Scoping Evaluation of the Technical Capabilities of DOE Sites for Disposal of Mixed Low-Level Waste Examples: Sandia National Laboratories and Los Alamos National Laboratory

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ABSTRACT

The disposal of mixed low-level waste has become an issue for the U.S. Department of Energy and the States since the inception of the Federal Facilities Compliance Act in 1992. Fifteen sites, including Sandia National Laboratories (SNL) and Los Alamos National Laboratory (LANL), have been evaluated to estimate their technical capabilities for disposal of this type of waste after it has been subjected to treatment processes. The analyses were designed to quantify the maximum permissible concentrations of radioactive and hazardous constituents in mixed low-level waste that could potentially be disposed of in a facility at one of the fifteen sites and meet regulatory requirements. The evaluations provided several major insights about the disposal of mixed low-level waste. All of the fifteen sites have the technical capability for disposal of some waste. Maximum permissible concentrations for the radioactive component of the waste at arid sites such as SNL and LANL are almost exclusively determined by pathways other than through groundwater. In general, for the hazardous component of the waste, travel times through groundwater to a point 100 meters from the disposal facility are on the order of thousands of years. The results of the evaluations will be compared to actual treated waste that may be disposed of in a facility at one of these fifteen evaluated sites. These comparisons will indicate which waste streams may exceed the disposal limitations of a site and which component of the waste limits the technical acceptability for disposal. The technical analyses provide only partial input to the decision-making process for determining the disposal sites for mixed low-level waste. Other, less quantitative factors such as social and political issues will also be considered.

INTRODUCTION

Since the passage of the Federal Facilities Compliance Act by Congress in 1992, the U.S. Department of Energy (DOE) and the States have been considering methods for the treatment and disposal of mixed low-level waste (MLLW). For more than fifty years, various activities of the DOE have generated this type of waste, which contains both radioactive and chemically hazardous components. We initially provided DOE's Disposal Workgroup with the results of a screening of forty-nine sites around the country where MLLW was either stored or expected to be generated. Based on this screening, the Disposal Workgroup and the States determined fifteen that were suitable for further evaluation to estimate their technical capabilities for disposal of MLLW (Figure 1). Two of the fifteen sites are Sandia National Laboratories (SNL) and Los Alamos National Laboratory (LANL).

A scoping analysis was designed for examining the radioactive component of MLLW (DOE, 1996), with an even higher-level scoping evaluation employed to examine the hazardous component.

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Neither of these evaluations are replacements for more detailed analyses that are performed before waste can actually be disposed of at a site. Instead, we intended the evaluations to provide a preliminary estimate of the technical capabilities of each site for disposal of (1) waste generated or stored at its site and (2) on an as-needed basis determined through discussions among the affected States, waste from other sites.

The methodology used in this evaluation for the radioactive component (i.e., for radionuclides) had its origins in detailed analyses that have been conducted for disposal facilities for low-level waste. Several sites around the country have conducted these "performance assessments" to determine the capabilities of the sites for disposal of low-level radioactive waste (e.g., Oak Ridge Reservation [ORNL, 1994] and Idaho National Engineering Laboratory [Maheras et al., 1994]). In addition, a peer review panel has been appointed by the DOE to determine the adequacy of these performance assessments and to make recommendations on conducting these analyses for areas in which the governing regulations do not provide adequate guidance (Wood et al., 1994).

Conversely, the methodology used in the scoping evaluation for the hazardous component of MLLW had less basis in precedent and the governing regulations. The hazardous-waste regulations do not specifically require a quantitative evaluation. Therefore, the scoping evaluation for the hazardous component was based more on science than on regulations and should not be construed as an approach to be used for the permitting of MLLW disposal facilities.

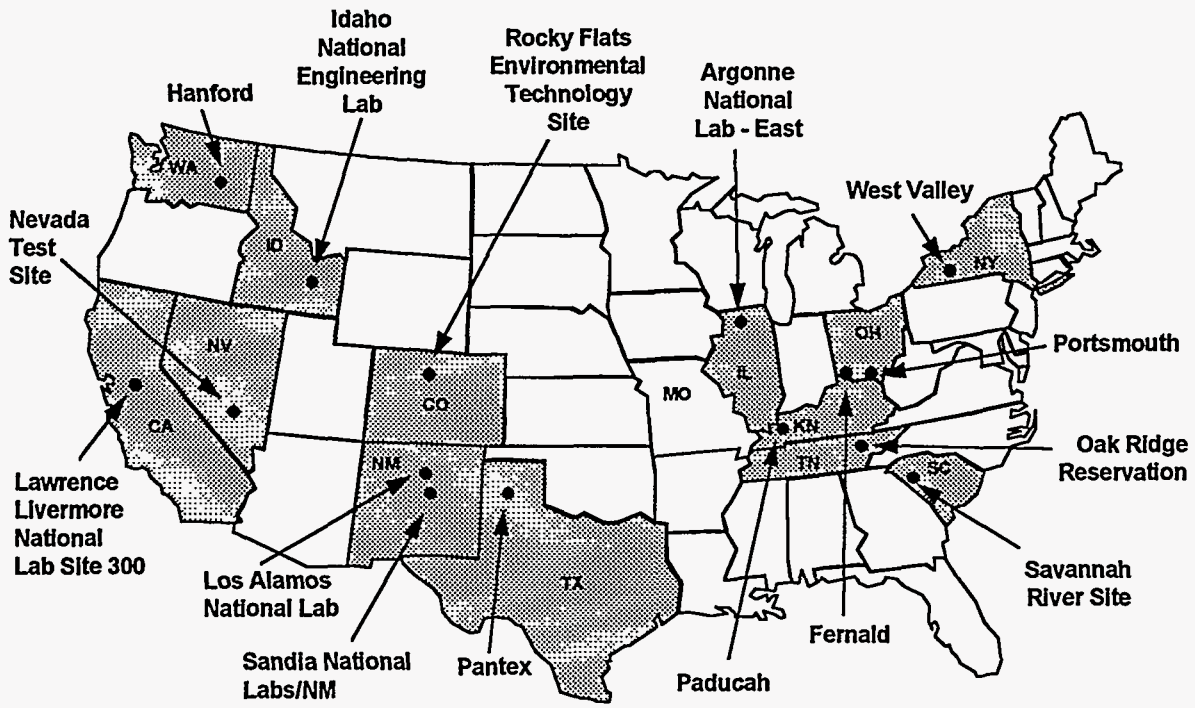

Figure 1. Fifteen sites considered in the evaluations for the radioactive and hazardous components of MLLW (Waters et al., 1996, Figure 2-2).

The objective of the scoping evaluations was to use a set of modeling assumptions that included sufficient detail to capture major site-specific characteristics and yet were general enough for consistent application at all sites. We made assumptions about the waste form and the disposal facility that were identical for all fifteen sites and developed conceptual models for each site that contained common elements but reflected site-specific data. We also interacted with personnel from each site to assure that we gained maximum benefit from important research, site characterization, modeling, and other analyses that had been performed.

The scoping evaluations provided several major insights about the disposal of MLLW. The results indicate that all of the fifteen sites, including SNL and LANL, have the technical capability for disposal of some waste. Maximum permissible concentrations for the radioactive component at both SNL and LANL are almost exclusively determined by pathways other than through groundwater. For the hazardous component, travel times through groundwater to a point 100 meters from the disposal facility are on the order of thousands of years.

A technical analysis by itself, however, is not sufficient for making decisions about the location of disposal facilities for MLLW. The information provided by the scoping evaluations is only part of the input to the decision-making process. Other factors that will need to be considered are possible site-determined limits on inventory, the degree to which a site is already contaminated, risks in transporting waste to the site, and social and political issues.

SCOPE OF THE MLLW ISSUE

The Federal Facilities Compliance Act requires establishing plans for the treatment of DOE's MLLW. Although the Act does not specifically address disposal of treated MLLW, both DOE and the States recognize that disposal issues are an integral part of treatment discussions.

Based on DOE's most recent revision of the Mixed Waste Inventory Report (mid-1995), the DOE currently generates, stores, or expects to generate (over the next five years) about 650,000 m^3 of MLLW at 41 sites in 20 states. Operations at SNL currently generate, store, or expect to generate over the same time frame about 180 m^3 of MLLW, while reports for LANL indicate about 715 m^3. Although the fifteen sites considered in the scoping evaluations have the technical capability to potentially dispose of some if not all of their own waste, another possibility is that the number of potential disposal sites could be further reduced as the DOE and States examine the treatment plans for each site and the information provided by the scoping evaluations. An additional factor to be considered is the disposition of waste from the sites that were previously determined not to have the technical capability for disposal.

METHODOLOGY OF THE EVALUATIONS

Actual inventories of MLLW at all sites, including SNL and LANL, that will ultimately require disposal are not known (e.g., some of the waste may not yet have been generated or fully characterized). We designed the scoping evaluations, therefore, to quantify the maximum permissible concentrations of the two components in DOE's treated MLLW that could be disposed of at each site such that exposure to humans would not exceed pre-determined performance measures. For the evaluation of the radioactive component, we examined DOE's inventory of MLLW and selected the 58 radionuclides in the waste with half-lives greater than five years. We based the performance measures on DOE Order 5820.2A (DOE, 1988), so that maximum radionuclide concentrations in the waste were directly tied to permissible dose limits for individuals:

- 4 mrem (0.04 mSv) per year from consumption of drinking water resulting from releases to groundwater;
- 10 mrem (0.1 mSv) per year from all exposure pathways resulting from atmospheric releases; and
- 100 mrem (1 mSv) per year from all exposure pathways resulting from long-term, chronic exposure of inadvertent intruders after loss of active institutional controls at the disposal site 100 years after disposal.

The analysis of the radioactive component of MLLW consisted of separate analyses of three pathways—water, atmospheric, and inadvertent intrusion. The most restrictive permissible concentration of the three pathways was determined for each radionuclide.

For the scoping evaluation of the hazardous component, we again examined DOE's inventory of MLLW and selected seven toxic metals as representatives of the hazardous component of MLLW. Although MLLW contains both organic substances and inorganic chemicals such as toxic metals, hazardous organic compounds usually can be degraded naturally or through treatment processes such as incineration while toxic metals can potentially remain toxic forever (Bunchheim and Persson, 1992). Specific performance objectives in the regulations enforcing the Resource Conservation and Recovery Act (RCRA) for the hazardous component of MLLW do not exist. Therefore, we used maximum contaminant levels (MCLs) established in the regulations enforcing the Safe Drinking Water Act (40 CFR Part 41) to estimate maximum concentrations for toxic metals in MLLW (Table 1).

Table 1. Regulatory Levels for RCRA Toxic Characteristic Metals

Contaminant	Maximum Contaminant Level (MCL)[a] (mg/L)
Arsenic (As)	0.05[b]
Barium (Ba)	2
Cadmium (Cd)	0.005
Chromium (Cr)	0.1
Lead (Pb)	0.05[b]
Mercury (Hg)	0.002
Selenium (Se)	0.05

a 40 CFR 141.62 unless otherwise noted
b 40 CFR 141.11

We assumed that the treated MLLW would be stabilized with grout. Immobilization/solidification techniques using cement-based grouts are considered the most appropriate and universal option for the treatment and ultimate disposal of MLLW for a variety of waste matrices (Gilliam et al., 1990; Weingardt and Weber, 1994).

The disposal-facility design considered in both evaluations was a trench that complied with RCRA regulations (i.e., that employed an engineered liner and leachate collection system and a cover system). The trench was assumed to be square with a plan area of 2500 m^2. We assumed that the waste accounted for two-thirds of the volume of the disposal facility, with the remaining one-third of the facility either non-waste volume or non-waste packaging.

Water Transport Analysis

A generic conceptual model was used to describe the water pathway. This conceptual model was modified for each site to reflect local conditions. Based on the performance measures, maximum concentrations of radionuclides and hazardous constituents (i.e., toxic metals) in the disposal facility at each site were estimated by accounting for attenuation due to release from the waste form and transport through the environment to the point at which the performance measures were applied (i.e., the performance boundary).

The attenuation that occurred between the waste in the trench and the performance boundary was represented as "concentration reduction factors" (CRFs). We used the CRF approach so that intermediate results could be displayed in a transparent manner that allowed comparisons of the effects of the disposal facility and site on overall performance. This approach also allowed comparisons of results from different sites. Dilution of leachate with groundwater was the only concentration attenuation mechanism used in the environmental transport of contaminants and was accounted for in the CRF for the water pathway. The CRF for the water pathway is analogous to the dilution attenuation factor used by the U.S. Environmental Protection Agency in developing the Land Disposal Restrictions of the RCRA regulations. An additional CRF for the source accounted for the attenuation between the waste and the leachate exiting the bottom of the trench. The values for the source CRF depended on parameters that were specific to the contaminants and the design of the trench; thus, values for the source CRF were the same for all sites. Calculation of the source CRF included equilibrium partitioning between the solid and liquid phases for contaminants sorbed on the grouted waste form and dissolved in pore water.

In the unsaturated zone, we assumed that leachate was generated by constant movement of water through the trench at a rate that was controlled by the assumed performance of the trench. For the first 30 years following closure of the disposal facility, the collection system was assumed to collect all leachate from the trench so that no releases from the site occurred. The liner and leachate collection systems were assumed to fail abruptly at 30 years after closure. At that time, releases of contaminants were assumed to be possible by movement of water through the cover into the trench. We calculated the rate of water movement through the trench based on the lesser of either a unit hydraulic gradient and a saturated hydraulic conductivity of 1×10^{-7} cm/s (as required by RCRA for the cover system), or on the site-specific value for natural recharge through native soils.

All engineered barriers were assumed to have failed by 100 years after closure, at which time the movement of water through the trench was assumed to be equal to the natural recharge through the native soils. We based the volumetric flow through the trench of water that generated leachate on the assumed performance and size of the trench. We assumed that no dilution occurred in the unsaturated zone, so at steady-state the concentration that reached groundwater equaled the leachate concentration. Lateral spreading was assumed not to occur, so the leachate flux through the unsaturated zone was confined to the soil column directly below the plan area of the facility.

As contaminated water entered the saturated zone, the contaminant was assumed to mix with clean groundwater, forming a plume with a shape controlled by aquifer and contaminant properties. We also assumed that complete mixing within the aquifer occurred directly below the trench. The depth of contaminant mixing was an estimated value. The performance boundary was assumed to be 100 meters from the edge of the trench.

The equation we used to estimate the maximum permissible concentrations of radionuclides in MLLW accounted for the performance measure of 4 mrem (0.04 mSv) per year effective dose equivalent

from consumption of drinking water; dose conversion factors for the water ingestion pathway; CRF values for the source and for environmental transport; and radioactive decay during detention in the trench plus retarded travel via environmental transport in the water pathway to the performance boundary. The equation we used to estimate the maximum permissible concentrations of toxic metals in MLLW accounted for the maximum contaminant level for a specific toxic metal and for the CRF values for the source and for environmental transport.

We also estimated the travel time of contaminants to the 100-meter performance boundary. Distribution coefficients (i.e., solid/liquid partition coefficients) were used to represent equilibrium partitioning between the solid and liquid phases for the contaminants sorbed on the geologic media and dissolved in pore water. Where available, these values were site-specific; in the absence of site-specific data, a generic set of distribution coefficients was used. Travel times were calculated as the sum of the retarded contaminant travel times in the unsaturated and saturated zones.

The conceptual model used in the scoping evaluations for SNL is illustrated in Figure 2. In the vadose zone, flow was assumed to be one-dimensional under a unit hydraulic gradient with leachate moving vertically through the unsaturated alluvial sediments of the Santa Fe Formation to the regional aquifer. Natural perched zones are not known to exist at the evaluated location, and lateral spreading of the leachate was assumed to be minimal. The distance from the land surface to the water table is approximately 150 m (492 ft).

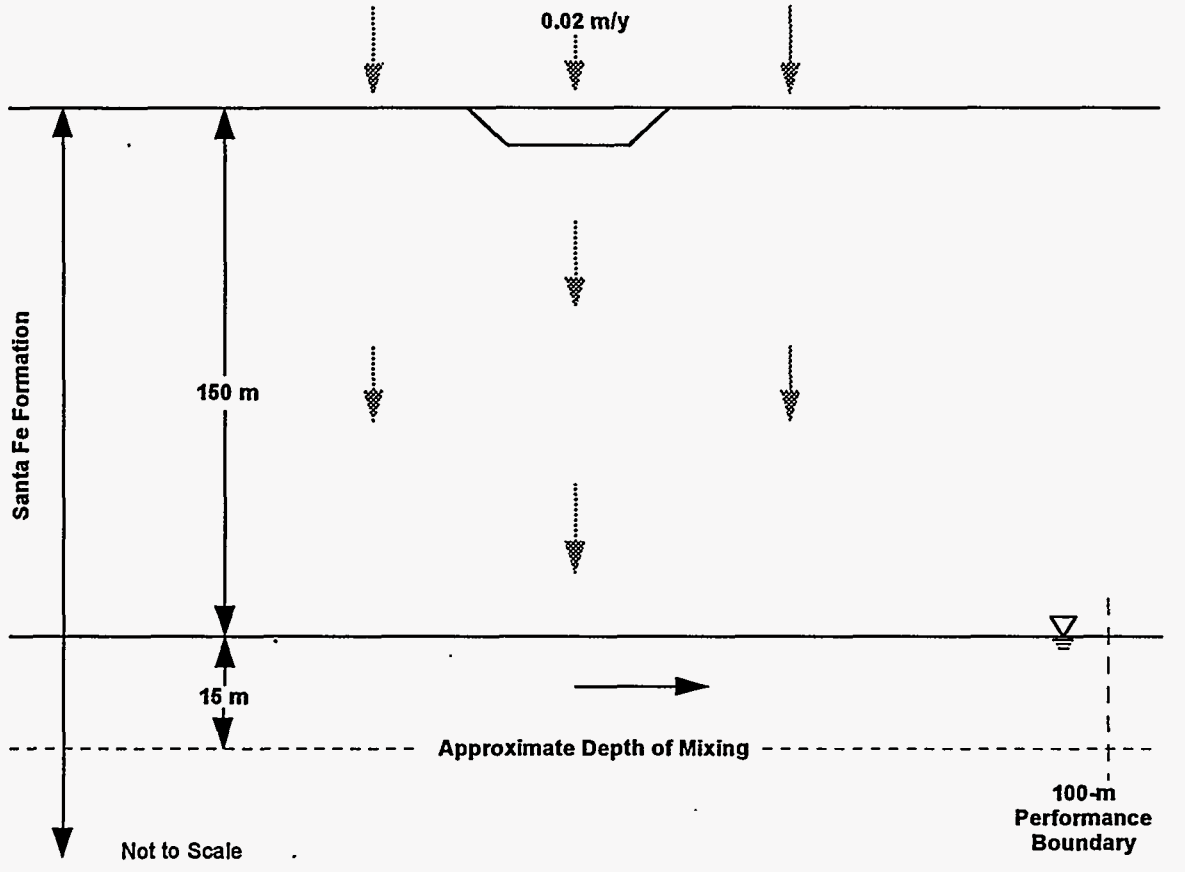

Figure 2. Conceptual model for water transport at SNL (based on Waters and Gruebel, 1996, Figure 9-4).

The saturated portion of the Santa Fe Formation is characterized by a large, unconfined regional aquifer that is the drinking water source for the City of Albuquerque. Some volume of contaminated fluid was assumed to leach out of the vadose zone and become diluted as it mixed with clean aquifer water in the Santa Fe Formation. The mixing depth was assumed to be equal to an estimated plume thickness of 15 meters at the 100-meter performance boundary.

The conceptual model for the water pathway used in the scoping evaluations at LANL is shown in Figure 3. The model consisted of a single pathway in which leachate exited through the bottom of the disposal facility, moved vertically from the disposal site to the water table, and traveled horizontally through the lower aquifer to the 100-meter performance boundary. We made the following assumptions in determining the geometry and behavior of the LANL flow and transport system:

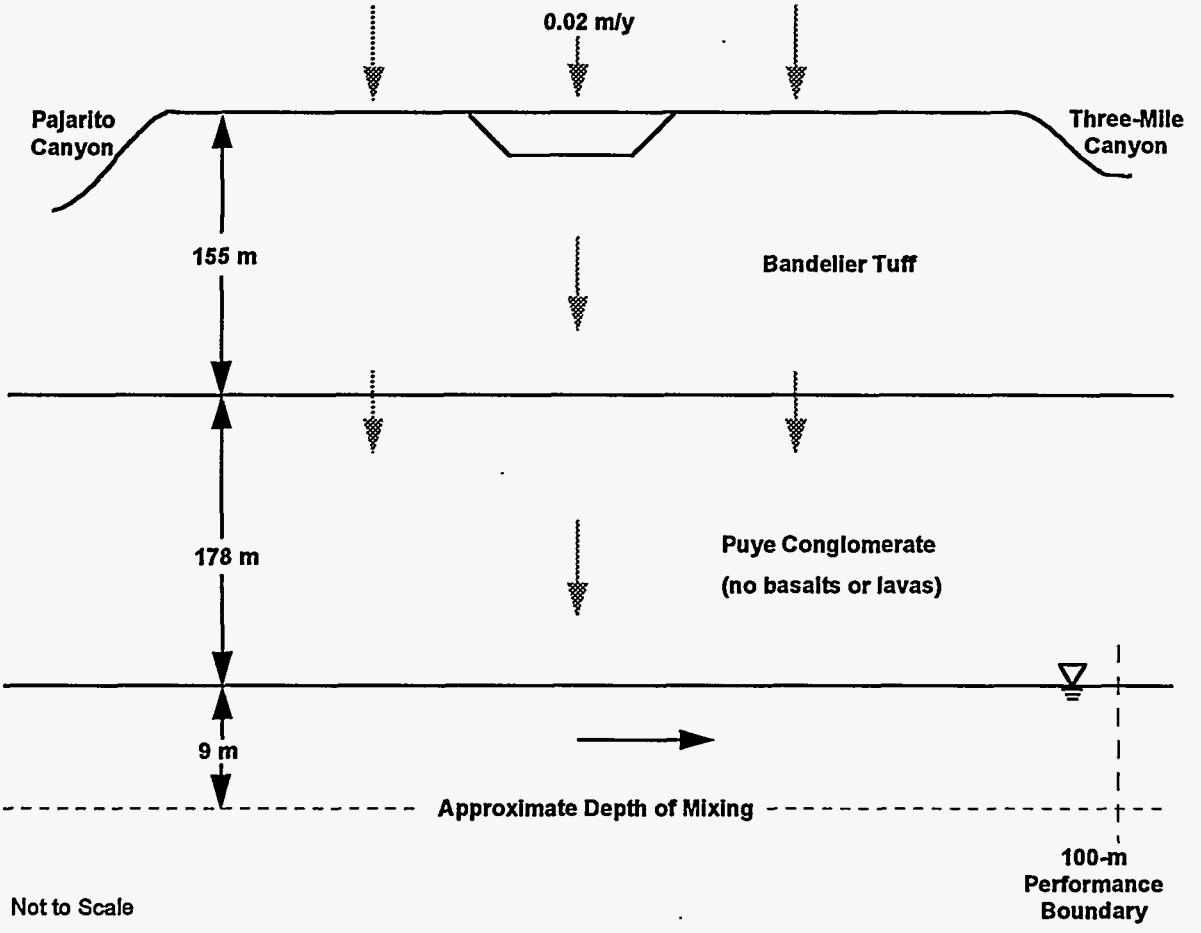

Figure 3. Conceptual model for water transport at LANL (based on Waters and Gruebel, 1996,Figure 8-6).

- The complex stratigraphy was simplified into two units (the Bandelier Tuff and the Puye Formation) based upon similar hydrologic characteristics. Average unit thicknesses were used to approximate the assumed hydrogeologic profile.
- The Bandelier Tuff consists of alternating welded (highly fractured) and non-welded (less fractured) units. Liquid-phase fracture flow was assumed to occur in the upper fractured tuff unit (uppermost unit of the Bandelier Tuff), thus creating a "fast-path." Due to the negligible travel time through this unit, it was not included in the assumed hydrologic stratigraphy.
- Groundwater flow was assumed to occur in the uppermost portion of the aquifer, the Puye Formation.

Some of the key values for site-specific parameters for SNL and LANL that were used in the scoping evaluations are shown in Table 2.

Table 2. Comparison of Site-Specific Parameters and Values Used in the Scoping Evaluations for the Water Pathway at SNL and LANL (from Waters and Gruebel, 1996, Tables 8-1 and 9-1)

Parameter	Value	
	SNL	LANL
UNSATURATED ZONE		
Natural recharge through native soils	0.02 m/y	0.02 m/y
Thickness between trench and saturated zone	141 m	333 m
SATURATED ZONE		
Porosity	0.30	0.30
Mixing depth	15 m	9 m
Darcy velocity	0.5 m/y	23 m/y

Atmospheric Transport Analysis

We used a conceptual model for evaluating the atmospheric pathway that was derived from performance assessments of disposal facilities for low-level waste. The model was generalized for the radionuclide evaluation but used site-specific values for several of the input parameters. An analysis was not conducted for toxic metals because none were expected to be volatile under disposal-facility conditions. Of the radionuclides considered in the evaluation, only H-3 and C-14 were expected to be volatile for the disposal-facility conditions and thus were the only radionuclides considered for atmospheric transport.

For the atmospheric pathway, we assumed that peak concentrations of airborne radionuclides were reduced by upward diffusion through the soil above the trench, by mixing in the ambient air above the trench, by dispersion through the atmosphere to the performance boundary, and by radioactive decay. We used a diffusion mechanism with conservative parameter values in order to bound results from other, harder-to-quantify release mechanisms (e.g., soil desiccation and cracking, burrowing animals, and plant root uptake).

A generic conceptual model was used to describe the atmospheric pathway (Figure 4). In the model, radionuclides were assumed to be transported from the trench through the soil diffusion zone to the soil surface by vapor (tritiated water) and gaseous diffusion (carbon dioxide containing the C-14 isotope).

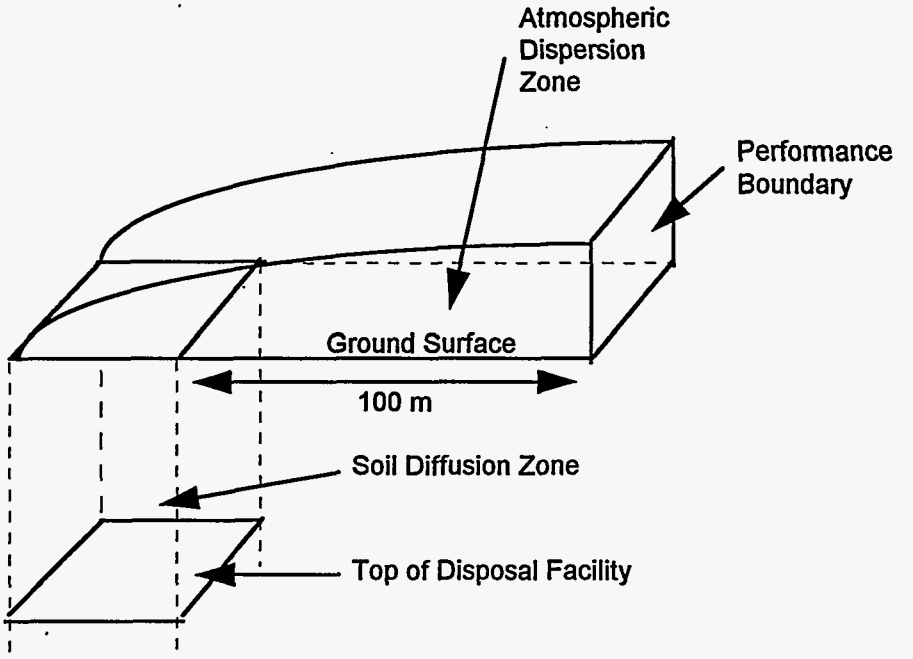

Figure 4. Generic conceptual model for the atmospheric pathway (Waters et al., 1996, Figure 5-5).

After reaching the soil surface, the radionuclides were assumed to be entrained in the air as volatiles. Once airborne, the radionuclides were assumed to be transported in the atmospheric dispersion zone to a receptor located at the performance boundary.

The arrival time of radionuclides at the performance boundary was assumed to be 100 years based on the following generic assumptions of the radionuclide evaluation:

- The waste form was grouted MLLW treatment residuals, which provided retention of the volatile radionuclides in the trench. Based on this assumption, tritium as vapor was bound in the pore water of the hydrophilic grout, and formation of carbon dioxide as a gas carrying the C-14 isotope was limited by the high pH of the grout.
- The trench was capped by a RCRA-compliant cover system. Based on this assumption, the cover system was assumed to be maintained to provide low permeability for 100 years.

Inadvertent Intrusion Analysis

For the intrusion analysis, we used standard scenarios that were developed for performance assessments of disposal facilities for low-level waste. These scenarios were based primarily on the assumptions used by the Nuclear Regulatory Commission in developing the waste classification system for near-surface disposal of radioactive waste in 10 CFR Part 61 (NRC, 1982). We used two long-term, chronic exposure scenarios in the radionuclide evaluation: the homesteader (agricultural) scenario and the post-drilling scenario. We did not perform an analysis of inadvertent intrusion for toxic metals.

In the homesteader scenario, an intruder was assumed to establish a permanent homestead directly above a disposal facility with the foundation of the home extending into the waste. As part of the scenario, a portion of the waste exhumed from the disposal facility was assumed to be mixed with native soil in the

intruder's vegetable garden. In the post-drilling scenario, an intruder was assumed to drill a well for a domestic water supply. The well was assumed to be drilled through the disposal facility, and the cuttings were mixed with native soil in the intruder's vegetable garden. The intruder was assumed to garden in some of the exhumed waste but not to reside permanently above the disposal facility. An important difference between the two scenarios is that the amount of material brought to the surface and subsequently mixed into the intruder's garden is about an order of magnitude less for the post-drilling scenario than for the homesteader scenario. In addition, the post-drilling scenario was assumed to occur earlier following closure.

In the radionuclide evaluation, we estimated the dose resulting from an intrusion scenario (the sum of the doses from all exposure pathways involved in that scenario) per unit concentration by using dose conversion factors that were applied to specific exposure pathways. The values for these conversion factors were radionuclide-specific and facility-design-specific and were the same for all sites. Estimates of the reductions due to radioactive decay were based on the time of intrusion into the disposal facility. The time of intrusion for the homesteader scenario was assumed to be 300 years after facility closure, while the time of intrusion for the post-drilling scenario was assumed to be 100 years after closure.

RESULTS OF THE EVALUATIONS

The results of the evaluations for radionuclides and toxic metals in MLLW are not directly comparable: the radionuclide evaluation was based on three pathways, while the toxic-metals evaluation analyzed the water pathway only. In addition, based on a recommendation for conducting performance assessments of disposal facilities for low-level waste (Wood et al., 1994), we used a 10,000-year period of consideration for the water-pathway analysis in the radionuclide evaluation, but the toxic-metals evaluation was not based on this recommendation. Instead, we reported travel times to the performance boundary regardless of the length of time.

Scoping Evaluation for Radionuclides

Fifty-eight radionuclides were considered in the radionuclide evaluation, each with characteristics that make its behavior in the environment and its radiotoxicity unique. However, there are sufficient commonalities among many of the radionuclides to allow grouping by their major characteristics. For the water pathway, we summarized the results of the radionuclide evaluation into eight different categories according to persistence (i.e., half-life), mobility, and radiotoxicity. We then chose an "indicator" radionuclide to represent each of the eight categories. A comparison of the results of the water-pathway analysis for SNL, LANL, and all sites considered in the radionuclide evaluation is shown in Table 3.

Two volatile radionuclides, H-3 and C-14, were analyzed for the atmospheric pathway. Even though we used site-specific data in the calculations, there are no significant differences in the permissible concentrations for each of these two volatile radionuclides at the fifteen sites because the atmospheric pathway analysis was basically generic. Because H-3 has a short half-life, its maximum permissible concentrations are much higher than those for C-14.

The estimated permissible waste concentrations based on analyses of the intruder scenarios were the same at all sites except Savannah River, where we made a site-specific modification. Except for Cs-137, the post-drilling scenario generally yielded more restrictive permissible concentrations than the homesteader scenario for the short-lived radionuclides (i.e., H-3 and Sr-90), primarily due to the earlier assumed time of intrusion. The permissible concentrations for the long-lived radionuclides were more

Table 3. General Summary of Maximum Permissible Concentrations (MPC) for Radionuclides in the Water Pathway (based on Waters et al., 1996, Chapter 7; and Waters and Gruebel, 1996, Tables 8-4 and 9-4)

INDICATOR NUCLIDE	RESULTS FOR SNL	RESULTS FOR LANL	GENERAL RESULTS FOR ALL 15 SITES
H-3 (short-lived, highly mobile, and volatile)	Unlimited concentration	Unlimited concentration	High permissible concentrations (often unlimited) at arid sites. Relatively high permissible concentrations at humid sites.
C-14 (medium-lived, highly mobile, and volatile)	MPC = 2E+06 $\mu Ci/m^3$ Arrival time at the performance boundary is beyond 10,000 years.	MPC = 4E+08 $\mu Ci/m^3$ Arrival time at the performance boundary is beyond 10,000 years.	High permissible concentrations at sites with long water travel times (Lawrence Livermore, SNL, LANL, and Pantex), no limit for arrival times beyond 10,000 years (Nevada Test Site). Low permissible concentrations at all other sites.
Sr-90 (short-lived, moderately mobile)	Unlimited concentration, with arrival time at the performance boundary beyond 10,000 years.	Unlimited concentration, with arrival time at the performance boundary beyond 10,000 years.	Limited for Fernald, Portsmouth, and Savannah River.
Tc-99 (long-lived, highly mobile)	MPC = 1E+02 $\mu Ci/m^3$	MPC = 2E+03 $\mu Ci/m^3$	Low permissible concentrations at all sites except Nevada Test Site, which has no limit. Permissible concentrations for arid sites generally greater than for humid sites.
Cs-137 (short-lived, low mobility)	Unlimited concentration, with arrival time at the performance boundary beyond 10,000 years.	Unlimited concentration, with arrival time at the performance boundary beyond 10,000 years.	Unlimited at all sites.
U-238 (long-lived, generally somewhat mobile but highly mobile at Hanford)	MPC = 4E+01 $\mu Ci/m^3$ Arrival time at the performance boundary is beyond 10,000 years.	MPC = 1E+03 $\mu Ci/m^3$ Arrival time at the performance boundary is beyond 10,000 years.	Relatively low permissible concentrations at all sites. No limit for arrival times greater than 10,000 years for most arid sites as well as Argonne-East and West Valley.
Pu-239 (long-lived, somewhat mobile)	Unlimited concentration, with arrival time at the performance boundary beyond 10,000 years.	Unlimited concentration, with arrival time at the performance boundary beyond 10,000 years.	High or unlimited permissible concentrations at all arid sites. No limit for arrival times greater than 10,000 years for most humid sites. Low permissible concentrations at Oak Ridge and Savannah River.
Am-241 (medium-lived, somewhat mobile); decays to Np-237 (long-lived, highly mobile)	MPC = 1E+04 $\mu Ci/m^3$ Am-241 decays prior to arrival at the performance boundary, and arrival time at the performance boundary for Np-237 is beyond 10,000 years.	MPC = 3E+05 $\mu Ci/m^3$ Am-241 decays prior to arrival at the performance boundary, and arrival time at the performance boundary for Np-237 is beyond 10,000 years.	Am-241 decays prior to arrival at the performance boundary, and arrival time at the performance boundary for Np-237 is beyond 10,000 years at all arid sites except Rocky Flats. Higher permissible concentrations at all humid sites except Oak Ridge.

restrictive for the homesteader than for the post-drilling scenario because the homesteader scenario involved a greater volume of exhumed waste and used more exposure pathways than did the post-drilling scenario.

A comparison of the results from the three pathways for the indicator radionuclides at SNL and LANL is shown in Table 4. After calculating the maximum permissible concentrations for the radionuclides, the lowest permissible concentration was selected as the limiting concentration. For the water pathway, we did not report a concentration if it arrived at the performance boundary beyond the 10,000-year period of consideration used in the radionuclide evaluation. The lowest permissible concentrations for six of the eight indicator radionuclides are from the intruder pathway. This table is representative of the results for the 58 radionuclides considered in the radionuclide evaluation for SNL and LANL: 56 radionuclides were limited by the intruder pathway, one radionuclide was limited by the atmospheric pathway, and one radionuclide was limited by the water pathway. In general, the intrusion pathway is the limiting pathway at the arid sites considered, whereas the humid sites are limited by a combination of the water and intruder pathways.

Table 4. Maximum Permissible Concentrations for Radionuclides in the Three Pathways at SNL and LANL (permissible concentration for the most limiting pathway is highlighted in bold italics) (based on Waters and Gruebel, 1996, Tables 8-7 and 9-7)

Nuclide	Maximum Permissible Concentration ($\mu Ci/m^3$)					
	SNL			LANL		
	Water[a,b]	Atmospheric[c]	Intruder[d]	Water[a,b]	Atmospheric[c]	Intruder[d]
H-3	NL	3E+09	***7E+07***	NL	2E+09	***7E+07***
C-14	--	***2E+03***	1E+04	--	***1E+03***	1E+04
Sr-90	--		***5E+04***	--		***5E+04***
Tc-99	***1E+02***		2E+04	***2E+03***		2E+04
Cs-137	--		***3E+05***	--		***3E+05***
U-238	--		***5E+03***	--		***5E+03***
Pu-239	--		***6E+03***	--		***6E+03***
Am-241 (Np-237)	--		***7E+03***	--		***7E+03***

a "NL" means No Limit - estimated permissible concentration is greater than the specific activity of the pure elemental radionuclide
b "--" indicates that the concentration arrives at the performance boundary beyond 10,000 years
c Results presented for radionuclides expected to be volatile under disposal-facility conditions
d Concentration is based on the most restrictive of the homesteader and post-drilling scenarios

Scoping Evaluation for Toxic Metals

A comparison of the results of the water-pathway analysis for SNL, LANL, and all sites considered in the toxic-metals evaluation is shown in Table 5. As discussed previously, the scoping evaluation did not include an analysis of the atmospheric and intruder pathways. In general, higher permissible concentrations and longer travel times to the performance boundary were associated with the arid sites.

Table 5. General Summary of Maximum Permissible Concentrations (MPC) for Toxic Metals in the Water Pathway

RCRA Toxic Metal	Results for SNL	Results for LANL	General Results for All 15 Sites
Arsenic	MPC = 1E+04 mg/m^3 Travel time to the performance boundary is estimated at 79,000 years	MPC = 3E+05 mg/m^3 Travel time to the performance boundary is estimated at 120,000 years	Permissible concentrations range from 2E+03 to 3E+05 mg/m^3. Travel times to the performance boundary at arid sites in excess of 10,000 years except at Rocky Flats; travel times less than 10,000 years at humid sites except at Argonne-East.
Barium	MPC = 5E+05 mg/m^3 Travel time to the performance boundary is estimated at 200,000 years	MPC = 1E+07 mg/m^3 Travel time to the performance boundary is estimated at 10 million years	Permissible concentrations range from 7E+04 to 1E+07 mg/m^3. Travel times to the performance boundary at arid sites in excess of 10,000 years except at Hanford and Rocky Flats; travel times less than 10,000 years at humid sites except at Argonne-East and West Valley.
Cadmium	MPC = 1E+04 mg/m^3 Travel time to the performance boundary is estimated at 1 million years	MPC = 3E+05 mg/m^3 Travel time to the performance boundary is estimated at 1.6 million years	Permissible concentrations range from 2E+03 to 3E+05 mg/m^3. Travel times to the performance boundary at all sites in excess of 10,000 years except at Paducah, Portsmouth, Oak Ridge, and Savannah River.
Chromium	MPC = 2E+04 mg/m^3 Travel time to the performance boundary is estimated at 920,000 years	MPC = 6E+05 mg/m^3 Travel time to the performance boundary is estimated at 1.4 million years	Permissible concentrations range from 3E+03 to 6E+05 mg/m^3. Travel times to the performance boundary at all sites in excess of 10,000 years except at Paducah, Portsmouth, and Oak Ridge.
Lead	MPC = 1E+05 mg/m^3 Travel time to the performance boundary is estimated at 3.5 million years	MPC = 3E+06 mg/m^3 Travel time to the performance boundary is estimated at 5.3 million years	Permissible concentrations range from 2E+04 to 3E+06 mg/m^3. Travel times to the performance boundary at all sites in excess of 10,000 years except at Paducah, Portsmouth, and Oak Ridge.
Mercury	MPC = 5E+02 mg/m^3 Travel time to the performance boundary is estimated at 1.8 million years	MPC = 1E+04 mg/m^3 Travel time to the performance boundary is estimated at 2.8 million years	Permissible concentrations range from 7E+01 to 1E+04 mg/m^3. Travel times to the performance boundary at all sites in excess of 10,000 years except at Paducah, Portsmouth, and Oak Ridge.
Selenium	MPC = 1E+03 mg/m^3 Travel time to the performance boundary is estimated at 2 million years	MPC = 3E+04 mg/m^3 Travel time to the performance boundary is estimated at 160,000 years	Permissible concentrations range from 2E+02 to 3E+04 mg/m^3. Travel times to the performance boundary at arid sites in excess of 10,000 years except at Hanford; travel times less than 10,000 years at humid sites except at Argonne-East and Fernald.

SUMMARY AND CONCLUSIONS

These analyses of the radioactive and hazardous components of MLLW are simple, scoping-level evaluations. They primarily provide physical-chemical information on the relative capabilities of fifteen DOE sites to dispose of treated MLLW containing up to 58 radionuclides and 7 toxic metals in a trench facility. The results of these analyses could change based on different assumptions about technical factors such as waste treatment, stabilized waste form, and disposal-facility design.

The scoping evaluations provide several major insights about the disposal of MLLW. The results indicate that all of the fifteen DOE sites, including SNL and LANL, have the technical capability for disposal of some waste. Maximum permissible concentrations at both SNL and LANL for the 58 radionuclides considered in the evaluation are almost exclusively determined by pathways other than through groundwater. For the hazardous component represented by toxic metals, maximum permissible concentrations are large, and travel times through groundwater to the performance boundary are on the order of thousands of years.

FUTURE WORK

The results of the scoping evaluations for the two components of MLLW pose the technical question of which component is potentially a greater risk to human health, the radionuclides or the toxic metals. Comparing the results of the two evaluations does not directly address this question because the answer depends on the relative amounts of radioactive and hazardous components in the treated MLLW and the ways in which they are affected by disposal-facility conditions and environmental transport.

We are currently beginning the process of comparing the results of the scoping evaluations with reported waste stream inventories to determine the technical ability of the fifteen sites for disposal of actual DOE MLLW. Information is being collected on waste streams that are planned for treatment within the next five years for all sites that are currently generating, storing, or expecting to generate MLLW. For waste streams with sufficient characterization data, we will estimate the concentrations of radionuclides and hazardous constituents. Appropriate modifications will be made for treatment processes other than grout stabilization and for specific waste types at the DOE sites.

A comparison of the estimates of radionuclide and toxic metal concentrations with the maximum permissible concentrations estimated in the scoping evaluations will be performed. These comparisons will indicate which waste streams may exceed the disposal limitations of the site and which component of the waste limits the technical acceptability for disposal. In cases where concentrations of radionuclides or hazardous metals in the waste streams exceed the estimated disposal limits, either more refined analyses or alternate methods of waste treatment may provide different results.

The scoping evaluations described here and other technical analyses will support policy decisions pertaining to the final disposal configuration for MLLW. However, they are only the technical beginnings for the discussions between the DOE and the States. The final configuration will also include consideration of institutional factors such as the existing disposal infrastructure, other on-going assessments of the DOE complex, and input from stakeholders.

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