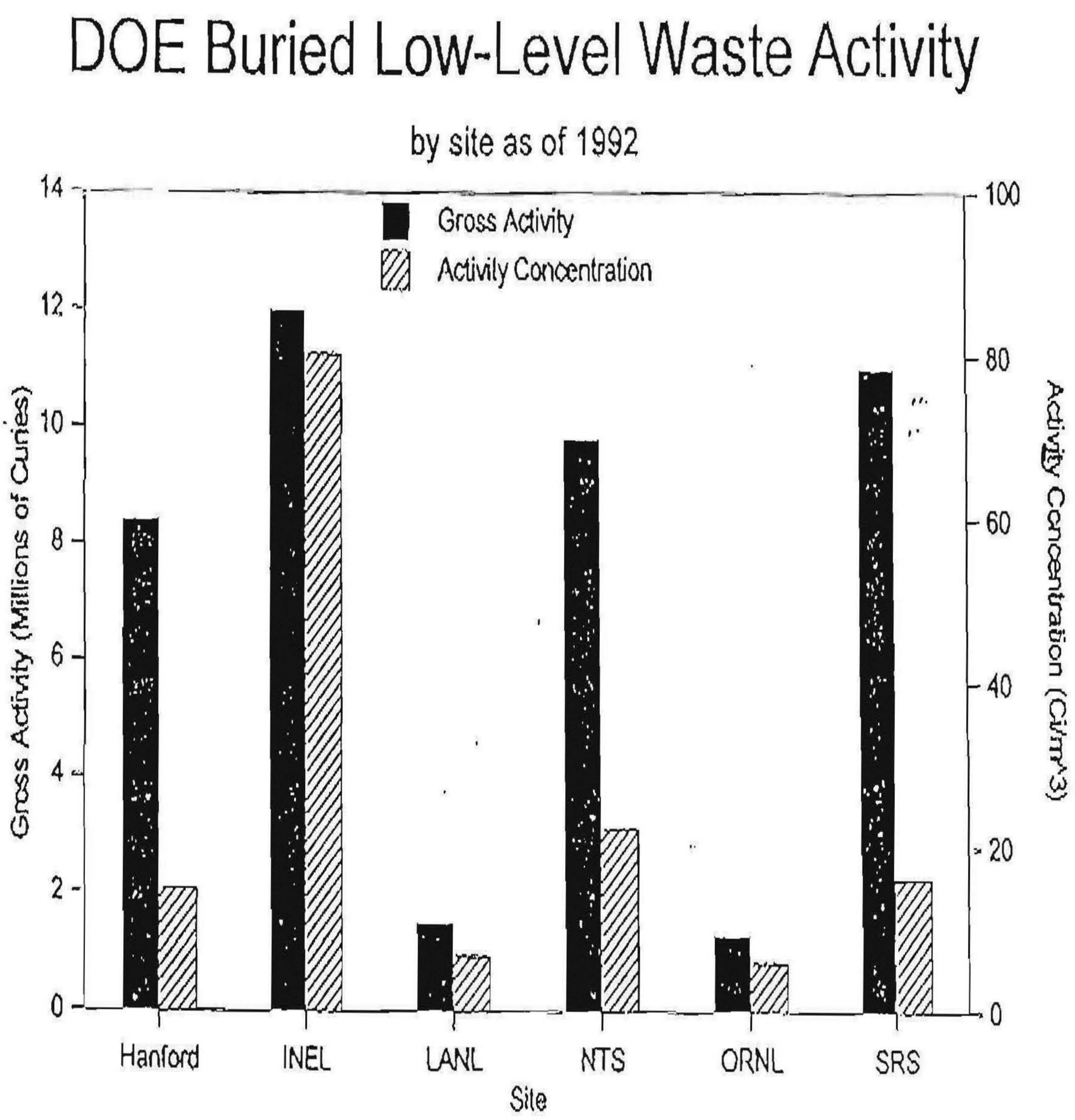


Figure A-3: This graph shows the activity (neglecting decay) from buried waste at DOE sites. Also shown is the average curie concentration, i.e., total activity divided by total volume. Source: *Integrated Database for 1993.*

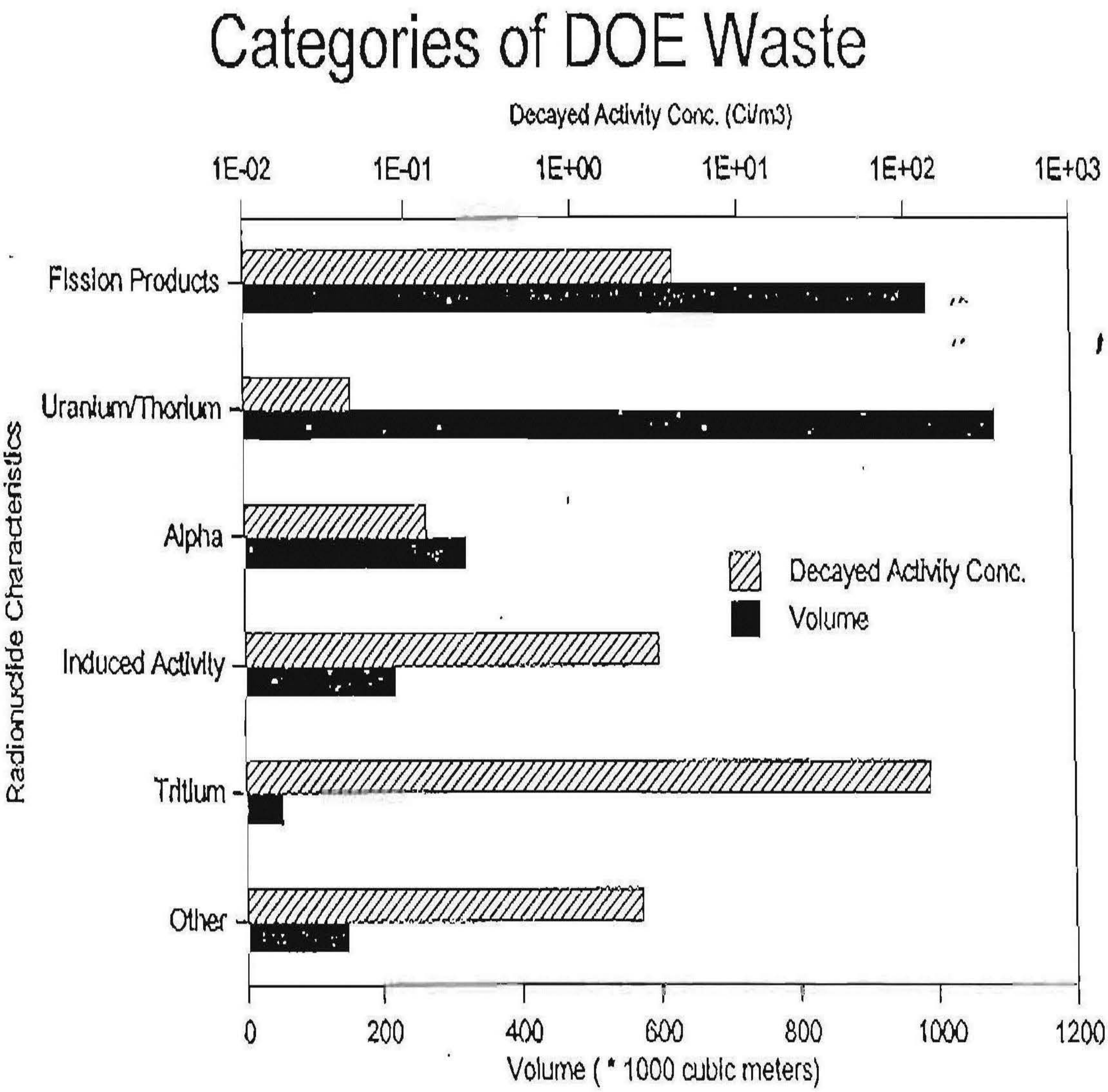


Figure A-4: This graph shows the volumes of waste within certain radionuclide characteristics. The average activity concentration is also given for each category. Source: *Integrated Database for 1993.*

Appendix B - Commercial Standards for Low-Level Waste Disposal and Department of Energy Requirements

Commercial low-level waste disposal standards are codified in the Nuclear Regulatory Commission's 10 C.F.R. Part 61. Further information on these standards is found in NRC's Branch Technical Position papers. Presented below are summaries of this information. The summaries also describe DOE policy, as expressed in the DOE Order 5820.2A, *Radioactive Waste Management*, relative to commercial standards. DOE and commercial standards are reviewed under the five functional areas of site suitability, design, operation, closure, and waste form. Commercial standards were used as a minimum reference point for low-level waste disposition.

I. Site Suitability:

Siting a disposal facility is the first, and arguably the most important, step for ensuring the isolation of waste. Historically, disposal facilities have relied upon the site hydrogeologic characteristics as the principal means to mitigate nuclide migration. Siting, however, has many associated uncertainties. Disposal facilities are designed to isolate waste for hundreds of years. Commercial facilities operate under standards codified in 10 C.F.R. Part 61, which are summarized below. Additional detail on the requirements of these standards can be found in the Nuclear Regulatory Commission's Branch Technical Position on Site Suitability:[37, 38]

A. The disposal site shall be capable of being characterized, modeled, analyzed and monitored. This implies that the site's geologic characteristics should vary within a narrow range and that hydrologic processes should be occurring at a consistent and definable rate.

B. The disposal site must provide sufficient depth to the water table that ground water intrusion, perennial or otherwise, into the waste will not occur.

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

D. Disposal sites should be located in an area which has low population density and minimal population growth potential. Disposal sites should be at least two kilometers from the property limits of the closest population centers.

E. Areas must be avoided having known natural resources. The primary concern is the likelihood of inadvertent intrusion by a resource exploiter after the period of institutional control.

F. 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 flood plain, coastal high-hazard area or wetland. Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units.

G. Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent that it may compromise the integrity of the facility.

H. Areas must be avoided where surface geologic processes, such as mass wasting, erosion, slumping, landsliding, or weathering could affect the ability of the site to isolate waste.

The general intent of these standards, as expressed in 10 C.F.R. Part 61, is to ensure that the location and hydrogeology of the site serve as a defense against the release of radioactive material.[39]

With regard to siting, DOE Order 5820.2A states that new disposal sites shall have hydrogeological characteristics which will protect the groundwater resource. In addition, the potential for floods, erosion, earthquakes, and volcanoes, shall be considered in site selection. Finally, the impact on current and projected populations and land use shall be addressed.[40] Although the intent of the siting requirements in the Order is the same as for commercial standards, the wording is much less specific. Criteria are not given, outside of the performance objectives, to judge how well the Order's requirements are met. As a result, the performance assessment is the principal means to defend the siting choice.

II. Design of the Disposal System and Engineered Barriers:

The design of a shallow land burial or greater confinement disposal facility includes aspects of road layout, trench spacing and dimensions, burial depth, backfill material selection, infiltration and intruder barrier development, and the creation of a subsurface and surface drainage system. These elements are important for the stability of the disposal facility during operation and after closure.

As expressed in 10 C.F.R. Part 61, the design of the system must ensure that the active waste disposal operations does not have an adverse effect on completed closure and stabilization measures.[41] The design should also ensure that infiltration, bathtubing, subsidence, and human intrusion are prevented.[42] A topical summary of commercial standards for design follows.[43, 44] It should be noted that 10 C.F.R. Part 61 and the Branch Technical Position for Design and Operation provide more specific guidance.

A. The disposal site must be designed to complement and improve, where appropriate, the site's natural characteristics. This is manifested in trench dimensions, the drainage system, and the choice of cover material.

B. 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. Additionally, covers should be mounded to facilitate drainage and be tied into the surface drainage system.

C. 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. The system should be able to handle the probable maximum precipitation for the site.

D. Wastes designated as Class C (see appendix E) 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 intruder for at least 500 years.

DOE Order 5820.2A does not require the criteria briefly described above. The Order states that, "disposal units shall be designed consistent with disposal site hydrology, geology, and waste characteristics and in accordance with the National Environmental Policy Act process." [45] Additionally, the Order requires that, "engineered modifications...for specific waste types and for specific waste compositions...shall be developed through the performance assessment model."[46] As a result, DOE sites have flexibility in the design of their disposal system. They can choose to conform to commercial standards, adopt less conservative practices, or more conservative ones, but their program must be modeled in a performance assessment.

III. Operations:

The proper handling and emplacement of wastes are important elements in a disposal program. The basic principle is to ensure that operations do not directly or indirectly compromise the integrity of the cover and waste form. Historically, low-level waste has been randomly emplaced in trenches using the "kick and roll" method. This emplacement procedure often damaged the integrity of the waste containers, thus removing the waste packaging as a defensive leaching barrier. It also created excessive void space which can promote cover subsidence. Below is a summary of commercial standards as they pertain to operations.[47, 48]

A. Wastes must be emplaced in a manner that maintains the package integrity during emplacement.

B. Wastes must be emplaced in a manner that minimizes the void spaces between packages.

C. Void spaces between waste packages must be filled with earth or other material to reduce future subsidence within the fill. This material may be gravel, sand, or the natural soil (if compaction of fill in voids can be assured).

D. Class A waste (see appendix E) must meet only minimum requirements on waste form and packaging when it is physically segregated from Class B and C waste (with more stringent waste form stability requirements) and buried in discrete disposal units. Class A Waste that is stable may be mixed with other classes of waste.

According to 10 C.F.R. Part 61, these standards are meant to ensure the long-term stability of both waste containers and the disposal unit cover.[49] The fourth requirement is particularly important. Commercial facilities must ensure that wastes which will be significantly radioactive for hundreds of years (defined as Class B and C wastes) maintain their physical dimensions for at least 300 years (see Section V, Waste Form, below).[50] These wastes must be isolated while they still pose a radiological threat. Covers or engineered barriers serve this function. In addition, long-lived waste is segregated from short-lived waste if the latter's structure is prone to rapid degradation. These measures help ensure the longevity of covers for long-lived wastes.

The primary operational requirements of DOE Order 5820.2A are:[51] (1) waste placement should minimize voids, and (2) operations should not affect filled disposal units. The Order does not address segregation based on activity, package integrity maintenance, and backfilling techniques. The lack of requirements on these three issues allows the disposer to place waste in units regardless of stability, use backfill which may not be appropriate, and compact waste containers while in disposal units. All three of these activities are not consistent with good practices identified by commercial industry.

IV. Closure:

The design of covers has already been discussed above in section II, Design. The timeliness of closure and stabilization measures are also important. Commercial standards and guidance in this area are:[52, 53]

A. 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.

B. Stabilization measures in humid climates could include planting of a short-rooted vegetative cover over the disposal unit cover, overall site grading and shaping, and use of rip-rap on steep slopes to protect against wind and water erosion. In arid climates, the use of gravel or cobbles over the disposal unit cover could achieve the same result.

DOE Order 5820.2A requires the following:[54]

A. Closure plans will address disposal unit closure within a 5 year period after each unit is filled.

B. Inactive disposal facilities as of 1988 shall be managed in conformance with the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation, and Liability Act, and the Superfund Amendments and Reauthorization Act.

Under commercial standards, closure is an ongoing process. For example, at the Barnwell Chem-Nuclear Low-Level Waste Disposal Site trenches are capped with a clay cover as the remainder of the trench is being filled. This helps to minimize the contact of waste with water. In contrast, closure at DOE sites does not need to occur until 5 years after the entire facility has been filled to capacity.

V. Waste Form:

As described in the NRC Branch Technical Position on Waste Form, the waste form was traditionally considered to be of little importance in mitigating releases from disposal facilities. However, in light of cover subsidence problems at older commercial burial grounds, it is now viewed as an important part of a disposal program.[55] As discussed in section III, Operations, of this appendix, 10 C.F.R. Part 61 requires certain waste forms to maintain their physical dimensions for at least 300 years. This can be accomplished by either stabilizing the waste, e.g., cementing or grouting it, or by placing the waste in an engineered container. The commercial standards in this area are described in the NRC Branch Technical Position on Waste Form and in the list of prohibited waste types, e.g., liquid waste, given in 10 C.F.R. Part 61.

DOE Order 5820.2A also recognizes the importance of prohibiting certain waste types from shallow land burial. DOE uses the same list of prohibited waste types as does the NRC. The prohibited wastes comprise an important category of material which engender dangerous situations or might allow excessive radionuclide leaching. Those wastes prohibited for the latter reason (primarily liquid and cardboard packaged materials) ensure that DOE has minimum criteria for waste form structural stability. These criteria, however, are not equivalent to commercial standards. The NRC requires all long-lived wastes to possess specific physical properties, such as compressibility, biodegradability, and resistance to radiation, leaching, and thermal cycling. Thus, commercial long-lived wastes are held to higher performance criteria than are DOE wastes.

Appendix C - Low Level Waste Disposal Technologies

Since the mid-1940s, most of the commercial low-level radioactive waste (LLRW) generated has been disposed of by shallow land burial (SLB). In the last decade, there has been an international shift towards using engineered structures rather than SLB. The following text summarizes several of the disposal technologies currently in use or planned for future facilities. In addition, a summary of the technologies used by domestic and foreign facilities is provided.[56, 57, 58]

I. Shallow Land Burial and Modular Concrete Canisters

In a typical SLB facility (Figure C-1), wastes are placed in excavated earthen trenches, which may be lined with concrete or heavy-gauge plastic sheeting. Once filled, the trenches are backfilled with sand or earth, compacted, and capped with a clay layer to minimize water infiltration. The cap is stabilized by covering it with topsoil and planting vegetation. Water accumulation is minimized by using sloped trench floors and sumps. Problems that have occurred in SLB facilities include water accumulation in trenches, trench cap subsidence, and minor on-site radionuclide migration. These can be attributed to poor siting, design, or operating practices.

Modular concrete canister (MCC) disposal is similar to SLB except that the waste is placed in reinforced concrete canisters to provide additional structural stability. These overpacks are grouted with a cement mixture to fill voids before being placed in trenches.

II. Above-Ground Vaults (AGV)

AGV disposal (Figure C-2) consists of placing waste in an engineered concrete vault and filling the voids with sand. A concrete roof is poured over each cell to provide water infiltration protection. AGVs allow more freedom in siting facilities because the facility's performance is largely independent of the site's hydrology and the vault can be built to withstand natural hazards. Being above-ground, however, means that there is no secondary barrier to prevent radionuclide releases to the atmosphere and thus less time would be available if remedial actions were required. In addition, the lack of an earthen cover leaves the vault exposed to degradation by wind, rain, and freeze-thaw cycles.

III. Below-Ground Vaults (BGV)

BGVs (Figure C-3) are enclosed, engineered structures built totally below the surface of the earth. The walls and roof are often constructed of concrete while the floor can be soil, rock or concrete. After waste is stacked in the vault, voids are backfilled with sand which is then compacted. The concrete roof is poured in place, and the vault is capped with an earthen cover. The vault protects the waste from erosion, water infiltration, plants, human intrusion, and seismic events. The vault and backfill also reduce the migration of liquid or gaseous radionuclides. The BGV is, however, susceptible to flooding and its limited access prevents visual inspections and hampers waste handling.

IV. Earth-Mounded Concrete Bunkers (EMCB) and Earthen-Covered Abovegrade Vaults (ECAGV)

EMCBs combine the concepts of earthen mounds and BGVs. Wastes are segregated based on their activities. Those with higher activities are placed in the below-ground bunker which is backfilled with sand and sealed with a concrete roof. The lower activity waste is stacked over the bunker. The voids between canisters are backfilled with sand and the wastes covered with an engineered earthen cover. ECAGVs are similar to EMCBs except that the vault is located above the natural grade of the disposal site (Figure C-4). Modular concrete canisters are sometimes used for both EMCBs and ECAGVs to provide additional structural stability. EMCBs and ECAGVs have the advantages of being resistant to many natural hazards and having a secondary barrier.

V. Disposal Technologies Used in the United States

The six commercial LLRW disposal facilities which have operated in the United States have all utilized shallow land burial. Of the six, only two are still operating and they are currently only accepting wastes from certain states or state compacts. As a result of the Low Level Radioactive Waste Policy Act and its amendments, each state or group of states, known as a compact, must establish and operate regional disposal facilities. These state compact facilities will also be used for all Department of Defense and other non-Department of Energy federal LLRW. The only compacts currently with an operating facility are those using older shallow land burial facilities (Barnwell, SC and Richland, WA). These were operating before the Act was passed.

Table C-1 lists the planned disposal technology for each state or state compact.[59] Most of the state compacts have chosen designs with engineered structures like vaults, earthen covers, and modular concrete canisters. Many of the technologies also incorporate barriers for inadvertent intrusion as well as emergency retrieval designs for making repairs on leaking waste containers or barriers. Only two compacts (Northwest and California) are planning to use shallow land burial. Most of the compacts which have not formally decided upon a technology have state laws which prohibit the use of shallow land burial.

VI. Disposal Technologies Used in Foreign Countries

Table C-2 lists the current and planned LLRW disposal technologies for nine foreign countries.[60] Their designs are illustrated in Figures C-5 through C-8. In addition to low-level waste, these facilities are often designed for the disposal of high-level waste. Some countries, like Canada and Taiwan, are storing their LLRW until disposal facilities are built. Recently, several countries have either modified previously existing trenches or developed new disposal facilities to incorporate engineered structures such as concrete trenches or pits. Other countries, like Germany and Sweden, are using deep underground repositories located in hardrock or salt.

Compact	Host State	Disposal Technology
Appalachian	Pennsylvania	Earth-mounded above-ground vault. Modular concrete canister overpacks.
Central	Nebraska	Above-ground vault. No overpacks.
Central Midwest	Illinois	Above-grade earth-covered concrete vault. Modular concrete canister overpacks.
DC	N/A	Not planning on siting a facility.
Massachusetts	Massachusetts	Shallow land burial is prohibited. Must allow monitoring and package retrieval.
Michigan	Michigan	State law limits disposal technology to above- or below-ground vaults or above- or below-ground modular canisters.
Midwest	Ohio	None selected at this time.
New Hampshire	N/A	Not planning on siting a facility.
New York	New York	State law bars shallow land burial.
Northeast	Conn/New Jersey	State laws prohibit shallow land burial.
Northwest	Washington	Use existing Richland site - shallow land burial.
Rhode Island	Rhode Island	On-site storage.
Rocky Mountain	N/A	Will use Northwest site.
Southeast	North Carolina	Integrated vault. Modular concrete canister overpacks.
Southwest	California	Enhanced shallow land burial. Has a multi-layered cap.
Texas	Texas	Below-ground concrete canisters. Has a multi-layered cap.

Table C-1: State Compact Disposal Technologies

Country	Status	Disposal Technology
Canada	Current	Below-ground vaults, above-ground vault, and earth-mounded concrete bunkers have been used for storage.
	Planned	Reinforced concrete, in-ground module with permeable floor. Covered with a concrete cap overlaid with an engineered cover containing barrier and drainage features.
China (PRC)	Current	Shallow land burial.
	Planned	Cement-immobilized waste in concrete silos and shallow land burial.
Finland	Current	Vertical, silo-type cavern with reinforced-concrete walls.
	Planned	Cavern with engineered barriers of concrete containers, concrete walls, and a backfilling of crushed rock.
France	Current	Earth-mounded concrete bunker. Higher-activity waste placed in below-ground monolith. Lower-activity wastes placed on top of monoliths. Multi-layer cap.
	Planned	Same as above, except all waste will be emplaced in vaults.
Germany	Current	*Deep geologic disposal in former salt and iron ore mines.
Japan	Current	Shallow burial using reinforced concrete pits, concrete covers, backfill, and a 4 m thick earth covering.
Sweden	Current	*Underground rock vaults below the Baltic Sea floor.
Taiwan	Current	All waste in storage because ocean dumping has been banned. Investigating improved shallow land burial.
United Kingdom	Current	Concrete vaults on an engineered clay base. Use steel overpacks.
	Studying	Deep geologic repository.

Table C-2: International Disposal Technologies. * All levels of waste disposed in same facility.

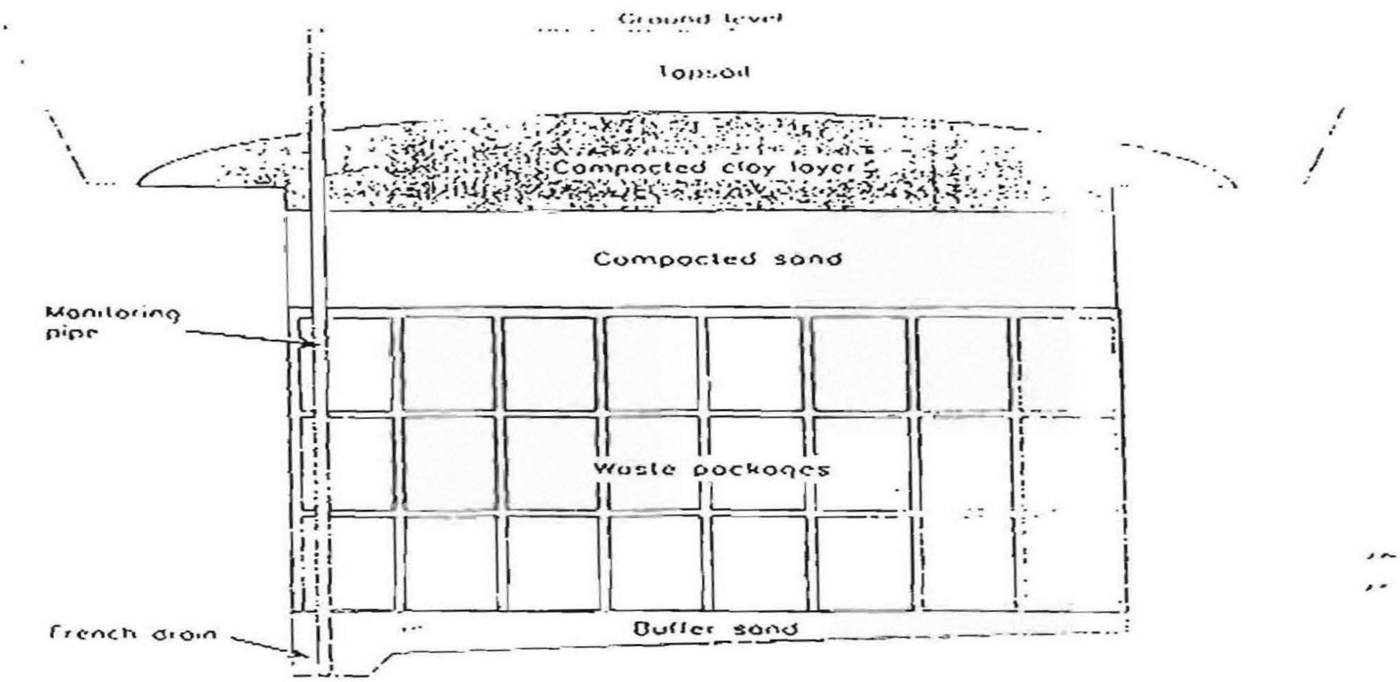


Figure C-1: Shallow Land Burial Disposal Facility[61]

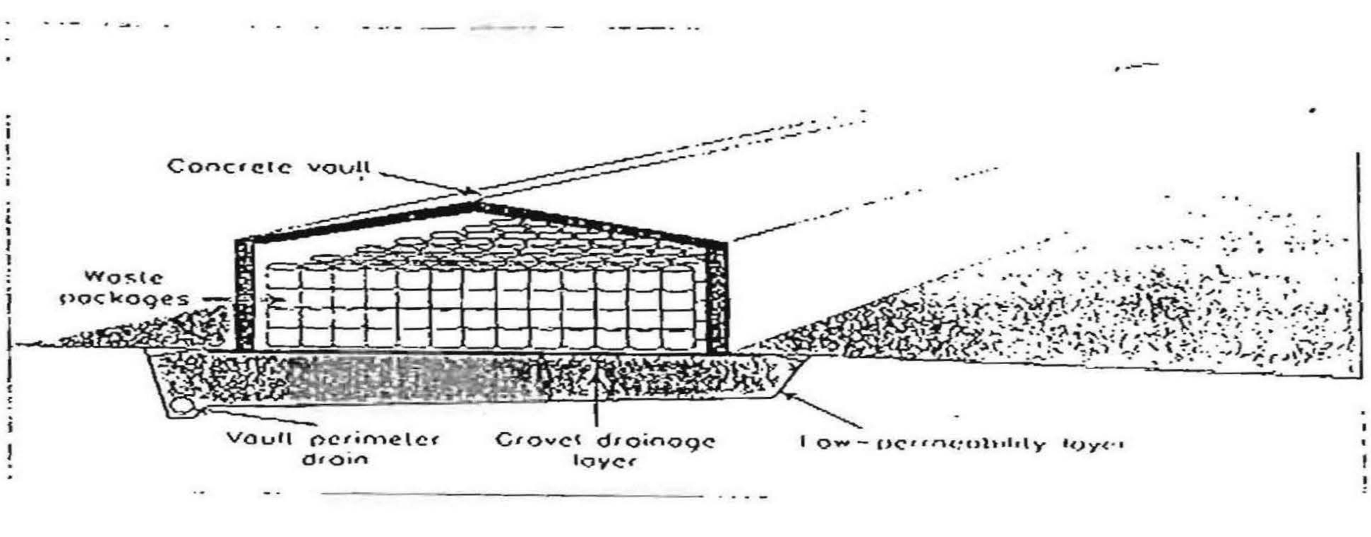


Figure C-2: Above-Ground Vault Disposal Facility[62]

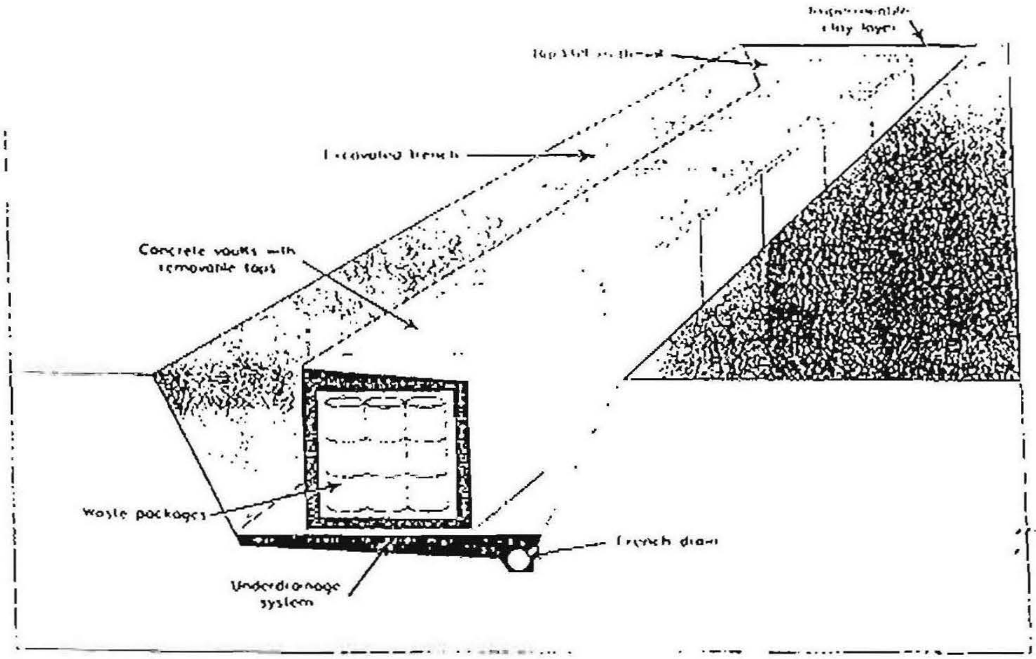


Figure C-3: Below-Ground Vault Disposal Facility[63]

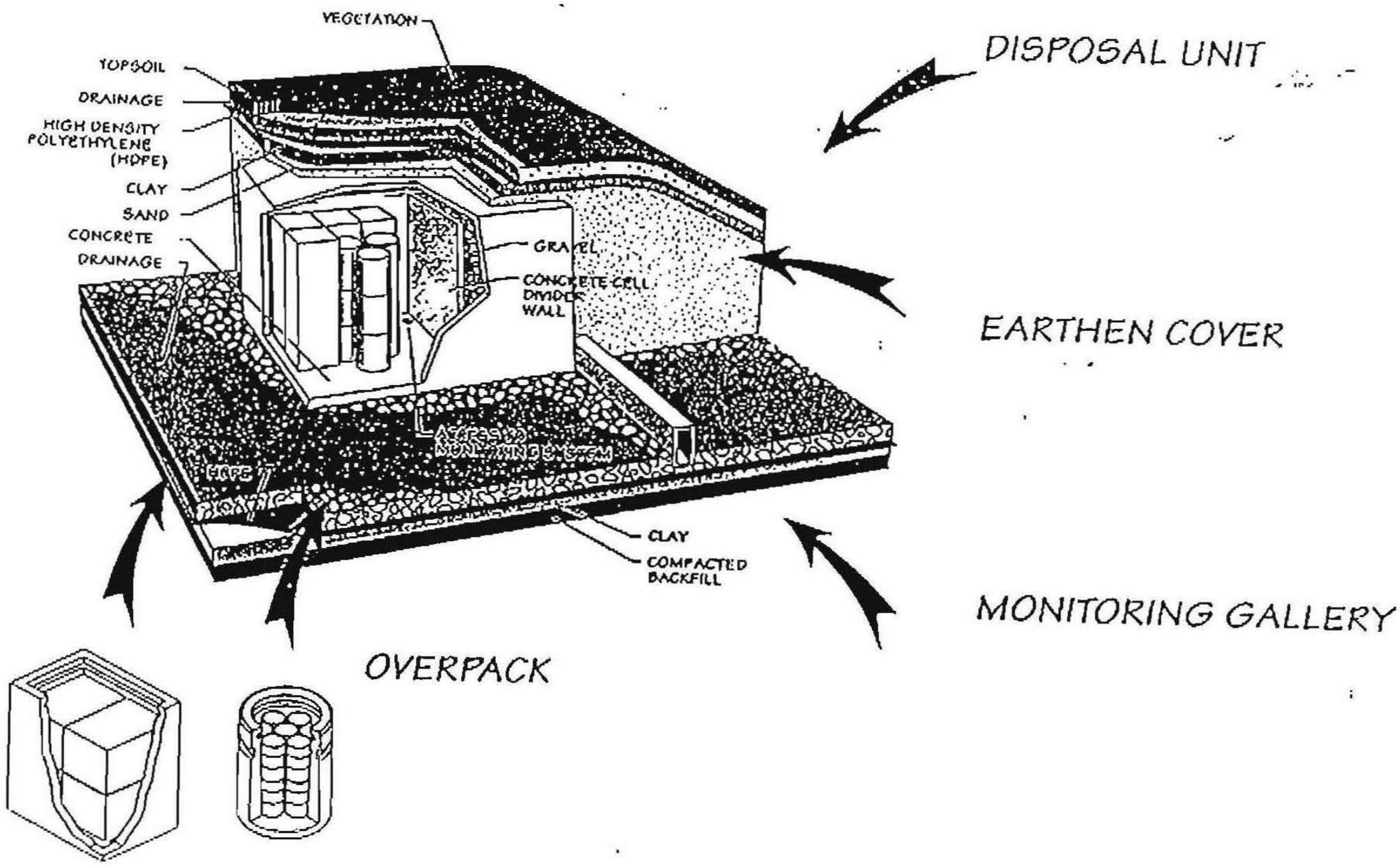


Figure C-4: Earthen-Covered Abovegrade Vault Disposal Facility[64]

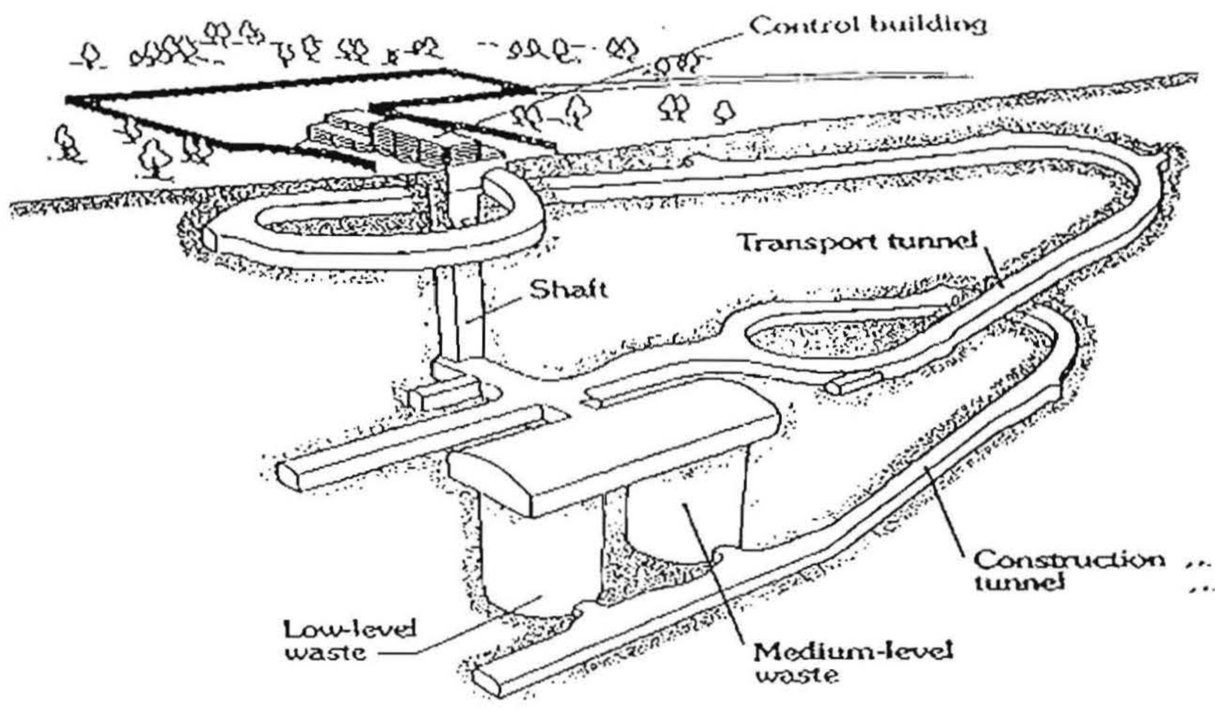


Figure C-5: The Finnish Repository on Olkiluoto Island[65]

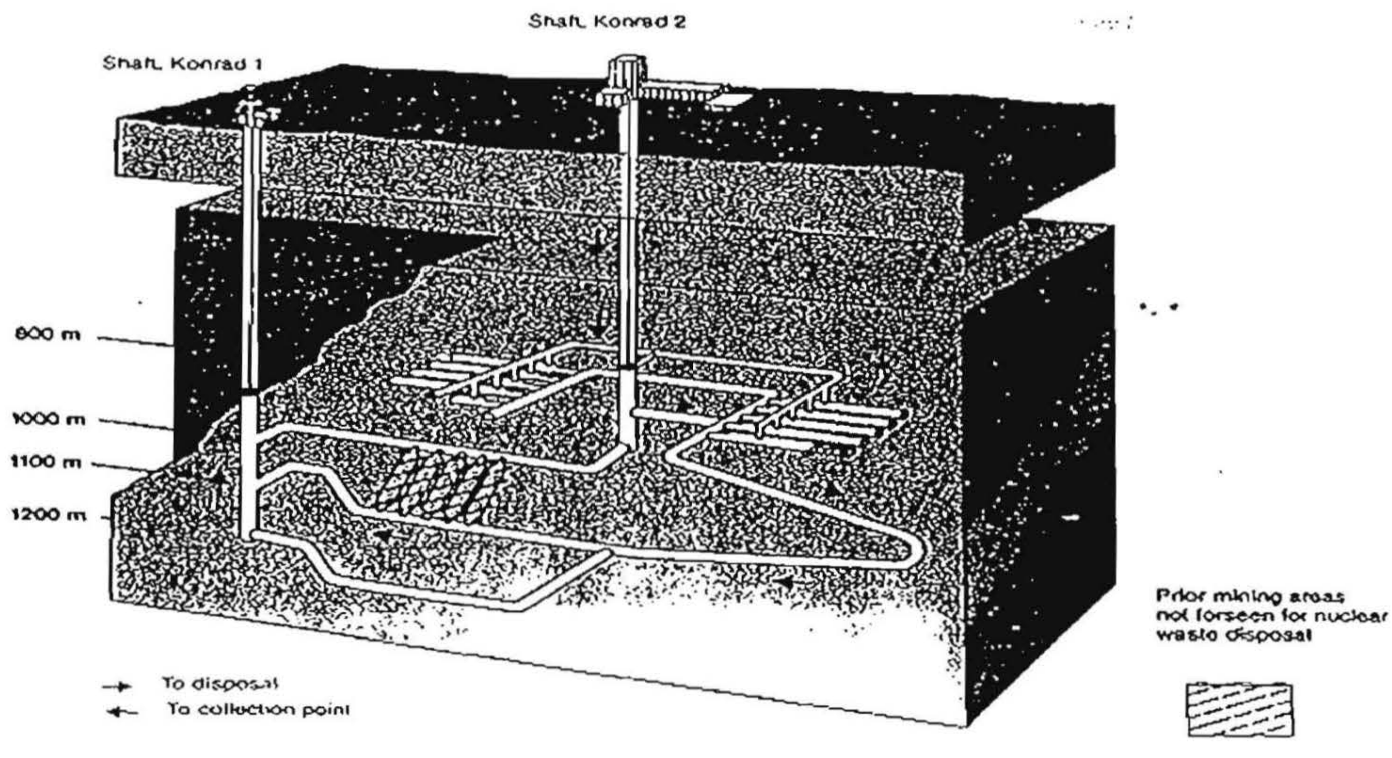


Figure C-6: The German Konrad Repository[66]

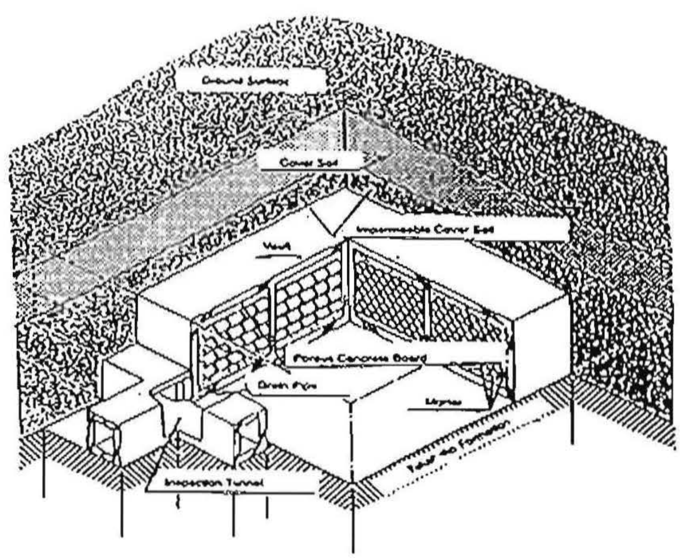
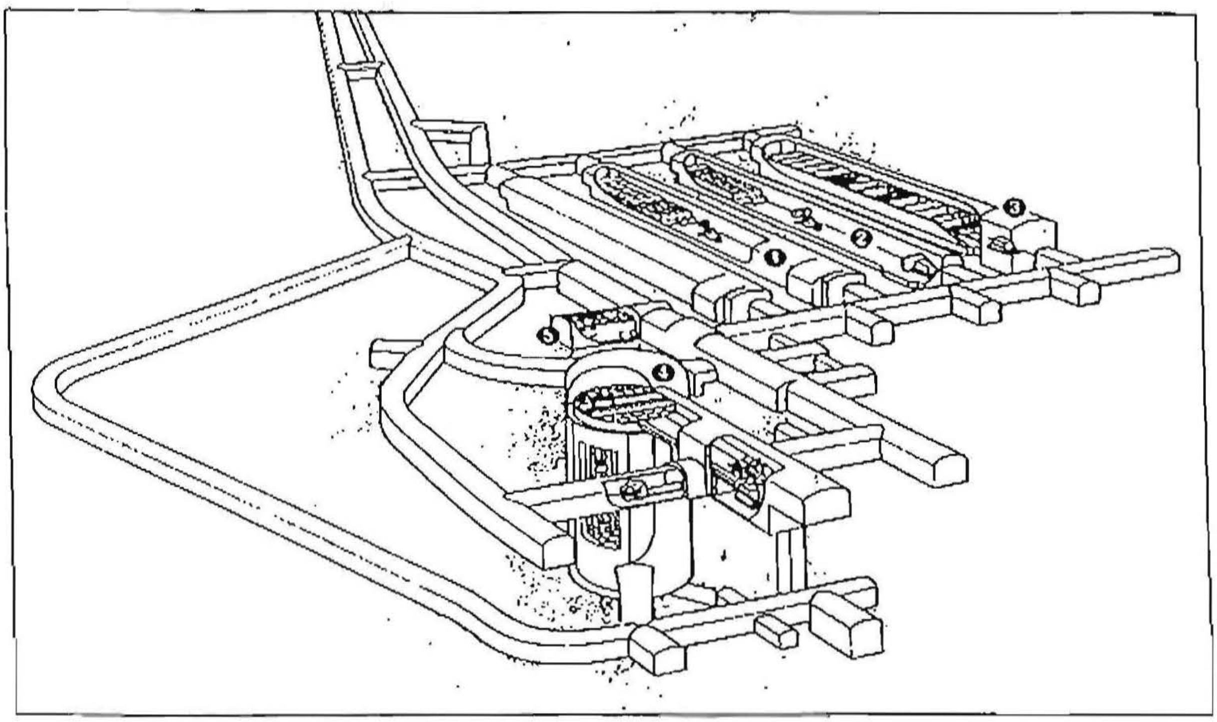


Figure C-7: The Japan Nuclear Fuel Ltd. Center at Rokkasho-mura, Aomori Prefecture[67]



1. Rock vault for intermediate-level waste in concrete tanks. The tanks are handled by forklift truck.
2. Rock vault for low-level waste in freight containers. The containers are handled by forklift truck.
3. Rock vault with pits for intermediate-level waste in metal drums or moulds. The waste is handled by a remote-controlled overhead crane.
4. Silo for intermediate-level waste in metal drums or moulds. The waste is handled by a special remote-controlled handling machine.
5. Operating building with operations center and personnel quarters.

Figure C-8: The Swedish Final Repository[68]

Appendix D - Disposal Practices at Three Major Department of Energy Facilities

This appendix summarizes the DNFSB staff's site observations for each of the functional areas described in appendix B. At the end of each sub-section, a "+" or a "-" is used to show if a given practice is a positive of negative element of the disposal program based upon the good practice concepts described in appendix B.

I. Hanford:

Site Summary - Given commercial standards, Hanford appears to be a suitable site for low-level waste disposal. The Hanford area receives little precipitation, has a deep water table, and is situated away from a population center. However, Hanford's burial grounds do not meet the intent of all commercial standards. The principal deficiency lies in design. It lacks provisions for both intruder barriers and engineered infiltration covers.

Site Suitability - Hanford is a semi-arid site with a precipitation rate of approximately 16 cm/year.[69] The geology of the area consists largely of sandy deposits, and the water table is located at a depth of 200 feet.[70] Although Hanford soil is quite permeable, studies suggest that the area experiences little recharge. The Westinghouse Hanford Company believes that the actual recharge rate is approximately 0.97 cm/year.[71] The combination of a small recharge rate and a large distance to the water table contributes favorably to low radionuclide contamination of the groundwater.

Hanford is also well situated in terms of its distance to the public. The site's burial grounds are located in both the 200-East and West areas. Consequently, they are further than the standard 2 km distance specified for commercial practice.

Two earthquakes have been recorded in the Hanford area, one in 1918 and the other in 1940. These earthquakes were of moderate intensity (Modified Mercalli intensity ranging from IV-VII).

Standards Summary:

Standard		Results
1. Modeling		Not enough information available
2. Depth of Water Table	+	Depth to groundwater is ~200 feet
3. No discharge on site	+	No surface waters in burial grounds
4. Population distance	+	The burial grounds are more than 2 km from public
5. Natural resources		Not enough information available
6. Flooding	+	Burial grounds not in 100 year floodplain
7. Seismic	+	Recent history does not suggest seismic activity poses a threat to shallow land burial facilities.
8. Erosion		Not enough information available

Design - Hanford employs shallow land burial for the disposal of low-level waste. Hanford's trenches are 20-23 feet deep, 82 feet wide, and have lengths up to 1640 feet The trench walls are sloped 45 degrees. The covers consists of approximately 8 feet of Hanford soil, a sandy material of high permeability. Hanford has stated its intention to design a long-term Resource Conservation and Recovery Act of 1976 (RCRA) type cover for its disposal units, however this is still preliminary. The present cover is not an engineered barrier. It is not designed to minimize animal intrusion, erosion, and it is not mounded. Further, the cover does not take advantage of less permeable materials than Hanford soil, or use multiple layers to promote drainage around a capillary break. The design does, however, complement the natural characteristics of the region since the facility only uses materials present on site, and the trench depth is well above the water table.

It is interesting to note that near the 200 East Area is the U.S. Ecology commercial low-level waste disposal facility. This facility uses a mounded cover that is consists of 8 feet of soil backfill, 6 inches of cobblestones, and 10-15 feet of soil. Consequently, this design provides a greater soil cover to mitigate any infiltration, it has a coarse stone layer to minimize biologic (animals and plants) intrusion, and the mounded shape helps to facilitate drainage.

Standards Summary:

Standard		Results
1. Complement region	+	Cover material is Hanford soil, and shallow trench
2. Cover design	-	No engineered cover
3. Drainage system	-	No drainage system
4. Intruder protection	-	No intruder protection

Operations - Hanford stacks its waste 2.5 m from the surface. Backfill is forced into voids by moving heavy machinery over the waste. In the past, waste packages were also compacted during this process since wastes were not stacked in an orderly fashion nor were they all packed in high strength materials, e.g. steel boxes. Hanford does segregate structurally unstable and stable wastes. This is consistent with commercial standards.

Standards Summary:

Standard		Results
1. Package	+	Integrity generally maintained during emplacement
2. Voids	+	Stacked waste
3. Backfill	+	Use Hanford soil which is sandy
4. Segregation	+	Provide segregation

Closure - Hanford has not prepared a final closure plan. Studies are underway to determine if additional modifications to the present cover are needed. This situation is in compliance with DOE Order 5820.2A which allows facilities to have a closure plan within 5 years after the facility has reached its capacity. However, this situation is not as conservative as commercial standards. The NRC Branch Technical Position on Design and Operation says that closure should be an on-going operation.[72] This standard states that a closure plan should be in place before the disposal unit receives waste, and closure operations should start as the unit is filled and covered. This practice would minimize water coming in contact with waste.

With respect to stabilization of disposal unit covers, Hanford does place regional vegetation on-top of the disposal unit to minimize infiltration and enhance evapotranspiration. However, commercial standards take the position that the long-term survival of vegetation in a dry climate is questionable.[73] As such, they suggest incorporating stone layers into the cover to mitigate erosion.

Standards Summary:

Standard	Results
1. Timeliness	- Plan being developed
2. Stabilization	- Natural vegetation used, but no stone layer

Waste Form - Hanford has developed waste form criteria in accordance with commercial standards. The Nuclear Regulatory Commission requires Class B and C waste, long-lived and/or high curie concentration waste, to maintain their physical dimensions for at least 300 years.[74] This helps to prevent subsidence of the disposal unit cap. Hanford has adopted the standards given in the NRC Branch Technical Position on Waste Form verbatim into its Waste Acceptance Criteria.

In addition to Hanford's stabilization program, the site also prohibits certain waste types, e.g. liquid waste, in accordance with both DOE Order 5820.2A and 10 C.F.R. Part 61. This prohibition, however, was not followed prior to 1988.

Standards Summary:

Standard	Results
1. Stabilization	+ Adopted commercial standards
2. Prohibited Waste	+ In compliance with Order and 10 C.F.R. Part 61

II. Los Alamos National Laboratory:

Site Summary - The Los Alamos National Laboratory (LANL) has issues regarding facility siting, design, and operation. The disposal facility is situated far above the water table, but the area is subject to erosion, seismic activity, and the burial site is near the site boundary. Operationally, (1) the design of the disposal facility includes a minimal infiltration cover - it is not mounded and presently does not use layers to prevent erosion and biologic intrusion; (2) there is no active attempt to minimize cover subsidence by segregating stable and unstable wastes; (3) waste packages are damaged during compaction processes; and (4) the backfill may conduct water less readily than does the surrounding soil. However, LANL is presently disposing of certain wastes with provisions for intruder protection.

Site Suitability - The Los Alamos National Laboratory is located in a semi-arid region and is not in any known floodplain. The soils consist of volcanic deposits, tuff. The tuff is a highly porous material (50 percent porosity)[75], however, its hydraulic conductivity is small- 1×10^{-8} cm/s (20-40 percent moisture).[76] Additionally, the site is characterized by a 850 feet depth to the water table.[77] This distance, coupled with the small hydraulic conductivity of the tuff, provides a substantial defense against groundwater contamination. However, in April 1994, the DNFSB staff was told by LANL personnel that they had not presently reached a consensus on a model to describe the transport of contaminants.

The LANL disposal facility is different from other disposal sites in that it is located atop a narrow mesa near the site boundary. Trenches are constructed at least 50 feet from the cliff edge. The short distance to the edge does not provide as much protection against horizontal contaminant migration as the facility has for vertical movement. Additionally, in the long term, cliff retreat due to erosion may expose buried waste.

The Area G disposal facility is adjacent to the lands of the San Ildefonso Pueblo. In addition, there are known Native American archeological sites within Area G. These sites may provide people incentive to excavate areas on or near the disposal site.

Finally, LANL is located in a seismicly active area. However, LANL has yet to complete its performance assessment demonstrating that a seismic event will not adversely affect the geologic structure of the area. Until other information is presented, it seems that given the site's past history, LANL would not conform to commercial standards which call for avoidance of seismic areas.

Standards Summary:

Standard		Results
1. Modeling		Not enough information available; studies in progress
2. Depth of Water Table	+	Depth to water table is 850 feet
3. No discharge on site	+	No surface waters in burial grounds
4. Population distance	-	Adjacent to Pueblo Land
5. Natural resources	-	Archeological ruins near site
6. Flooding	+	Burial grounds not in 100 year floodplain
7. Seismic	-	Active area; studies in progress
8. Erosion		Not enough information available; studies in progress

Design - The Los Alamos National Laboratory disposes of its low-level waste via shallow land burial. The trenches are approximately 60 feet x 80 feet x 700 feet. They are unlined and the floors are slopped to a french drain. Crushed tuff is used as backfill, and the cover consists of at least 3 feet of crushed tuff beneath 0.5 feet of soil. LANL has evidence which suggests that the crushed tuff is less permeable than undisturbed tuff.[78]

Although LANL is in a relatively dry climate, the area does experience infiltration from short intense storms and snow-melt. LANL relies upon its cover to minimize this infiltration. However, the DNFSB staff believes there are three problems with the design of the cover. First, commercial standards provide for a mounded cover to facilitate drainage.[79] LANL's cover is not mounded, but conforms to the natural grade. Second, the use of the cover material, crushed tuff, as a backfill does not appear to be appropriate because it may have a lower permeability than the surrounding undisturbed tuff. A backfill material which is more permeable than both the surrounding soil and cap helps ensure that water is not kept in contact with waste packages longer than necessary. Also a more permeable backfill provides a capillary break between the cap and waste packages (this assumes a mounded cover). This encourages water to flow around waste instead of through it. The NRC recommends that a freely flowing non-cohesive material such as sand be used for this purpose.[80] Third, LANL's cover does not incorporate coarse stones. LANL's facility may be impacted by erosion and biologic intrusion. The use of coarse stones helps to prevent both of these.

The cover and trench design do complement the regional characteristics. The depth of the trench is large yet still it maintains more than a 700 feet depth to the groundwater. Additionally, the cover material is less permeable than the undistributed tuff, thus it improves the site's resistance to infiltration and helps to guard against bathtubing.

With regard to intruder protection, LANL has recently adopted procedures which conform to industrial practice. LANL places all waste which requires intruder protection, as defined by the NRC, at least 5 m below the surface. The NRC accepts this distance as a sufficient barrier.[81] This practice however, is informal and has not been incorporated into the standard operating procedures.

Standards Summary:

Standard		Results
1. Complement	+	Use regional materials
2. Cover	-	No engineered cover
3. Drainage System	+	French Drain
4. Intruder Protection	+	Provided

Operations - Waste is neatly stacked and compacted in place. This latter method does not meet the intent of commercial standards which require emplacement to maintain the integrity of waste packages. Compaction deforms waste packages, but helps to decrease void space. This practice thus has both disadvantages and advantages. On one hand, the reduction of voids decreases the chance of cover subsidence. On the other hand, it removes the defensive layer provided by waste packaging. An alternative to compaction is to compress waste packages before disposal. This would minimize void space and maintain package integrity. Also, unstable waste is not segregated from stable waste, in accordance with commercial standards. Waste separation lessens the probability of cap subsidence.

Standards Summary:

Standard		Results
1. Package	-	Compacted in place
2. Voids	+	Stacked waste; compacted in place
3. Backfill	+	Use of crushed tuff (see design)
4. Segregation	-	No segregation

Closure - LANL has indicated to the DNFSB staff that it is undertaking a study to determine final closure options. This study is still preliminary.

LANL uses regional vegetation to stabilize its covers. Present designs do not incorporate stone layers as suggested by commercial standards.

Standards Summary:

Standard		Results
1. Timeliness	-	No plan yet.
2. Stabilization	-	No use of coarse stones in plan

Waste Form - LANL does not have provisions for stabilizing long-lived and higher activity waste forms as identified in 10 C.F.R. Part 61 and the associated Branch Technical Position. Consequently, LANL could expect greater rates of waste degradation. It should be noted that LANL has not seen any evidence of subsidence in its disposal units.

LANL does prohibit certain waste types from land disposal, e.g. liquid waste, in accordance with DOE Order 5820.2A, but, this prohibition was not followed prior to 1988. In addition, LANL's practice would not comply with 10 C.F.R. Part 61 as it uses cardboard packaging for disposal.

Standards Summary:

Standard	Results
1. Stabilization	- No stabilization program
2. Prohibition of Waste	+ In accordance with Order

III. Savannah River Site:

Site Summary - The Savannah River Site is located in a humid area with a shallow water table. Additionally, the disposal facility is in close proximity to surface waterways.

There are deficiencies in the design and operation of the SRS burial grounds. They lack engineered infiltration and intruder barriers, and emplacement operations are generally not geared toward maintaining the long-term stability of waste forms and disposal trenches. However, the recently constructed vault system is a major improvement in facility design practice. As presently planned, this facility will either meet or exceed commercial standards for design and operation.

Site Suitability - The Savannah River Site is a humid region which experiences an estimated 124 cm/yr annual rate of precipitation and a 40 cm/yr rate of infiltration.[82] The water table is located at a depth of 45 feet.[83]

The distance to the water table is generally an important factor in site suitability. The Nuclear Regulatory Commission takes the position that in the limiting case, waste can be buried below the water table provided that diffusion is the dominate means of water transport[84], i.e., the hydrogeology is characterized by a hydraulic conductivity on the order of 1×10^{-7} cm/s.[85] In Savannah River's case, the hydrogeologic unit used for burial is a clay-to-silty sand. Its saturated hydraulic conductivity is approximately 1×10^{-4} cm/s.[86] Thus, given the high rates of infiltration in the area, diffusion is not necessarily the primary means of transport. Consequently, contaminant transport in the water table is an important scenario for the design of SRS' low-level waste disposal facilities.

Although the water table is located close to the surface, this does not mean that radioactive contaminants have direct access to the regional confined aquifer. This confined aquifer is located approximately 300 feet from the surface.[87] It is separated from the uppermost unconfined aquifer by three confining layers of low hydraulic conductivity. Additionally, beneath E-Area, the flow of groundwater from the regional aquifer is upward. This information, coupled with the isolating capacity of the confining layers helps to minimize contamination of the regional aquifer. SRS has performed hydrogeologic studies which suggest that contaminants which reach the water table will discharge into nearby streams rather than the regional aquifer.

The Savannah River Site has been subject to moderate intensity earthquakes, but is not located in an extremely seismically active zone. Over the last two hundred years, earthquakes in the vicinity of SRS have produced ground motions of less than 0.1 g. Two earthquakes have had epicenters in the SRS boundaries since 1985. Resulting ground accelerations have been less than or equal to 0.002 g. The seismic hazard at SRS is still being debated.

Standards Summary:

Standard		Results
1. Modeling		Not enough information available
2. Depth of Water Table	-	Depth to water table 45 feet
3. No discharge on site	-	The unit discharges to a stream ~ 2 km away.
4. Population distance	+	Population center more than 2 km away.
5. Natural resources	+	No known resources
6. Flooding	+	Burial grounds not in 100 year floodplain
7. Seismic		Not enough information available
8. Erosion		Not enough information available

Design - SRS has constructed two types of disposal facilities. Traditionally, the site has used shallow land burial. However, a vault system, a greater confinement disposal facility, has been constructed and is expected to open in 1995. Both facilities are described below.

Burial Grounds: The E-Area burial grounds have operated since 1953. They have employed two types of trenches- the slit trench and the engineered low-level trench (ELLT). The slit trench is a long narrow unit (20 feet x 15 feet x 150-400 feet) used for intermediate level waste (low-level waste which must be remotely handled). The pit is capped with four feet of earth and the cover is not mounded. The ELLT has been used at the burial grounds since 1986. The trench dimensions are modeled after the Barnwell Low-Level Waste Facility design. The ELLT is generally 18 feet x 150-400 feet x 900-1200 feet and the walls are sloped at a 1:1 gradient. The top of the ELLT is mounded with at least four feet of earth.

The facility covers are interim. SRS plans to study the possibility of developing an engineered barrier for the burial grounds, but the details are preliminary. The study is scheduled to be completed by 1999. The present cover does not represent an effective attempt to engineer an infiltration barrier - impermeable materials and multi-layering are not used, and the slit trenches are not mounded.

The burial grounds use a french drain system. In addition, the overall facility drainage design has been recently upgraded. The burial ground experienced four severe rainstorms since 1965 which have flooded the trenches. The drainage system was upgraded in 1992 to handle a 100 year recurrence flood.

In additional, both the slit and ELLT trenches are not designed with intruder barriers although they contain the equivalent of Class C waste. Commercial standards require intruder barriers for long-lived waste.

Standards Summary:

Standard		Results
1. Complement	+	Complements site characteristics
2. Cover	-	No engineered cover
3. Drainage	+	Design basis flood is 100 year recurrence flood
4. Intruder Protection	-	None

Vaults: The construction of the vaults is a new step for DOE. The vaults are an attempt to decouple the waste inventory from the groundwater pathway. There are actually 3 types of vaults - Low Activity Waste Vaults, Intermediate Level Non-Tritium Vaults, and Intermediate Level Tritium Vaults.[88]

The Intermediate Level Vaults accept waste radiating more than 200 mR/h at 5 cm. The Non-Tritium Vaults are 189 feet x 48 feet x 29 feet concrete structures. The walls are 2.5 feet thick yielding 200,000 cubic feet of disposal space. The structures conform to American Concrete Institute Standard 349-85 with a specification for concrete related nuclear structures, and SRS Site Specification 7096 for maximum resistance structures.[89] There are 10 Non-Tritium Vaults each with 7 cells. Tritium Vaults are the same as the Non-Tritium, but smaller - 57 feet x 48 feet x 2 feet. There are 10 vaults each with 2 cells. The vaults are fitted with a silo system designed to accept 142 overpacked tritium crucibles. Both types of Intermediate Level Vaults are below grade and fitted with man-made interim covers. These caps are both concrete shielding blocks and steel rain covers. The former is used for radiation protection while the latter is used to divert rainwater from the Vaults to the drainage system. Drainage for the Intermediate Level Vaults consists of an in-cell system and a sub-drainage system designed for a 25 year recurrence flood.

One third of the Low Activity Vaults are above grade. They accept waste radiating less than 200 mR/hr at 5 cm. The Low Activity Vaults are divided into separate operational modules and cells. There are 21 such vaults, 19 of which have 3 modules, each with 4 cells. The remainder have 2 modules. Each 3 module vault has 1,700,000 cubic feet of space. Each 2 module vault has 1,133,000 cubic feet. All walls are concrete and are 2 feet thick. One wall on each cell has a roll up door, 26 feet wide, which is replaced with a concrete cast for closure. The base slab is 2.5 feet thick. The roof is concrete with prestressed concrete beams, 3.5 feet thick. The structure conforms to American Concrete Institute Standard 349-85 and to Site Standard 7096.[90] The drainage system consists of a steel gutter along the lateral edge, and a crushed stone bottom. The vault floor is sloped at 2 per cent, and it drains to the stone bottom.

Overall, the vault system both complements and improves the site's natural characteristics by acting as an infiltration and intruder barrier. Additionally, before closure the rain covers serve as an impermeable infiltration barrier (effective only during institutional control). A multi-layered clay closure cover will be put on-top of the vaults, but the details are not complete.

Standards Summary:

Standard		Results
1. Complement	+	Improves sites characteristics
2. Cover	+	Engineered interim cover
3. Drainage	+	Design basis flood is 25 year recurrence flood
4. Intruder Protection	+	Provided

Operations - Operational practices at the burial grounds and the E-Area Vaults are described below.

Burial Grounds: SRS stacks its waste, uses natural site material for backfill, and does not segregate unstable waste from stable waste. Similar to Hanford, backfill compaction at SRS historically resulted in some waste form damage. However, with the institution of new packaging and emplacement procedures, this has been stopped. Additionally, SRS plans to use dynamic compaction before the disposal units are closed. This refers to the dropping of a heavy weight (~5 metric tons) from a height of 40 feet onto the waste packages. Compaction can negate the release protection afforded by waste packages. However, the practice of dynamic compaction could reduce subsidence.

Standards Summary:

Standard		Results
1. Package	-	Dynamic compaction
2. Voids	+	Stacked waste; dynamic compaction
3. Backfill	-	Use natural site material which is not as freely flowing as sand.
4. Segregation	-	No Segregation

Vaults: The vaults generally exceed the operational standards for commercial practice. The vaults act as a stable container for the waste. As a result, stabilization and segregation of unstable and stable waste do not seem to be required to meet the intent of commercial standards. The Intermediate Level Vaults also provide additional stabilization as the waste packages are sealed in layers of grout. The grout is injected around the waste, sealing the packages into a monolith form. Finally, voids are minimized in the Low-Activity Waste Vault by carefully stacking waste packages.

Standards Summary:

Standard		Results
1. Package	+	Vault provides stability
2. Voids	+	Stacked waste
3. Backfill	+	Grout in Intermediate Level Vaults
4. Segregation	+	Vault provides stability

Closure - Closure at the burial grounds and the E-Area Vaults are described below.

Burial Grounds: SRS is studying whether the present cover design should be modified. The selection of a final closure design will occur through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process. SRS will negotiate the application of standards and technologies for design with appropriate regulatory organizations. Compliance with these agreements will be demonstrated through a risk assessment rather than a performance assessment. Although one assessment is cancer risk based while the other is dose based, there is no evidence to suggest that these would result in different conclusions.

SRS went through a similar process during its closure of its mixed waste facility. The final cover, which conformed to RCRA standards, consists of three layers: (1) a foundation of 1-4 feet of mounded soil, (2) a three foot clay barrier, and (3) two feet of topsoil to support vegetation.

The delay in construction of a final cover is in compliance with DOE Order 5820.2A. However, the lack of a final closure plan does not meet commercial standards. The NRC requires that an approved closure plan be in place, so that closure and stabilization measures can be carried out as each disposal unit is filled and covered.[91] This practice minimizes the amount of rain-water that contacts waste.

At present, SRS is stabilizing its interim covers with regional vegetation. This is appropriate for humid regions.

Standards Summary:

Standard	Results
1. Timeliness	- No final closure plan
2. Stabilization	+ Use short rooted plants

Vaults: The vaults have adequate interim covers to prevent infiltration and reduce worker radiation exposure during the institutional life of the facility. Final closure plans are being developed along with cap stabilization plans. The cap is intended to cover the entire vault facility. It is not clear however, if cover construction will be an on-going process that occurs as vaults are filled.

Standards Summary:

Standard	Results
1. Timeliness	Not enough information available
2. Stabilization	Not enough information available

Waste Form - The waste form criteria for both the Burial Grounds and Vaults are described below.

Burial Grounds: SRS does not have provisions for stabilizing waste forms as identified in 10 C.F.R. Part 61 and the associated Branch Technical Position. Consequently, relative to compliant commercial facilities, SRS should expect greater rates of waste degradation and therefore a greater potential for subsidence.

Since 1988, SRS prohibits certain waste types from land disposal, e.g. liquid waste, in accordance with both DOE Order 5820.2A and 10 C.F.R. Part 61.

Standards Summary:

Standard	Results
1. Stabilization	- No stabilization program
2. Prohibition of Waste	+ In accordance with Order and 10 C.F.R. Part 61

Vaults: The vault design is meant to act as a stable container for waste. This design is predicted to meet the stability criteria of 10 C.F.R. Part 61. Thus, it appears waste does not need to be stabilized before emplacement to meet commercial standards.

In addition, the vaults will continue the burial ground's prohibition of certain waste types, in accordance with DOE Order 5820.2A and 10 C.F.R. Part 61.

Standards Summary:

Standard	Results
1. Stabilization	+ Vaults act as stable container
2. Prohibition of Waste	+ In accordance with Order and 10 C.F.R. Part 61

Appendix E - Definitions of Key Terms

Buffer zone - The smallest region beyond the disposal unit that is required as controlled space for monitoring and for taking mitigative measures, as may be required. [DOE Order 5820.2A, Definitions]

Class A, B, and C Waste - Classification of low-level waste using the tables in 10 C.F.R. Part 61.55, where Class A waste is a waste that is usually segregated from other waste classes at the disposal site, Class B is a waste that must meet more rigorous requirements on waste form to ensure stability after disposal, and Class C is waste that not only must meet more rigorous requirements on waste form to ensure stability but requires additional measures at the disposal facility to protect against inadvertent intrusion. [Summarized from 10 C.F.R. Part 61.55, Waste Classification]

Closure - Operational closure is defined as those actions that are taken upon completion of operations to prepare the disposal site or disposal unit for custodial care (e.g., addition of cover, grading, drainage, erosion control). Final site closure is defined as those actions that are taken as part of a formal decommissioning or remedial action plan, the purpose of which is to achieve long-term stability of the disposal site and to eliminate to the extent practical the need for active maintenance so that only surveillance monitoring, and minor custodial care are required. [DOE Order 5820.2A, Definitions]

Cover - *See* Engineered Barrier

Disposal - Emplacement of waste in a manner that assures isolation from the biosphere for the foreseeable future with no intent of retrieval and that requires deliberate action to regain access to the waste. [DOE Order 5820.2A, Definitions]

Disposal Facility - The land, structures, and equipment used for the disposal of waste. [DOE Order 5820.2A, Definitions]

Disposal Unit - A discrete portion (e.g., a pit, trench, tumulus, vault, or bunker) of the disposal site into which waste is placed for disposal. [DOE Order 5820.2A, Definitions]

Disposal Site - That portion of a disposal facility which is used to dispose of waste. For low-level waste, it consists of disposal units and a buffer zone. [DOE Order 5820.2A, Definitions]

Engineered Barrier - A man-made structure or device that is intended to improve the performance of a disposal facility. [DOE Order 5820.2A, Definitions]

Inadvertent Intruders - A person who might occupy the 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 waste. [10 C.F.R. Part 61.2, Definitions]

Institutional Control - A period of time, assumed to be about 100 years, during which human institutions continue to control waste management facilities. [DOE Order 5820.2A, Definitions]

Low-Level Waste - Waste that contains radioactivity and is not classified as high-level waste, transuranic waste, or spent nuclear fuel or 11e(2) byproduct material as defined by DOE Order 5820.2A. Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided the concentration of transuranic is less than 100 nCi/g. [DOE Order 5820.2A, Definitions]

Performance Assessment - An in-depth technical analysis which contains a logical description of the source term and potential contaminant transport pathways that can impact the public's health and safety and the environment. Calculational models are used to determine compliance with performance objectives and typically require various simplifying assumptions to facilitate this analysis. [Summarized from DOE/LLW-93, "Performance Assessment Review Guide for DOE Low-Level Radioactive Waste Disposal Facilities", October 1991, page 14]

Storage - Retrievable retention of waste pending disposal. [DOE Order 5820.2A, Definitions]

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