Department of Energy
Washington, DC 20585

October 2, 1996

The Honorable John T. Conway
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW
Suite 700
Washington, D.C. 20004

Dear Mr. Chairman:

Enclosed is the "Evaluation of the Safety Merits and Demerits of Using Privately Operated Facilities for Disposal of the Department of Energy (DOE) Low-Level Waste" report dated September 1996. This document is a deliverable due to you as detailed in Secretary O'Leary's April 1996, Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 94-2, task IV.B.4. This report was developed as part of the Systems Engineering task for low-level waste management.

This report evaluates safety issues associated with low-level waste disposal at privately operated facilities versus DOE managed facilities. Further, the Privatization report will be used to establish guidance and criteria for sites to use when considering disposal options. Based on conversations with your staff, this guidance and criteria (specified as part of the Task IV.B.4 deliverable) will be part of the Low-Level Waste Program Management Plan deliverable.

Sincerely,

Alvin L. Alm
Assistant Secretary for
Environmental Management

Enclosure

EVALUATION OF THE SAFETY MERITS AND DEMERITS OF USING PRIVATELY OPERATED FACILITIES FOR DISPOSAL OF DOE LOW-LEVEL WASTE

September 1996

Evaluation of the Safety Merits and Demerits of Using Privately Operated Facilities for Disposal of DOE Low-Level Waste

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EXECUTIVE SUMMARY

One of the tasks delineated by the Defense Nuclear Facility Safety Board in its Recommendation 94-2 was an evaluation of privately operated facilities for disposal of Department of Energy (DOE) low-level waste (LLW). The safety merits and demerits of using private disposal facilities (e.g., Envirocare and Barnwell) compared to disposing of LLW at DOE facilities have been evaluated using a systems approach based on seven functional areas: siting, design, operations, closure, waste form, performance assessment, and approval and oversight.

Siting. Privately operated LLW disposal facilities licensed by the Nuclear Regulatory Commission (NRC) or NRC Agreement States must meet the siting requirements of 10 CFR Part 61. Generally, the siting process begins with an entire state, and screening criteria are applied to arrive at the potential disposal locations. Detailed site investigations are performed at the selected site to provide data to evaluate its suitability and identify any restrictions on wastes that must be imposed. The siting requirements for DOE disposal facilities are contained in DOE Order 5820.2A. The DOE selects sites for its disposal facilities from within the boundaries of its reservations. Similar to commercial sites, permissible inventories of radionuclides for disposal are based on performance assessments that consider the design of the proposed disposal facility, the final form of the disposed waste, and the surrounding environmental conditions.

Design. Both privately operated and DOE-managed disposal facilities generally use shallow trenches in arid regions of the country and tumulus or vault designs in humid regions of the country. The primary advantage of the more engineered designs such as the tumulus or vault is for disposal of wastes containing shorter-lived radionuclides: for a water pathway to the compliance point, these radionuclides are detained longer in the disposal facility and decay to low levels while migrating through the environment; for inadvertent intrusion, these radionuclides have an opportunity to decay to low levels because the more-engineered facilities are assumed to deter intrusion for longer periods of time.

Operations. Privately operated disposal facilities segregate waste for disposal according to the NRC's waste classification system. This classification system is considered when developing the waste acceptance criteria (WAC) for privately operated facilities. The DOE also bases its WAC on site-specific performance assessments and safety analysis reports, although it does not use a waste classification system. For both privately operated and DOE-managed facilities, radiological limits vary from site to site based on the capability of the natural and man-made features incorporated into the design.

Closure. Privately operated disposal facilities are required to have a closure plan as part of the application for a license. The sites are located on land leased from a state or federal entity, and the site returns to that government entity upon meeting all closure requirements, including a surety bond for any necessary future remedial action. The DOE may take control of these lands if requested by the controlling government entity. The DOE disposal facilities are located on federally controlled reservations, and long-term control is provided by DOE.

Closure plans for these facilities are also required but have not been developed by the sites to serve as input for performance assessments; assumptions about the final closure configuration are contained in the performance assessments. This issue is addressed in the corrective action plans developed to resolve vulnerabilities identified in the complex-wide review of the LLW system conducted as part of DOE's implementation plan for Recommendation 94-2.

The large sizes of the DOE reservations generally will provide more protection to the public than the privately operated sites, although the disposal facilities at the Oak Ridge Reservation, which are located near the reservation boundary, are a notable exception.

Waste Form. The primary purpose of waste forms for disposal of LLW is to provide stability for the disposal facility. All LLW disposal facilities have requirements to ensure stability of waste based on compressive strength of the waste or package and minimized void space. Waste forms can also aid in minimizing releases of radionuclides to the environment. Facilities in humid regions of the country benefit most from this aspect of waste forms due to the higher potential infiltration rates at these sites. In all environments, enhanced waste forms may be important in deterring inadvertent intrusion by allowing the intruder to recognize the waste as a hazard. As with more-engineered disposal facilities, more-engineered waste forms are important primarily for shorter-lived radionuclides; longer-lived radionuclides will not decay appreciably while being retained within more durable waste forms.

Performance Assessment. The assessment methodologies used to analyze performance of commercial and DOE LLW disposal facilities are similar. However, the differences in conservatism used by the analysts for the site-specific assessments may be very different. The performance assessments result in site-specific concentration limits, which are used to develop WAC for the disposal facility. The concentration limits for radionuclides at Barnwell and SRS are generally similar for most radionuclides. However, at Barnwell, the limits for tritium and Tc-99 are two and three orders of magnitude higher than those for the nearby DOE SRS, indicating that the performance assessment for SRS is more conservative than that at Barnwell for releases to the environment. The limits at Envirocare are generally equivalent to the NRC Class A limits. There are no site-specific limits on radionuclide concentrations in LLW at the Nevada Test Site (NTS).

Approval and Oversight. All privately operated disposal sites must meet the requirements specified by the NRC in 10 CFR Part 61 and those specified by the Agreement State. These requirements include obtaining and operating under a license, submitting to periodic compliance reviews and appraisals, and maintaining the financial capability to pay for any future remedial activities. The operator is licensed and monitored by an external, independent government organization. Sites controlled by the DOE are required to submit site-specific radiological performance assessments and composite analyses, as well as safety analysis reports and other documentation to DOE headquarters for review and approval. Oversight and compliance reviews are conducted by DOE's Office of Environment, Safety, and Health (EH), which is a separate office within the department from the Office of

Environmental Management (EM) that has programmatic responsibility over the LLW disposal facilities. Although EH and EM are functionally independent within the department, they both report to the Secretary of Energy. Outside of DOE, this functional independence may not be readily apparent. The DOE's self-regulating policy is perhaps the largest difference between privately owned and DOE-owned disposal sites related to approval and oversight.

CONCLUSIONS

Although the requirements and practices for privately operated and DOE-managed facilities often differ within the seven functional areas, the resulting level of protection provided by the aggregate of these functional areas are similar for both systems. The similarity in approaches of DOE and NRC is not surprising because both organizations evolved from the same parent organization and have continued close communication about waste disposal.

However, in practice some differences are worth noting:

- The concentration limits at Barnwell for highly mobile radionuclides (e.g., tritium and Tc-99) are two and three orders of magnitude higher than at DOE's SRS. The disposal facilities at both sites are vaults, and the primary difference appears to be due to the differences in conservatism used in the analysis of releases to groundwater.

- In some instances, the DOE Orders have not been implemented as intended. For example, the requirement for the development of closure plans was not always being followed by the DOE sites. This deficiency is now being addressed in the corrective action plans for the complex-wide review of DOE's LLW system, which was conducted as part of the DOE Implementation Plan for Recommendation 94-2. Implementation of plans to resolve other deficiencies identified in Recommendation 94-2 is also proceeding.

- The siting requirements of NRC and DOE are similar: however, one major difference is apparent. While privately operated facilities are sited on property specifically selected for the purpose of LLW disposal. DOE is limited to selecting locations from within the boundaries of the reservations under its control. In general, the locations for these reservations were selected for reasons other than for their suitability for disposal of LLW, although, in general, suitable locations for disposal have been found at these sites.

- Privately operated facilities use the NRC waste classification system to determine the type of packaging and waste segregation required for waste being disposed of at a site. DOE has chosen not to use such a system, relying instead site-specific performance assessments to determine waste acceptance criteria. Both systems are sufficiently protective.

INTRODUCTION

A qualitative and quantitative comparison of the approaches for disposal of low-level waste (LLW) used for privately operated facilities licensed by the Nuclear Regulatory Commission (NRC) or NRC Agreement States and used for Department of Energy (DOE)-managed facilities developed under DOE Order 5820.2A is contained in this report. This comparison identifies the safety merits and demerits of using private facilities for disposal of DOE LLW relative to using DOE-managed disposal facilities. Comparisons are made using information and data related to currently operating DOE and private disposal facilities.

Analyses based on generic disposal facilities result in comparing the requirements in the NRC regulations and the DOE orders. This type of comparison has recently been made as a deliverable to the Defense Nuclear Facilities Safety Board (DNFSB) pursuant to its Recommendation 94-2 (Cole et al., 1995). This report builds on the work of Cole et al. to evaluate the effects resulting from the differences in requirements of NRC and DOE.

Currently, two privately operated sites, Envirocare of Utah and Barnwell in South Carolina, accept DOE LLW. The DOE's six operating LLW disposal sites are Hanford in Washington state, the Nevada Test Site (NTS), the Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory (LANL) in New Mexico, the Oak Ridge Reservation (ORR) in Tennessee, and the Savannah River Site (SRS) in South Carolina.

Background

The fundamental approaches to regulate and manage disposal of LLW now used by NRC and DOE are a result of the lessons learned from the early commercial disposal facilities in the 1970s.

Early commercial sites for LLW disposal (Beatty, Nevada; Maxey Flats, Kentucky; West Valley, New York; Richland, Washington; Sheffield, Illinois; and Barnwell, South Carolina) used shallow-land disposal (INEL, 1994), a practice that was commonly used at the time at the national laboratories involved in defense programs and atomic energy research. Shallow-land disposal was used near the point of waste generation, thereby reducing transportation costs. The strategy underlying shallow land disposal was that the natural characteristics of the earthen material would be sufficient to slow the movement of radionuclides until they decayed to background levels. The strategy, however, presupposed that disposal site locations would be selected that provided these kinds of natural barriers, that the form of the waste would not allow for easy release of radionuclides, and that disposal facility operations would not reduce the safety of the system.

The significant problems leading to radionuclide migration were site instability and difficulties in surface water and groundwater management (INEL, 1994). The instability of the sites also made prediction of long-term performance difficult. Experience at these sites indicates that a combination of unstable waste forms, specific site characteristics, and certain design and operational practices led to problems with water management and site instability.

Inadequate waste forms was a significant factor leading to failures at 3 (Maxey Flats, Sheffield, and West Valley) of the 6 early commercial disposal sites (INEL, 1994). Because waste disposal was inexpensive, there was little incentive for waste generators to minimize the amount of waste produced or to compact the material into a more stable waste form. Waste material degradation and compression, which were accelerated by contact with water, led to settlement of the trench contents and subsidence or slumping of the trench covers, which in turn routed surface water into the disposal trench and accelerated the degradation cycle.

Early operating practices also contributed to rapid waste degradation, subsequent slumping of the trench covers, and the entry of water into the disposal units. Waste was placed within the disposal trenches with little or no attempt to segregate waste types according to their chemical content or the relative stability of the waste packages. In general, little compaction was applied to the disposed waste, backfill, and trench covers other than that obtained by driving over the disposal trenches with heavy trucks. Thus, considerable void space probably existed within the trenches, promoting rapid settling. At the humid sites, water from rainfall was frequently allowed to accumulate in the open disposal trenches while they were being filled, promoting rapid waste degradation and settling. In many cases, the soil surrounding the trenches was less permeable to water than the soil that was used to cover the trench. This difference in permeability allowed the trenches to fill with water, a phenomenon known as the "bathtub" effect (INEL, 1994).

The characteristics of several of the disposal site locations also contributed to the problems. Low-permeability soils retained the water that entered the disposal units, allowing it to become contaminated with radionuclides before its slow release. Sand lenses served to route groundwater into and out of disposal trenches. At Sheffield, a permeable layer at the bottom of the trenches conducted contaminated water away from the trenches and off-site. At Maxey Flats, a permeable layer provided communication between trenches. At West Valley, the low-permeability material surrounding the trenches caused infiltrating water to fill a trench and seep out through the cover system.

Problems of this magnitude and type were not experienced at Richland, Barnwell, and Beatty. The Richland, Washington, site and the Beatty, Nevada, site are in arid to semi-arid environments and do not experience water management problems. The site at Barnwell, South Carolina, although in a humid environment, has benefited from the experiences of the other sites.

The experiences in the developmental years of commercial LLW disposal led to the formulation of 10 CFR Part 61 by NRC in 1982. The goal of this regulation was to attain four performance objectives:

- protect the general population from releases of radioactivity,
- protect any individual who inadvertently enters a disposal site after the site is closed,

- protect workers during site operations, and
- ensure long-term stability at disposal sites to eliminate the need for ongoing active maintenance after closure.

The DOE formalized its Order 5820.2A for LLW disposal in 1988. The goal of the Order is to also attain four performance objectives:

- protect the public health and safety in accordance with applicable standards,
- protect the general population from releases of radioactivity,
- protect an individual who inadvertently enter a disposal site after the site is closed, and
- protect groundwater resources.

Both NRC and DOE require performance assessments to be done, and the performance standards for permissible doses are similar. NRC requires that the site characteristics be considered in terms of the indefinite future and evaluated for a 500-year time frame. The DOE requires that the potential for natural hazards such as floods, erosion, tornadoes, earthquakes, and volcanoes be considered in site selection. The site selection should also address the impact on current and projected populations, land use resources and development plans. The NRC and DOE both require consideration of long-term site characteristics and mechanisms for contaminant release.

Although there are differences in implementation, the approach used by NRC and DOE for many aspects of LLW disposal are similar. This similarity should not be surprising: the NRC and DOE evolved from the same parent organization, the Atomic Energy Commission, and the NRC and DOE have continued close interactions related to disposal of LLW. For example, the NRC relied on the DOE national laboratories to help provide the technical basis for its LLW rule. The effects of the differences in approaches used by the NRC and DOE are identified in this report.

Purpose

This report results from the Secretary of Energy's response to DNFSB Recommendation 94-2. Specifically, it serves as the basis for establishing the guidelines set for Task 4: Evaluation of Privatization of Chapter IV of the Implementation Plan for Recommendation 94-2 (DOE, 1996b). The purpose of this deliverable is to compare the safety merits and demerits of using privately operated facilities (i.e., those not part of the LLW compact system) for the disposal of DOE LLW relative to using DOE managed disposal facilities. The evaluation is based on seven functional areas: siting, design, operations, closure, waste form, performance assessment, and approval and oversight.

A report that compares and outlines the major differences in the approaches used by NRC and DOE to regulate and manage disposal of LLW for these same seven functional areas has recently been prepared for DOE (Cole et al., 1995). While the comparisons of approaches contained in that report serve as a data source for this work, the usefulness of that report is limited because it contained no analyses and little discussion pertaining to the benefit of one approach over the other. Those types of analyses and discussions are contained in this report.

Approach

For each of the seven functional areas, the DOE and NRC approaches to regulating and managing LLW disposal are compared and the safety merits and demerits of using private facilities are identified. To the extent possible, the differences in these two approaches are qualified and quantified. The quantitative differences in the approaches are derived by comparing site-specific commercial waste acceptance criteria with results compiled from various DOE reports about the performance of specific and generic disposal facilities. A systems approach is used to identify the differences in privately operated and DOE-managed disposal facilities using the seven functional areas. Differences in site characteristics (e.g., hydrology) are included as part of this systematic evaluation.

The next section of the report provides a comparison and discussion of the seven functional areas and highlights the differences between privately operated and DOE operated disposal facilities. The last section of the report contains conclusions based on these analyses.

COMPARISONS BY FUNCTIONAL AREAS

This section provides comparisons of privately operated and DOE-managed disposal facilities based on seven functional areas: siting, design, operations, closure, waste form, performance assessment, and approval and oversight.

Siting

For privately operated LLW disposal facilities licensed by the Nuclear Regulatory Commission or an Agreement State, the selected location must meet the siting requirements laid out in 10 CFR Part 61. The purpose of the siting criteria is to select a location which is satisfactory for a disposal facility that will contain Class A, B, and C wastes. The Part 61 siting criteria include requirements for:

- choosing a location which can be characterized, modeled, analyzed, and monitored,
- avoiding locations of population growth, future development, or where nearby facilities could adversely impact the site,
- avoiding locations that (1) have known natural resources, (2) are in flood plains, (3) have a significant upstream drainage area, (4) are known active tectonic or volcanic areas, (5) have surface geologic processes occur often, and (6) the ground water discharges to the surface within the disposal site, and
- choosing a location with sufficient depth to ground water, or with ground water in which molecular diffusion is the dominant means of transport.

The typical approach for meeting these criteria has been to apply a screening process with pre-established criteria to all the land within a state's boundary and to eliminate from consideration areas of the state that fail the screening criteria. The areas that remain after this screening are considered potential sites for further evaluation. Concerns have been identified about this type of screening process based on the lack of success to date, on shortcomings in the amount and quality of technical data available for screening, and on professional differences about the importance of various screening requirements (Newberry, 1994).

For DOE facilities that dispose of LLW, the siting requirements are contained in DOE Order 5820.2A (DOE, 1988). While the requirements of NRC and DOE are similar (see Table B-1 in Cole et al., 1995), one major difference is apparent. The DOE is limited to selecting locations from within the boundaries of the reservations under its control. In general, the locations for these reservations were selected for reasons other than for their suitability for disposal of LLW, although, in general, suitable locations for disposal have been found at these sites.

Both the DOE and NRC use a defense-in-depth approach for systematic design of disposal facilities. This defense-in-depth approach includes performance of the surrounding environment, design of the disposal facility, selection of waste form, and limits on inventories of radiologically significant radionuclides. The following examples are derived from performance assessments for disposal facilities for DOE LLW, although in principle, the concepts apply to both DOE and privately operated facilities. More detail on the quantitative aspects of the disposal facility design and waste form are provided in later sections of the report.

Surrounding Environment

The geologic and hydrogeologic characteristics of the environment surrounding some DOE disposal facilities are relatively complex. For example, at Los Alamos National Laboratory (LANL), the vadose (unsaturated) zone in the area of the LLW disposal facility consists of approximately 750 feet of welded and nonwelded volcanic tuff with pumice interbeds that overlie approximately 400 feet of conglomerates with basalt interbeds. At the Idaho National Engineering Laboratory (INEL), the vadose zone in the area of the LLW disposal facility consists of a series of basalt flows with silty interbeds of sedimentary deposits extending to great depths. The basalt flows are strongly fractured and fissured and exhibit a classic structure of massive rock in the center grading to highly vesicular rubble at the top and bottom. At the Oak Ridge Reservation (ORR), the vadose zone is thin or nonexistent, and the water table is a subdued replica of the surface topography that is constrained by ground surface elevations at streams. Groundwater normally discharges to streams. Additionally, the groundwater flows in fractures and weathered zones that are generally parallel to geologic strike, causing severely anisotropic flows (DOE, 1996a).

The complex geology at LANL, INEL, and ORR were modeled in the performance assessments for those sites in a simple and conservative manner. At LANL, the welded tuffs containing or suspected of containing fractures were not included in the analysis of performance, and the effective thickness of the vadose zone was reduced by approximately 50 meters (DOE, 1996a). At INEL, the basalt flows were not included in the analysis of performance, and the effective vadose zone thickness was reduced by approximately 220 meters (Maheras et al., 1994). At ORR, the tumulus disposal facility was modeled as if a "bathtub effect" would result, and compliance points were established at surface water locations predicted to receive the contaminated groundwater and at groundwater locations, even though these groundwater formations could not sustain water production rates required to support a drinking-water well. The groundwater compliance point was shown to provide the most restrictive limits for releases from the disposal facility (ORNL, 1994).

The actual degree of conservatism that results from the simplifications of the subsurface geology provided in the performance assessments for these three sites cannot be estimated (see, e.g., Oreskes et al., 1994). However, the simplifications used in the performance assessments lead to defense-in-depth by foregoing credit for the zones of complex geology that likely provide some attenuation.

Disposal Facility Design

In the arid or semi-arid region of the country at Hanford, INEL, LANL, NTS, and Envirocare, facilities for disposal of DOE LLW are shallow subsurface trenches. In the humid region of the country at ORR, SRS, and Barnwell, however, tumulus and vault technologies are used for disposal facilities. The primary benefit of these more-engineered facilities is hydraulic isolation of the wastes because the large amounts of low-permeability concrete used in these facilities effectively isolate the wastes from infiltrating water.

The absolute service life of the tumulus and vault facilities is not known due to the lack of long-term experience with these facilities. The performance assessments at ORR (ORNL. 1994) and SRS (MMES et al.. 1994) address this uncertainty by making conservative assumptions about the duration of performance for these facilities based on their structural stability. The engineered barriers in these facilities are assumed to fail at some point in the future. and the facility is then assumed to perform no better than the surrounding environment. The primary consequence of this assumption is that engineered facilities are assumed to offer no significant long-term advantages for the disposal of wastes containing longer-lived radionuclides. The primary advantage of engineered barriers is for the disposal of wastes containing shorter-lived radionuclides. This discussion also applies to the Barnwell commercial LLW disposal facility near SRS, which recently started using vault facilities.

Waste Form

The primary purpose of using specific waste forms for disposal of LLW is to provide structural stability for the disposal facility. Failures of early commercial disposal facilities at Maxey Flats, Sheffield, and West Valley were primarily the result of the interaction of water with the waste from subsidence cracking of the cover systems due to consolidation of unstabilized waste.

Another purpose of using specific waste forms is to minimize mobilization of radionuclides. The performance assessments for the LLW disposal facilities at ORR and SRS use conservative estimates for the release of radionuclides from wastes relative to the experimental evidence, both in terms of magnitude of release and delay prior to release. In both performance assessments, grouted wastes are modeled by diffusion and desorption processes. The desorption processes are conservatively modeled by selecting lower values for desorption parameters (i.e.. K_d values) than are believed to be measured in the stabilized waste. This approach results in assumed calculated releases of radionuclides that are higher than are expected to occur under disposal facility conditions. As with more-engineered disposal facilities, shorter-lived radionuclides tend to benefit most from enhanced waste forms because they decay to low levels while entrapped in the waste.

Limiting Inventories

Limits on inventories for the radionuclides in LLW are determined from site-specific performance assessments for both DOE and privately operated facilities. These site-specific performance assessments incorporate the performance aspects of the specific geologic and hydrologic conditions of the site when estimating permissible limits on radionuclides. Other analyses, such as facility safety analyses, are also used to provide limits on inventories of certain radionuclides. Privately operated facilities are prohibited from accepting waste that is greater-than-class C. The DOE Order requires that wastes that are equivalent to greater-than-class C, as defined in 10 CFR Part 61.55, must be handled as special case waste and are generally not suitable for disposal in near-surface LLW disposal facilities. Because of the simplifications and conservatisms used in the performance assessments for disposal facilities for LLW, the estimates of limiting concentrations of radionuclides are lower than those that would be provided by a more realistic analysis of performance. These lower limits are the deliberate result of an approach that attempts to use conservatism to counteract the uncertainty associated with complex hydrologic environments and engineered disposal facilities.

Summary Comparison of DOE and Privately Operated Facilities - Siting

Developers of privately operated disposal facilities are required to follow strict guidelines for siting these facilities. This requirement has generally resulted in a site-screening process based on exclusionary criteria that is often challenged on the basis of lack of data and disagreement about the importance of the selected technical factors. Site-specific performance assessments are used to determine permissible concentrations of radionuclides, which are incorporated into the WAC based on the license granted by the NRC or Agreement State. Wastes with concentrations of radionuclides determined to be greater-than-class C are prohibited from disposal at privately operated facilities.

The DOE selects sites for its disposal facilities from within the boundaries of its reservations and determines the permissible inventories of radionuclides for disposal based on performance assessments and other safety documentation. The DOE also generally excludes wastes that are designated as greater-than-class-C, as defined in 10 CFR Part 61.55, from disposal in near-surface LLW facilities (DOE, 1988). Similar to privately operated facilities, this exclusion effectively places an upper limit on the concentrations of certain radionuclides in waste disposed of in DOE LLW facilities.

It may be expected that siting for privately operated facilities would result in geologically more suitable locations than those chosen by DOE because the process for the private facilities generally begins with a much larger universe of potential disposal locations. However, as discussed in later sections of this report, this may not always be true. First, the regulatory thresholds for radionuclide concentrations in commercial and DOE LLW (i.e., Class C waste limits) effectively result in a search for sites that are sufficiently adequate to contain these wastes. When site-specific characteristics or other reasons dictate, additional limits on concentrations of radionuclides are placed on the waste accepted at both DOE and privately operated facilities. Second, some DOE reservations are located in areas that are extremely amenable to disposal of LLW (see the discussion of NTS in the Performance Assessment section of this report). Therefore, although the NRC and DOE requirements and practices for siting disposal facilities are different, no clear safety merits or demerits of using privately operated facilities are evident based on siting considerations.

Design

The type of design selected for the disposal facility is a key factor in limiting inventories of radionuclides that can be disposed of at a particular site for both releases to the environment and inadvertent intrusion. In the assessment of performance of disposal facilities for LLW; the selected scenarios for inadvertent intrusion are usually shown to limit the permissible inventories of many radionuclides at most sites. However, for several radionuclides, releases from the disposal facility to the environment are important for limiting inventories, especially at sites in humid regions of the country (e.g., ORNL, 1994; MMES et al., 1994).

The type of disposal facility designs used at both currently active DOE sites and privately operated disposal sites are listed in Table 1. At sites in humid regions of the country (e.g., ORR, SRS, and Barnwell), facilities with additional engineered features are used.

Table 1. Facility Designs Used at LLW Disposal Sites (from Cole et al., 1996a).

Disposal Site	State	Disposal Facility Design
DOE Hanford Reservation	Washington	Trench, Vault
DOE Idaho National Engineering Laboratory (INEL)	Idaho	Trench
DOE Nevada Test Site (NTS)	Nevada	Trench
DOE Los Alamos National Laboratory (LANL)	New Mexico	Trench
DOE Oak Ridge Reservation (ORR)	Tennessee	Above-grade Tumulus
DOE Savannah River Site (SRS)	South Carolina	Above-grade Vault
Envirocare	Utah	Trench
Barnwell	South Carolina	Below-grade Vault

In this section, the differences in performance of trench, tumulus, and vault disposal facilities are identified. Performance is measured in terms of limiting concentrations of radionuclides in waste with respect to releases to the environment. To make these comparisons, the results of the performance evaluation (PE) project (DOE, 1996a) are used. That project evaluated several different sites for disposal of mixed low-level waste (MLLW) using generic trench and tumulus facilities; a vault facility was evaluated at SRS because that site was using vault technology. Although developed for evaluating options for disposal of MLLW, the PE is applicable to LLW disposal because the performance of MLLW disposal facilities were assumed to be similar to those for LLW. Site-specific performance assessments were not used in the analysis of design because they evaluate only the disposal facility design planned for that site and therefore, do not provide results relative to different designs.

To facilitate the discussion of environmental behavior, the 58 radionuclides evaluated in the PE project were grouped into 8 categories according to persistence (i.e., half-life), mobility, and radiotoxicity. An indicator radionuclide was chosen to represent each of the 8 categories (Table 2). While all 58 radionuclides cannot be definitively categorized into a single one of the eight groupings, a generalized grouping is shown in Table 3. As a consequence of the impact of radiologically significant decay products, some of the radionuclides appear in more than one grouping. Because transport values of radionuclides depend on localized conditions, site-specific groupings may be different than those presented here.

Table 2. Characteristics of the Indicator Radionuclides (from DOE, 1996a).

Radionuclide	Half-Life (years)		Mobility	Radiotoxicity
H-3	Short	12.3	High and Volatile	Low
C-14	Medium	5700	High and Volatile	Low
Sr-90	Short	29.1	High	Medium
Tc-99	Long	213,000	High	Low
Cs-137	Short	30.2	Medium	Medium
U-238	Long	4.47 billion	Medium	Medium
Pu-239	Long	24,100	Low	High
Am-241 (Np-237)[a]	Medium (Long)	433 (2.14 million)	Low (High)	High (High)

Half-life - Short: $t_{1/2} \leq 30$ y; Medium: $30 < t_{1/2} \leq 10,000$ y; Long $t_{1/2} > 10,000$ y
Mobility - High: $K_d \leq 5$ mL/g; Medium: $5 < K_d \leq 100$ mL/g; Low: $K_d > 100$ mL/g
Radiotoxicity - Low: PDCF ≤ 1 (rem/y)/(mCi/L); Medium: 1 < PDCF ≤ 100 (rem/y)/(mCi/L); High: PDCF > 100 (rem/y)/(mCi/L)
a Although Np-237 is a decay product of Am-241 it has significantly different properties. See text for discussion of this indicator radionuclide.

Table 3. A General Grouping of the 58 Radionuclides Evaluated in the PE (from DOE. 1996a).

Indicator Radionuclide	Nuclides with Similar Half-Life and Mobility Characteristics
H-3	Volatile
C-14	Volatile
Sr-90	Co-60, Cd-113m, Ba-133
Tc-99	(I-129)[a], (Np-237), (Am-241)[b], (Pu-241)[b]
Cs-137	(Nb-93m), Eu-152, Eu-154, (Pb-210), (Ra-228)
U-238	(Al-26), (Cl-36), (K-40), (Pd-107), U-233, U-234, U-235, (U-236), Pu-238[c]
Pu-239	(Ni-59), (Se-79), (Zr-93), (Nb-94), (Sn-126), (Cs-135), Th-230, Th-232, Pa-231, Pu-242, Pu-244, Cm-243[d], Cm-247, Cm-248
Am-241[e]	(Si-32), (Ni-63), (Ag-108m), (Sn-121m), (Sm-151), Ra-226, Th-229, U-232, Pu-238, Pu-240, Pu-241[f], Am-243, Cm-244[g], Cm-245, Cm-246, Cf-249, Cf-250[h], Cf-251

a Parentheses indicate that toxicity category is different than for indicator radionuclide.
b Am-241 and Pu-241 are based on their decay product Np-237.
c The characteristics of Pu-238 are based on its decay product U-234.
d The characteristics of Cm-243 are based on its decay product Pu-239.
e The listed radionuclides are similar to Am-241 only for early arrival times at the performance boundary. Because these radionuclides have medium half-lives and are generally of low mobility, later arrival times will result in significant radioactive decay. Later arrival times for Am-241 result in its mobile, long-lived, radiologically significant decay product, Np-237, contributing significantly to the dose.
f The characteristics of Pu-241 are based on its decay product Am-241.
g The characteristics of Cm-244 are based on its decay product Pu-240.
h The characteristics of Cf-250 are based on its decay product Cm-246.

Performance of Facility Design for the Water Pathway

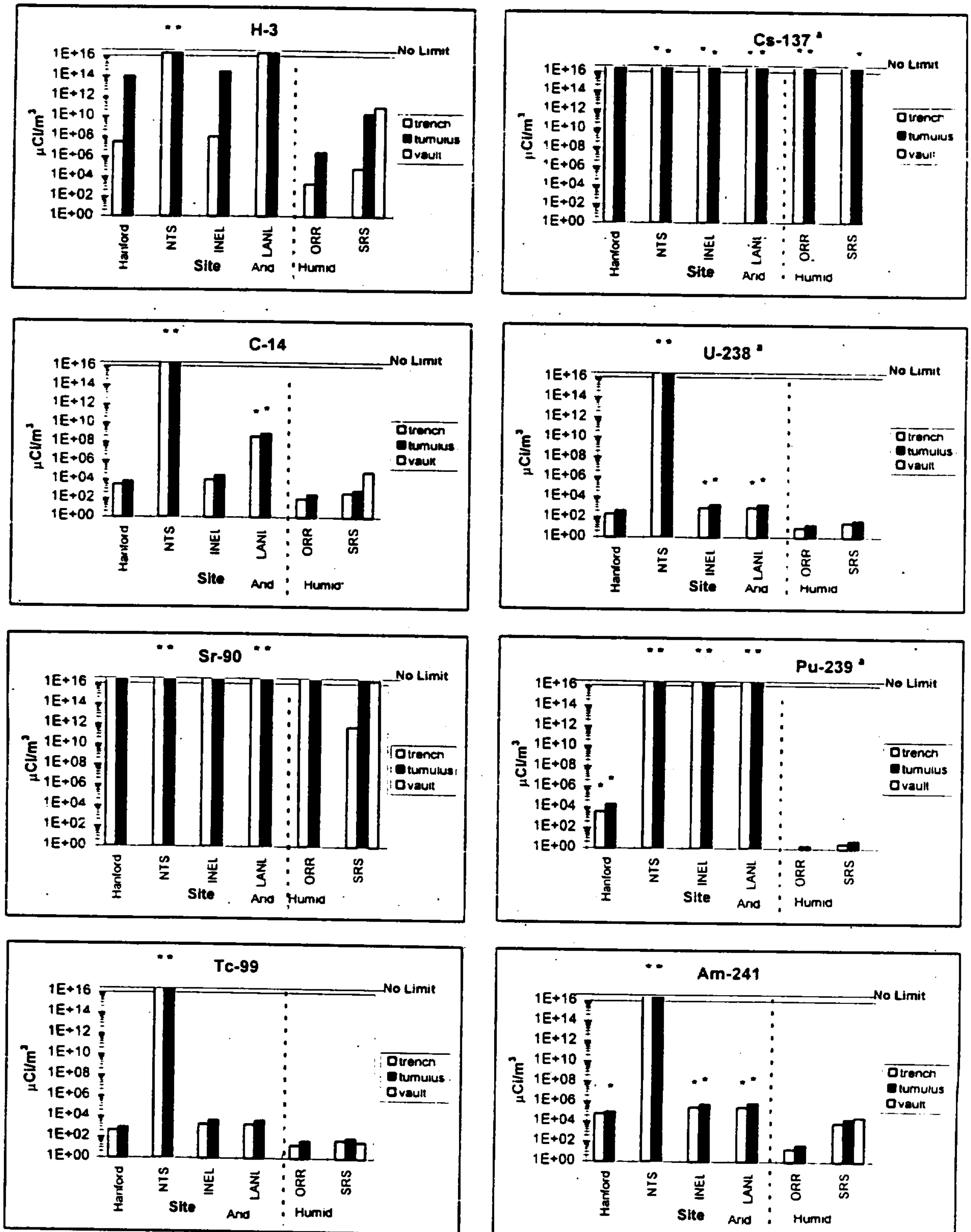
The permissible concentrations of radionuclides in waste for each of the indicator radionuclides based on the analysis of the water pathway for the 6 DOE LLW disposal sites are shown in Figure 1 for both the trench and tumulus designs. Results for the vault design at SRS are also included. These sites represent a wide range of climates and site conditions.

For shorter-lived, mobile radionuclides represented by tritium (H-3), the vault facility at SRS and the tumulus facilities at all sites, except NTS and LANL, allow increased permissible concentrations that are several orders of magnitude greater than those for the trench facility. This increase is primarily due to the assumption that the tumulus and vault facilities minimize infiltration of water for much longer periods than the trench facility; thus, the shorter-lived radionuclides decay while still within the tumulus or vault facility. The permissible concentrations of these radionuclides in waste at NTS and LANL are unlimited for the water pathway. At NTS, an assumption used in the PE and performance assessment (Shott et al., 1996) is that there is no downward migration of water to the regional aquifer. At LANL, the long water travel time in the vadose zone causes tritium to decay to very low levels in the vadose zone.

The differences in permissible concentrations between the trench and tumulus facilities for medium- to longer-lived radionuclides of medium to high mobility (e.g., C-14, Tc-99, and U-238) are minor. The assumed differences in duration of these facility designs are small relative to the half-lives of these radionuclides; the only effect is that the radionuclides are detained in the facility until the engineered barriers are assumed to fail. For the vault design at SRS, the permissible concentrations for C-14 are approximately 2 orders of magnitude higher than those for the trench and tumulus designs due to the longer detention assumed for the vault (3000 years) (MMES et al., 1994) relative to the trench (100 years) and tumulus (300 years) facilities and relative to the half-life of C-14.

For the shorter-lived radionuclides of medium to low mobility that are represented by Sr-90 and Cs-137, the permissible concentrations are unlimited for most sites for both the trench and tumulus facilities. These radionuclides decay to low levels while migrating through the environment prior to reaching the performance boundary. For longer-lived radionuclides like Pu-239 and Am-241 (and its radiologically significant decay product Np-237), differences in permissible concentrations between the trench, tumulus, and vault facilities are minor.

Because of the increased amounts of infiltrating water, the permissible concentrations based on the water pathway for sites located in humid regions of the country (e.g., ORR, SRS, and by extension, Barnwell) are generally lower than for the sites located in arid regions of the country. The increased amount of infiltrating water is a primary reason that humid-zone sites use more engineered tumulus or vault disposal facilities. The principal purpose of these engineered facilities is to provide hydraulic isolation of the wastes for longer periods of time, a requirement not as important at sites located in the arid region of the country



* Arrival time greater than 10,000 y

ª Cs-137, U-238, and Pu-239 were not evaluated in the SRS PA water pathway analysis

Figure 1. Permissible waste concentrations (mCi/m³) for the water pathway (from DOE, 1996a).

Performance of Facility Designs for Intrusion vs. the Water Pathway

The scenarios to evaluate the chronic, long-term exposures to an inadvertent intruder at DOE sites in humid environments (e.g., ORNL, 1994 and MMES et al., 1994) include a homesteader scenario and a "post-drilling" scenario. In the homesteader scenario, the homesteader's house is constructed above the disposal facility with the basement extending into the partially exhumed waste. A portion of the exhumed waste is placed in the soil of the family's garden plot. Exposures occur through external exposure while in the house and garden and through internal exposure from ingestion of contaminated foodstuffs and associated soils. This scenario was assumed to occur after 300 years for the trench facility and after 500 years for the tumulus facility.

In the post-drilling scenario, the homesteader's water well is drilled through the disposal facility, and the cuttings are mixed with the soil of the family's garden plot. Exposures occur though external exposure while in the garden and through internal exposure from ingestion of contaminated foodstuffs and associated soils. This scenario was assumed to occur after 100 years for both the trench and tumulus facilities unless site-specific conditions dictated otherwise. While the post-drilling scenario provides for less interaction of intruders with waste, the earlier assumed time of intrusion causes shorter-lived radionuclides to be limited by this scenario. The limiting concentrations in waste for the indicator radionuclides based on the intrusion scenarios are shown in Figure 2.

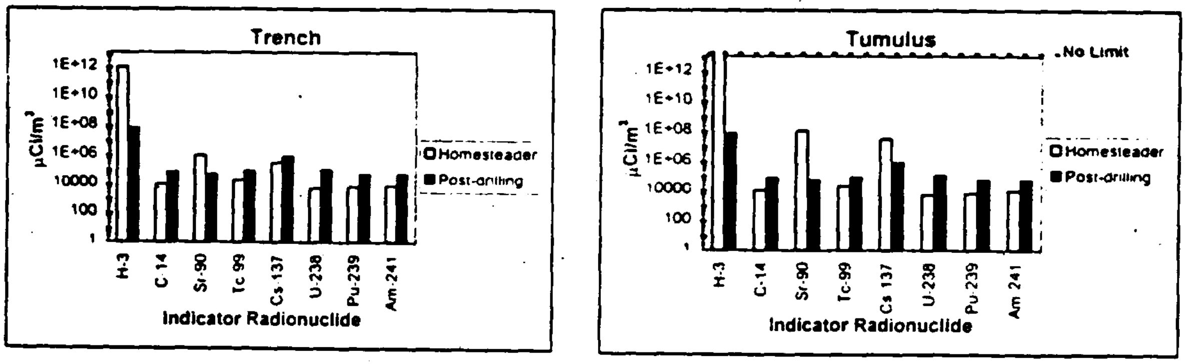


Figure 2. Permissible waste concentrations ($\mu Ci/m^3$) for the trench and tumulus designs for the standard intrusion scenarios (DOE, 1996a).

A comparison of the limiting concentrations in waste for the indicator radionuclides based on the water pathway and on the scenarios for inadvertent intrusion indicates the following:

- For sites in arid and semi-arid regions (e.g., NTS, LANL, INEL, Hanford, and by extension, Envirocare), the water pathway will limit concentrations for only the longer-lived and highly mobile radionuclides like Tc-99 regardless of the type of disposal facility used. Therefore, the trench facilities, which are less costly to develop and operate, are typically used at these sites.

- For sites in the humid region of the country (e.g., ORR, SRS, and by extension, Barnwell), the water pathway is more important for limiting radionuclide concentrations. The more-engineered tumulus and vault facilities will permit higher limits of shorter-lived radionuclides than will the trench facilities. However, because the differences in assumed time of performance between the tumulus, vault, and trench facilities are small relative to the half-lives of longer-lived radionuclides, there is little difference in performance of any of these facilities for the longer-lived radionuclides. Tumulus and vault facilities are now typically used at these humid sites.

Summary Comparison of DOE and Privately Operated Facilities - Design

The permissible concentrations and inventories for the shorter-lived, mobile radionuclides will increase most from the use of more engineered facilities. The permissible concentrations for the longer-lived radionuclides do not increase appreciably from use of more engineered facilities because the engineered features are assumed to perform for a finite period of time. Beyond this time, the longer-lived radionuclides, which have decayed by only a minor amount, can migrate from the disposal facility and through the environment at rates dependent on site conditions rather than on facility conditions. Therefore, the primary advantage of engineered barriers in tumulus and vault disposal facilities is for disposal of wastes containing shorter-lived radionuclides. Engineered barriers offer no significant long-term advantages for the disposal of wastes containing longer-lived radionuclides.

The sites that benefit from use of more engineered facilities are ORR, SRS, and Barnwell in humid regions of the country, and these sites already use additional engineered features. For disposal sites in arid and semi-arid regions of the country (i.e., NTS, INEL, Hanford, LANL, and Envirocare), the differences in performance between trench, tumulus, and vault facilities are minor, and these sites have typically used the lower-cost trench facilities. Therefore, based on design considerations, there is no apparent safety merits or demerits for using privately-operated facilities for disposal of DOE LLW.

Operations

In this section, the activity tracking systems used by DOE at their LLW disposal facilities are discussed. Also discussed are the safety aspects of using a waste classification system. The safety merits and demerits of using privately operated disposal facilities for DOE LLW are summarized. The comparison of the operational safety and health of workers at DOE and privately operated facilities is beyond the scope of this report, and metrics such as accident rates and worker exposure were not examined. However, it should be noted that both DOE and privately operated facilities must meet requirements (e.g., OSHA, NRC, or DOE Orders) that in general are similar.

For privately operated facilities, the NRC has established a waste classification system with three categories of waste that are acceptable for disposal in a near-surface burial facility. Using this system, wastes having greater radiological hazards are required to be disposed of with greater protection. The waste classification system in 10 CFR Part 61 consists of three classes: Class A, Class B, and Class C. Class A wastes contain lower concentrations of shorter-lived radionuclides. These wastes can be disposed of with only the minimum waste form requirements. Class B and C wastes contain longer-lived radionuclides or higher concentrations of short-lived radionuclides and require additional packaging and more isolation. The WACs for privately operated facilities are based on the license granted by NRC or the agreement state and may be different than the limits based on the NRC classification system. For example, the license for Envirocare places limits on concentrations of radionuclides that are similar to Class A waste.

The DOE installations that operate disposal facilities are required by DOE Order 5820.2A to develop and implement facility operating procedures that protect the environment and the health and safety of the public and facility personnel; ensure the security of the facility; minimize the need for long-term control; and meet the requirements of the closure/post closure plan. Operating procedures include training for facility personnel, emergency response plans, and a system of reporting unusual occurrences.

Disposal of DOE's LLW is to be achieved by methods appropriate for meeting the performance objectives. For each disposal site, engineered modifications (e.g., stabilization, packaging, burial depth, and barriers) to handle specific waste types and compositions must be evaluated as part of the performance assessment process. In the course of this process, site-specific waste classification limits may be developed to determine how specific wastes should be stabilized and packaged for disposal. The Order also specifies requirements intended to improve disposal site stability and facilitate waste handling, including specifying limitations on waste characteristics and packaging designs. The DOE has chosen to rely on the performance assessment results to determine the waste acceptance criteria of the disposal facility rather than having predetermined low-level waste classifications.

Activity Tracking Systems

The radiological WAC for a disposal facility for DOE LLW are based on the performance assessment and safety analysis reports (SAR) for that facility. The performance assessment provides information that results in limits on inventories or concentrations of certain radionuclides based on estimates of long-term performance of the facility. The SAR provides similar information based on analyses of operations of the facility and impacts to the public and site operations personnel.

The limits on inventories or concentrations generally apply to the total facility. Except where noted in the SAR, these analyses provide no direct correlation for limits on individual packages of waste. Instead of applying concentration limits based on the facility scale to individual waste packages, the DOE facilities disposing of LLW have developed inventory tracking systems (i.e., record keeping systems) to ensure that the total inventories of important radionuclides are kept below the inventory limits established by the performance assessment for the entire facility.

In implementing these tracking systems, special consideration is given to high activity waste packages or the radionuclide inventories exceeding a substantial fraction of the facility limits (e.g., 10% or more). The types of considerations that are used in these cases include both requirements for advanced warning and/or special approvals before shipping for disposal, and provisions in the design of the disposal facility to ensure that such unusual wastes would be relatively inaccessible after disposal. The degree of concentration averaging provided by this approach must be consistent with the exposure and release scenarios used to develop the inventory limits for the disposal facility. These guidelines were intended to reflect a common sense approach to ensuring acceptable disposals and to prevent abuses of reasonable methods of concentration averaging (Wood et al., 1994).

The DOE approach for these unusual wastes is similar to that used by NRC for Class C wastes, in that DOE's requirement to make the wastes "relatively inaccessible" is similar to NRC's requirement to place Class C wastes at least 5 m below ground surface and to place intrusion barriers over them. The DOE approach provides for more flexibility for disposal of waste but requires more frequent and close interaction between the waste generators and those operating the disposal facilities.

Waste Classification System

The NRC regulations for privately operated disposal facilities include the use of a waste classification system. One of the factors used by NRC in developing a waste classification system was that disposal facility operators must accept waste as delivered to them (NRC, 1982, p. 5-23). The NRC staff stated that a waste classification system, which would set requirements that must be met by waste generators, would be the most reasonable way of achieving the performance objectives and technical criteria for disposal facilities.

The approach of NRC for developing a waste acceptance criteria that minimizes interaction between waste generators and waste disposers was practical for their particular situation because without such a system, the large and varying number of waste generators would make the necessary interactions with waste disposers extremely difficult. Because the operators of disposal facilities for DOE LLW have a smaller number of waste generators with which to deal and because the wastes generated by DOE can vary greatly in form and radionuclide content, a waste classification system similar to that of NRC has never been adopted by DOE.

Summary Comparison of DOE and Privately Operated Facilities - Operations

Operation of private disposal facilities utilizes waste segregation based on the waste classification system developed by NRC. This system provides an effective interface between waste generators and waste disposers that minimizes the need for their interaction. Privately operated sites consider this classification system when developing their WACs, which are based on site-specific performance assessments and result from licenses granted by the NRC or Agreement States.

DOE bases its operational WAC on the results of site-specific performance assessments and SARs. The radiological limits vary from site to site based on the capability of the natural and man-made features incorporated into the design. An activity tracking system is used to ensure that the total inventory of each important radionuclide is maintained below the facility limits. The application of this tracking system for wastes with higher activities of certain radionuclides is similar in approach to NRC's treatment of Class C waste: it provides for additional isolation of these wastes. While the activity tracking system approach provides more operational flexibility for DOE, it does not appear to result in any safety merits or demerits relative to using an NRC-style waste classification system.

Prior to their acceptance, DOE LLW that are being considered for disposal in privately operated facilities must be qualified based on the WAC for that disposal site. Therefore, there appear to be no significant safety merits or demerits of using privately operated disposal facilities for DOE LLW based on operational concerns.

Closure

Closure of a disposal facility comprises a set of systematic actions after waste emplacement operations are completed. Closure includes all the necessary actions to put the facility in the required configuration to enter the post-closure period, to achieve radiation protection goals, and to fulfill environmental requirements. The components of closure are

- Completion of disposal facility operations and installation of the cover system.
- Dismantling of auxiliary facilities and engineered systems.
- Collection and management of records.
- Preparation of a post-operation safety report,
- Finalization of an environmental survey program, and
- Obtaining regulatory approval of the closure plan and institutional control provisions.

Regulatory Guidelines

A comparison of the regulatory guidelines for privately operated facilities and DOE disposal facilities has been detailed in Cole et al. (1995) and is summarized here. The regulations in 10 CFR Part 61 govern privately operated facilities for LLW disposal. A description of the plans for site closure and other long-term issues must be addressed by the licensee in the license application (Section 61.12). These plans, although preliminary, are used in the development of the performance assessment for the facility.

As a method to ensure long-term institutional control, privately operated facilities must be located on lands leased from state or federal government entities. In Section 61.29, the licensee is required to observe, monitor, and carry out all necessary maintenance and repairs at the disposal site before the license is transferred by the Commission. Responsibility for the site must be maintained by the licensee for 5 years after closure and, based on site-specific conditions a shorter or longer time period for post-closure observation and maintenance may be established and approved as part of the site closure plan.

When the requirements for closure are met, control of the waste and surrounding land returns to the control of the government entity. The NRC requires a surety bond that will provide funds for environmental restoration in the event of disposal facility failure (Section 61.63). Section 151 of the Nuclear Waste Policy Act of 1982 gives the Secretary of Energy the authority to assume title and custody of inactive disposal facilities if requested and if the facilities meet all closure requirements of the NRC.

For the DOE-managed facilities, the DOE is committed to retaining control of contaminated lands until they can be released under provisions contained in DOE Order 5400.5 (expected to be codified into 10 CFR Part 834). The primary requirement of this Order is to ensure that the measured dose to a member of the public from all sources of exposure is kept below 100 mrem per year. The DOE is currently evaluating potential future exposures from combined source terms near LLW disposal facilities using composite analyses and will evaluate the impact of all combined sources on their reservations using "comprehensive analyses" (DOE, 1996b).

DOE Order 5820.2A, Section 3j(1) (DOE, 1988) states, "Field organizations shall develop site-specific comprehensive closure plans for new and existing operating LLW disposal sites. The plans shall address closure of disposal sites within a 5-year period after each disposal site is filled." However, as identified in vulnerability number 6 of DOE's "Complex-Wide Review (CWR) of DOE's LLW Management ES & H Vulnerabilities" (DOE, 1996c) for Recommendation 94-2, closure plans for some sites have not been prepared, and assumptions about the configuration of the closed facilities are being made in the performance assessments. This issue is being addressed by the corrective action plan developed to resolve the vulnerabilities identified in the CWR.

The Order provision to analyze site performance for a worst case scenario of the loss of institutional control after 100 years has been widely misinterpreted. The promulgation of 10 CFR 834 will clarify this provision. Consistent with the earlier discussions about releasing land under provisions of 10 CFR 834, LLW disposal facilities are not expected to be released, and therefore, DOE is committed to retaining control of LLW disposal sites and to continuing maintenance and monitoring activities as long as the land is under the control of the Department. The 100-year institutional control period is to be used only in analysis as an assumption for when complete efficacy of institutional controls may begin to erode. This approach is consistent with that used for commercial LLW disposal.

Proximity of Disposal Area to Property Boundary

DOE LLW disposal sites are typically located within large reservations, while commercial disposal sites are located on smaller plots of land with property lines that are relatively close to the disposal area. The DOE requires in a performance assessment that analyses for transport of radionuclides in groundwater be conducted for a performance boundary located 100 meters from the disposal facility. Therefore, if future DOE reservation boundaries are not significantly different than existing boundaries, DOE sites may have a level of protection that is not accounted for compared to commercial sites. However, at ORR the LLW disposal site is less than 200 meters from the boundary of the reservation. Therefore, the large size of the DOE reservations alone does not always provide much greater protection than do commercial sites.

Although larger buffer zones surrounding disposal facilities will generally provide more protection, the vadose zone typically provides greater delay in radionuclide migration than does the saturated zone. However, for humid sites like ORR, SRS, and Barnwell, the water travel times in the saturated zones are comparable to those in the vadose zone, and the total water travel times are about 1 to 10 years. Sorption on environmental media, waste form performance, and engineered barriers generally play a larger role in overall protection from radionuclide release at humid sites.

Summary Comparison of DOE and Privately Operated Facilities - Closure

The NRC regulations require that closure plans be included in the license application for a LLW disposal facility. These closure plans are used as the basis for development of the performance assessment. While DOE has similar requirements for developing closure plans, it typically has not developed these plans, and assumptions about the final closure conditions of the facility are contained in the performance assessments. This issue is being addressed in the corrective action plans developed to resolve the vulnerabilities identified in the CWR.

Privately operated disposal facilities are located on land leased from a state or federal government entity and must transfer its operating license after all conditions of closure are met, including a surety bond for potential future remedial activities. In addition, DOE may accept control of properly closed commercial disposal facilities if requested. Because DOE manages its disposal facilities and controls the land used for disposal, the long-term control of the land resides with DOE. In addition, as a government entity, DOE is required to supplement the EIS governing its closure operation if there are substantial changes to the plan or significant new circumstances.

Waste Forms

The primary purpose of waste forms for disposal of LLW is to provide stability for the disposal facility, which will minimize differential settlement resulting in breaches in the cover system and increased infiltration of water This condition is met at privately operated and DOE-managed disposal facilities by the requirements for compressive strength of the waste or packaging material and minimized void space. Additional packaging is required for Class B and C wastes to minimize releases and to decrease the potential for interaction with inadvertent intruders.

In humid to semi-arid environments, the waste form can play a significant role in hindering contaminant migration. In arid locations, waste forms do not play as crucial a role in limiting contaminant migration because the hydrology of the site itself prevents significant release and migration. In such cases, waste forms may still be important in reducing the risk by inadvertent intrusion by allowing the intruder to recognize the waste as a hazard. Different waste forms have different leaching performance as well as different susceptibility to environmental degradation. Thus, the choice of waste form may be significant for some radionuclides in the overall performance of a disposal option.

This section provides a description of the waste forms accepted at the LLW disposal sites, a comparison of physical requirements for commercial and DOE waste, a scoping-level comparison of the performance of grout, polyethylene microencapsulation, and glass waste forms, and an indication of which sites and which radionuclides may benefit from enhanced waste forms.

Waste Forms Accepted at LLW Disposal Facilities

Barnwell has traditionally accepted cement-stabilized waste. However, new forms such as vinyl ester styrene, vinyl chloride, and bitumen are now being accepted (SCDHEC, 1995). The Barnwell license requires that the leaching index of 6 or greater be met using the ANS 16.1 test for all waste forms. The majority of the wastes being accepted at Barnwell are Class A LLW such as trash and dried solid material. Only a small percentage of the waste is dewatered ion-exchange resins, which have higher activities. High density polyethylene containers are accepted as high integrity containers.

Envirocare of Utah accepts grouted waste forms. Envirocare has its own stabilization facility near the disposal site which can also use other types of stabilization agents. Macroencapsulated lead is accepted; lead bricks, lead shots, and lead blankets are allowed. At this time there are no environmental testing requirements for macroencapsulation. Rocky Flats has sent macroencapsulated lead with 2 inches of low density polyethylene surrounding the waste. Microencapsulation using polyethylene is being investigated at Envirocare in cooperation with Brookhaven National Laboratory, with an application in progress. Performance criteria have not yet been set for this waste form.

The DOE disposal sites also accept waste that has been stabilized using a variety of stabilization matrices. The primary considerations are stability of the waste form and minimized void space.

Physical Requirements for Waste

An extensive comparison of the physical requirements of commercial and DOE waste has been compiled by DOE (Cole et al., 1995, Table C-1). The NRC limits free liquids ($\leq$0.5% by volume or $\leq$ 1% volume if within a high-integrity container) and void space in commercial waste. Class B and C waste must be stabilized to minimize contaminant releases to the environment, and Class C waste must be in a form that minimizes intrusion. The Waste Form Technical Position Document (NRC, 1991) provides guidance on other criteria such as compression strength and resistance to radiation and biological effects.

DOE sites have physical requirements for waste that are similar to NRC requirements. All wastes must be stabilized, and requirements for free liquids are the same as those of the NRC at SRS and Hanford (Cole et al., 1995, Table C-1). Void spaces must be minimized. At Oak Ridge, the waste forms must be stable in the presence of moisture and microbial activity, and must withstand internal factors such as radiation effects and chemical changes. At Hanford, the final process waste must satisfy performance criteria of the NRC (1991).

Performance for Grout, Polyethylene Microencapsulation, and Glass

Enhanced waste forms can be considered as a means of increasing the limiting concentrations for certain radionuclides by reducing their leachability. To illustrate this point, scoping level estimates of the performance of grout, polyethylene microencapsulation, and vitrified glass waste forms at Hanford and SRS (SNL, 1996) are compared. Due to the hygroscopic nature of Portland cement, radionuclides leaching from grouted wastes are modeled assuming that the concentrations of radionuclides in the solid phase are in equilibrium with the concentrations in the liquid phase. Releases from polyethylene encapsulated wastes are modeled using a diffusion process, with rates determined by the waste loading; higher waste loadings result in higher diffusion rates. Releases from glass waste forms appear to be limited by the dissolution rate of the glass; as the glass dissolves, the radionuclides near the outer, exposed surfaces are released. Waste loading also affects the dissolution and release rates for glass waste forms.

An estimate of relative retention performance for these waste forms normalized to grout performance is shown in Table 4. This relative retention performance assumes that sufficient water is available to contact with the waste, implying disposal in more humid environments. Tc-99 is relatively poorly bound in grout, Cs-137 is bound to a moderate degree, and Pu-239 is tightly by the grout. The relative differences in performance of the different waste forms reflect these conditions. For example, a glass waste form loaded at 40% with wastes containing Tc-99 will perform about 390 times better than a grouted waste form loaded at 50%; given equal initial concentrations of Tc-99 in the two wastes, the concentration of Tc-99 in the leachate from the glass waste form will be 390 times lower than that from the grouted waste form. Other values are interpreted similarly.

Table 4. Relative Retention Performance of Waste Forms Normalized to Grout Performance (from SNL, 1996).

Waste Form	Waste Loading (%)	Radionuclide		
		Tc-99	Cs-137	Pu-239
	10	39,000	4400	440
Glass	30	3900	440	44
	50	390	44	4.4
	30	3200	370	37
Polyethylene	40	110	12	1.2
	50	6	0.7	0.07
Grout	50	1	1	1

In general, the performance of the glass waste form is much better than that of the polyethylene and grout waste forms, and lower loading rates result in lower release rates. However, glass tends to degrade more rapidly in high-pH conditions, so that the combination of glassified wastes in concrete vaults must be evaluated carefully.

At lower loading rates, polyethylene performs better than grout for all three radionuclides, although at higher loading rates, there is little benefit for Tc-99 and less benefit for Cs-137 and Pu-239. These differences reflect the relative strength of the chemical binding of the wastes with the cement in the grouted waste form relative to the physical entrapment of wastes represented by the performance of the polyethylene waste form.

<u>Sites and Radionuclides that May Benefit From Enhanced Waste Forms</u>

Because the interaction of the waste forms with water is necessary to cause releases of radionuclides, sites located in the humid regions of the country stand to benefit most from use of enhanced waste forms. The disposal sites in the humid region of the country are ORR, SRS, and Barnwell. Oak Ridge uses a tumulus disposal facility, and SRS and Barnwell use vault facilities to reduce the infiltration of water and minimize its contact with the waste. Because the infiltration rates in arid and semi-arid regions of the country are low, the site conditions tend to limit the release of radionuclides from LLW disposal facilities. Therefore, enhanced waste forms do not provide significantly greater reduction in release of radionuclides.

Radionuclides that are highly-mobile and short- to moderately long-lived can benefit most from enhanced waste forms because they are retained in the disposal facility for longer periods of time and are released at lower rates. However, shorter-lived radionuclides that are not highly mobile in the environment (e.g., Co-60, Sr-90, Cs-137) tend not to benefit greatly from enhanced waste forms because they decay to low levels prior to reaching receptor locations.

Longer-lived radionuclides tend not to benefit from enhanced waste forms as much as shorter-lived radionuclides because, like more-engineered disposal facilities, the long-term performance of waste forms is not known and conservative assumptions are used to model release over the longer times. Therefore, at some point in the future, the benefit of the enhanced waste forms is assumed to diminish, and the longer-lived radionuclides can migrate at higher rates.

Some radionuclides are not well suited to some waste forms. For example, the high temperatures associated with the vitrification process used to make glass waste effectively prevent radionuclides with low volatility from being incorporated into the glass. Tritium and I-129 are examples of volatile radionuclides that will not be entrained into glass. Tritium, C-14, Tc-99, and I-129 release relatively easily from grouted waste without some type of added material to help bind them to the matrix.

Other radionuclides are well suited to some waste forms. The high pH associated with grout results in formation of uranium compounds with low solubility, so that aqueous releases of uranium from grout are very low. This solubility-limited condition allows for higher levels of uranium bearing wastes to be disposed of in grout.

Summary Comparison of DOE and Privately Operated Facilities - Waste Form

The primary purpose of waste forms for LLW disposal is to provide stability to the disposal facility. This stability is provided by specifying a minimum compressive strength of the waste form or waste package and by requiring that void space be minimized. Privately operated and DOE-managed disposal facilities have similar requirements for waste form stability. A wide range of waste matrices are accepted by privately operated and DOE-managed disposal facilities, as long as the stability and leach requirements are met.

Disposal facilities in the humid regions of the country will benefit most from enhanced waste forms because of the greater potential for water to infiltrate into the disposal facility and contact the waste. Barnwell, SRS, and ORR use more-engineered disposal facilities to minimize the infiltration of water and subsequent contact with waste. Facilities in the arid region of the country do not benefit greatly from enhanced waste forms due to the lower amounts of infiltrating water.

The physical requirements for waste forms and the facility designs are similar for privately operated and DOE-managed disposal facilities. Therefore, based on waste form considerations, there appear to be no significant safety merits or demerits for using privately operated facilities for disposal of DOE LLW.

Performance Assessment

Performance assessments are intended to indicate whether a projected release of radionuclides from a disposal site will meet certain radiological performance objectives for protection of human health and the environment. Releases to water and the atmosphere and scenarios of inadvertent intrusion are considered. The performance assessments are conservative representations of the actual processes occurring in nature. The following section compares concentration limits for DOE and private disposal facilities at arid sites (NTS and Envirocare) and humid sites (SRS and Barnwell). The comparison also provides an indication of the relative conservatism of the performance assessments for the commercial sites and the DOE sites.

Limiting Concentrations

A comparison of contaminant concentration limits for wastes at arid and humid DOE and commercial sites is shown in Table 5. For Envirocare, SRS, and Barnwell, the limits are from their WAC; the limits listed in Barnwell's WAC are the same as Class C limits. For NTS, the limits are "action levels" being developed for the revised WAC. Action levels are not limits on concentrations, rather they are being established to identify wastes that require greater levels of characterization and verification (DOE-JFO, 1996). For SRS, the limits are from the WAC for the E-Area vault for non-tritium, non-combustible wastes.

Table 5. Concentration Limits ($\mu Ci/m^3$) for Radioactive Constituents at Commercial and DOE Disposal Sites (assuming waste bulk density of 2.4 g/cm^3)

Nuclide	Arid Sites (Trench)		Humid Sites (Vault)	
	NTS Action Levels[a]	Envirocare WAC	SRS WAC[b]	Barnwell WAC[c]
H-3	2E+11	5E+05	*4E+06*	7E+08[d]
C-14	6E+03	1E+06	*9E+03*	8E+06
Sr-90	4E+07	5E+04	*7E+08*	7E+09
Tc-99	3E+06	2E+04	*2E+03*	3E+06
Cs-137	9E+06	1E+03	*7E+08*	5E+09
U-238	2E+06	7E+04	*5E+04*	-[e]
Pu-239	6E+05	2E+03	*7E+05*	2E+05
Am-241	5E+05	6E+03	*4E+05*	2E+05

[a] Values for NTS are based on "action levels" being developed by that site to identify wastes that require greater levels of characterization and verification. Action levels are not limits on concentrations of radionuclides.

[b] Based on Ci/package limits in the E-Area Vault WAC and the volume of a B-25 box (96 ft^3)

[c] Limits for Barnwell are for NRC Class C waste

[d] Limit for Class A waste, concentrations of H-3 are not limited for Class C waste

[e] No concentration limits in 10 CFR Part 61

The concentration limits based on the Envirocare WAC (UDEQ, 1989) are lower than the action levels at NTS by two or more orders of magnitude for all radionuclides except C-14. For C-14, the NTS action level is lower than the Envirocare value by more than two orders of magnitude; this difference is likely due to the difference in the approach used by NRC and DOE in developing its intrusion scenario for that radionuclide.

The absence of site-specific limits for radionuclide concentrations at NTS is based, in part, on the results of the scientific studies supporting the draft performance assessment for that site (e.g., Detty et al., 1993 and Conrad, 1993). These studies provide evidence to support the assertion that there is no net downward migration of water in the vicinity of the disposal site -- effectively eliminating groundwater as a migration pathway. Therefore, there are no limits on inventories or concentrations of radionuclides based on releases to groundwater Additionally, because of the legacy of the weapons tests at the site, DOE plans to maintain long-term institutional control of the NTS. Waste management personnel at the site indicate that this long-term institutional control, in combination with the extreme arid nature of the site and the practice of disposing of more highly contaminated waste at depths up to 60 feet below the ground surface, results in a low probability for inadvertent intrusion. Therefore, limits based on intrusion are also not used at NTS. The upper limits on concentrations of radionuclides at NTS are based on the definition of LLW, particularly the 100 nCi/g limit related to TRU radionuclides.

The concentration limits based on the SRS WAC are similar to the Barnwell limits for Sr-90, Cs-137, Pu-239, and Am-241. The limits for tritium and Tc-99 at SRS are lower than the limits at Barnwell by more than two orders of magnitude; the lower values at SRS are likely due to the high environmental mobility of these radionuclides, which results in limits based on protection of groundwater. As with the arid sites, the lower limit for C-14 at SRS is likely due to the difference in the approach used by NRC and DOE in developing its intrusion scenario for that radionuclide.

Comparing the limiting concentrations of the four disposal facilities indicates the conservatisms used in some of the analyses and highlights differences in disposal at arid and humid sites. Because the analyses of the four facilities were done independently, differences in the degree of conservatism used in the analyses can sometimes mask the differences due to actual site conditions. For example, the Envirocare facility in Utah has the lowest limits of all sites for all indicator radionuclides except C-14 and Tc-99. For Pu-239 and Am-241, which are longer-lived radionuclides (Am-241 being limited by its long-lived progeny, Np-237) with moderate environmental mobility, the limits are about two orders of magnitude lower than at the other three sites. The arid conditions and remoteness of this site are more similar to NTS than SRS and Barnwell, so that the low limits for radionuclide concentrations imply that a higher degree of conservatism was used in the development of the Envirocare WAC. A primary source of this conservatism is probably due to assumptions made about the characteristics of wastes received at the facility. Envirocare disposes primarily unpackaged LLW from D&D remedial action projects.

Because there are no site-specific limits on radionuclide concentrations at NTS (the action levels result in administrative actions and not limits), this site can accept LLW with the highest levels of radionuclides. The arid climate, procedures for burying wastes with higher concentrations of radionuclides at greater depths, and planned long-term institutional controls at this site are the primary reasons for the absence of site-specific limits at NTS.

At SRS and Barnwell in the humid southeast region of the country, the vault facility designs result in relatively high limiting concentrations for the shorter-lived radionuclides (e.g., H-3, Sr-90, and Cs-137). As discussed in the Design section of this report, more-engineered facilities like the vault can retain these shorter-lived radionuclides until they decay to low levels, effectively resulting in higher limits.

<u>Summary Comparison of DOE and Privately Operated Facilities - Performance Assessment</u>

The disposal facility at the NTS, located in the arid region of the country, has no site-specific limits on concentrations of radionuclides in LLW; the limits are based on the regulatory definition of LLW, particularly related to TRU radionuclides. In supporting these limits, NTS takes credit for its arid environment and resulting absence of a groundwater pathway, the planned long-term institutional controls of the site based on the legacy of its former mission, and its practice of burying highly contaminated wastes at depths of up to 60 feet. The absence of site-specific limits at the NTS illustrates the benefits of arid sites for disposal of LLW.

The Envirocare disposal facility in Utah, which has climatic and hydrologic attributes similar to the NTS, has relatively restrictive limits for radionuclide concentrations that are in the range of NRC's Class A waste. Because it has an arid climate more similar to NTS than SRS and Barnwell, these lower limits appear to result more the type of wastes being disposed rather than from site-specific performance. Therefore, from a safety standpoint based on performance assessment, if concentrations of radionuclides meet the Envirocare WAC, disposal of DOE LLW at Envirocare should not be of concern.

Barnwell and SRS are located near each other in the same climatic region and in similar geologic environments. Both sites use vault disposal facility designs. At SRS, the concentration limits for radionuclides are based largely on the site-specific performance assessment, which establishes limits based on releases to groundwater and the atmosphere, and on protection of inadvertent intruders. The concentration limits for Barnwell are the NRC Class C limits, which were based primarily on scenarios of inadvertent intrusion into generic facilities. For most radionuclides, the concentration limits for SRS and Barnwell are similar. However, for the radionuclides that are more mobile in the environment (e.g., tritium and Tc-99), the limits at SRS based on releases to groundwater are more restrictive than Barnwell for these radionuclides.

While the disposal facilities located in arid environments are capable of disposing of LLW with higher concentrations of all radionuclides, the Envirocare WAC illustrates that this capability is not always used. However, as both Barnwell and SRS illustrate, disposal sites in the humid region of the country that use more engineered facilities can dispose of relatively high levels of shorter-lived radionuclides. While sites in arid regions can, in general, dispose of LLW with higher concentrations of radionuclides than can sites in humid regions, the performance assessment for each site results in a site-specific WAC that accounts for these differences. Therefore, as long as the site-specific WACs are met, there appear to be no significant safety merits or demerits based on performance assessments from disposing of DOE LLW at facilities in humid or arid environments.

Approval and Oversight

In this section, the approaches used by NRC or the Agreement States and DOE to obtain approval for disposal facility operations and to maintain oversight of those facilities is presented. The differences in the approaches related to safety issues are highlighted.

Approach Used by NRC and Agreement States

To obtain a license from NRC or an Agreement State for a facility to dispose of LLW, an applicant must comply with the requirements of 10 CFR Part 61. An application must be submitted prior to construction of the disposal facility. This application must contain, in addition to general information, the results of the site selection process, results of a detailed investigation of the site characterization, and an analysis of performance of the site. The license application is reviewed by the NRC or Agreement State and if approved, a license is issued and disposal operations can commence. Prior to licensing, financial assurances are required of the applicant to ensure that all phases of disposal facility activities, including monitoring and any required maintenance during the institutional control period will be funded.

The land on which the site is located must be owned by the State or Federal government and leased to the operator. This requirement is to ensure the long-term control of the land after the site is closed. The site must be operated in accordance with Part 61 and any additional requirements listed in the license. Periodic license renewal is required. The operating history of the facility is reviewed at that time and a decision is made to either permit or deny continued operations. Ongoing compliance is maintained through reviews and inspections of waste generator operations, and by inspections and audits of the disposal facility operations; these are both conducted by the NRC or the Agreement State regulatory agency.

When the operations phase is completed, the license is amended to indicate the site closure phase. In addition to decommissioning activities, the licensee is required to maintain post-closure monitoring activities for 5 years to ensure that the site is stable and ready to be turned over for institutional control. A longer or shorter period may be set if conditions warrant. After the NRC or Agreement State finds that the disposal site closure is satisfactory, it transfers the license to the State or Federal government entity that owns the site. If the DOE owns the site, the license is terminated because NRC lacks regulatory authority over DOE for this activity.

Approach Used by DOE

DOE LLW disposal facilities are required to submit site-specific radiological performance assessments demonstrating compliance with Order 5820.2A performance objectives to DOE headquarters for review and approval. A Peer Review Panel (PRP), established by DOE headquarters, of experts in the fields of performance assessment, health physics, modeling, and hydrogeologic processes, reviews the performance assessment and other appropriate documentation for technical adequacy. The performance assessment, the findings of the PRP, and other documentation are then reviewed by DOE headquarters staff, and a decision on the acceptance of the performance assessment is made by the Assistant Secretary for Environmental Management

LLW disposal facilities are also required to submit composite analyses accounting for all sources of radioactive material that may exist in the ground at a DOE site that may contribute to the dose projected to a hypothetical member of the public from an active or planned LLW disposal facility. The composite analysis and other appropriate documentation are reviewed by DOE headquarters staff, and a decision on its acceptance is made by the Assistant Secretary for Environmental Management.

Upon acceptance of these two analyses, DOE headquarters issues a Disposal Authorization Statement (DAS). The DAS sets forth the conditions for approval of the performance assessment and the composite analysis, and the conditions for the design, construction, and operation of the LLW disposal facility to provide a reasonable expectation of compliance with the performance objectives of Order 5820.2A and considering the results of the composite analysis or any other required assessments or documentation. The DAS functions similar to a license issued for the commercial disposal facilities.

DOE is responsible for oversight and compliance reviews and appraisals at its disposal facilities, and these are conducted by the Office of Environment, Safety, and Health, which is a separate office within DOE from the Office of Environmental Management, which has program responsibility over the LLW disposal facilities. As part of its programmatic responsibilities and in reference to DNFSB recommendation 94-2, EM completed a vulnerability assessment of each disposal site and of the LLW system as a whole (DOE 1996c).

Summary Comparison of DOE and Privately Operated Facilities - Approval and Oversight

Privately operated LLW disposal facilities are required to obtain a license prior to operation, to undergo compliance reviews and appraisals, and to receive approval and transfer of license after the facility is closed. The license and approvals are granted by an external, independent government organization, either the NRC or the Agreement State, with no ties to the operational aspect of the facility.

DOE LLW disposal facilities are now required to obtain a disposal authorization statement (for new facilities prior to operation) and to undergo compliance reviews and appraisals. The authorization to operate will be granted by the same office that is in charge of all other aspects of the disposal facility. The compliance reviews and appraisals are conducted internally within DOE, but by another office. Past weaknesses inherent in DOE's internal review and approval methods have been identified through the DNFSB Recommendation 94-2 and are being resolved. Improvements described in the 94-2 Implementation Plan in the Radiological Assessment tasks for approvals of the facility performance assessments and composite analyses and in the Regulatory Structure and Process task area for a revised Radioactive Waste Management Order chapter on LLW will result in improved approval and oversight of DOE LLW disposal.

Except for the differences in the relationship between the operator and regulator of disposal facilities (i.e., privately operated facilities are regulated by external, independent government agencies and DOE disposal is self-regulated), the requirements for both are similar. Therefore, there appear to be no significant safety merits or demerits from using privately operated facilities for disposal of DOE LLW.

CONCLUSIONS

One of the tasks delineated by the Defense Nuclear Facility Safety Board in its Recommendation 94-2 was an evaluation of privately operated facilities for disposal of DOE LLW. The safety merits and demerits of using private disposal facilities compared to disposing of LLW at DOE facilities have been evaluated based on seven functional areas: siting, design, operations, closure, waste form, performance assessment, and approval and oversight.

The specific requirements and practices for privately operated and DOE-operated facilities often differ within these functional areas, primarily due to the difference in requirements of the NRC or Agreement State and DOE. The NRC developed regulations to apply to commercial waste generators that are distinct entities from those that dispose of LLW, and the type of waste generated in the commercial sector is generally similar from site to site. The disposal practices for DOE LLW developed from on-site disposal of wastes where closer relationships existed between generators and disposers and the need for a formal interface was less obvious. In addition, the varied types of waste generated by the DOE facilities related to weapons development and energy research did not lend itself to a general classification system.

Although there are differences in implementation between the NRC and DOE for these seven functional areas, the resulting level of protection provided by the aggregate of these seven functional areas are similar for both systems. This similarity is not surprising because NRC and DOE evolved from the same parent organization and have continued close communication about waste disposal and the DOE national laboratories were used extensively by NRC to develop the technical basis for its LLW disposal regulations.

While in general the NRC and DOE approaches result in similar levels of protection, in practice two differences are worth noting. First, the concentration limits at Barnwell for highly mobile radionuclides (e.g., tritium and Tc-99), which are based on the NRC Class C limits, are two and three orders of magnitude higher than at the Savannah River Site. The disposal facilities at both sites are vaults, and the primary difference appears to be the differences in conservatism used in the analysis of releases to groundwater. Second, the self-regulation of DOE has, in the past, resulted in some requirements of DOE Orders not being implemented. For example, the requirement for the development of closure plans was not being complied by the all of the DOE sites; this deficiency is now being addressed by the corrective action plans for the complex-wide review as identified in Revision 1 of the Implementation Plan for Recommendation 94-2.

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