Building Confidence in LLW Performance Assessments - 13386

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ABSTRACT

The performance assessment process and incorporated input assumptions for four active and one planned DOE disposal sites were analyzed using a systems approach. The sites selected were the Savannah River E-Area Slit and Engineered Trenches, Hanford Integrated Disposal Facility, Idaho Radioactive Waste Management Complex, Oak Ridge Environmental Management Waste Management Facility, and Nevada National Security Site Area 5. Each disposal facility evaluation incorporated three overall system components (1) site characteristics (climate, geology, geochemistry, etc.), (2) waste properties (waste form and package), and (3) engineered barrier designs (cover system, liner system). Site conceptual models were also analyzed to identity the main risk drivers and risk insights controlling performance for each disposal facility.

INTRODUCTION

Building confidence in the ability of Low Level Radioactive Waste (LLW) disposal facilities to meet performance objectives over the intended lifespan of the facility is a major challenge for the Department of Energy (DOE). In addition to waste streams generated from everyday operations, the DOE is faced with the challenges of legacy waste site remediation. Present and future waste disposal operations will involve the expansion of currently operating disposal facilities at locations such as Savannah River and Oak Ridge, along with possible construction of new facilities at Paducah, Portsmouth, and other sites across the DOE complex. Technical staff at each DOE site are given the task of conducting a performance assessment (PA) for resident LLW disposal facilities to demonstrate that the facility will meet regulatory requirements over the eleven hundred year post-closure period that includes one hundred years of institutional controls followed by one thousand years post-institutional controls [1]. This includes the creation of site conceptual models for transport of radionuclides to potential receptors (people and the environment) and modeling based on one or more conceptual models. While all LLW disposal facilities across the DOE complex are currently meeting their regulatory requirements, long-term uncertainties in predicting performance and approximations in modeling parameters resulting from gaps in data can lower the confidence stakeholders have in the overall assessment process and PA results. Also, the technical staffs at each site have preferred PA methodologies and modeling frameworks, further making analysis among sites and against a regulatory baseline difficult.

ANALYSIS OF SITE PROFILES

The performance of a LLW disposal facility is dependent not only on the engineered components of the actual disposal cells but on a number of variables and processes. It is therefore important to use a broad systems approach in which the engineered barriers are one component. Site properties and waste characteristics are the other two major components. The engineered barriers component is comprised of the various layers of a cover system, such as capillary barriers, biointrusion barriers, and evapotranspirative systems, in combination with a liner system that may contain layers of compacted clay, geomembranes, geosynthetic clay, and leachate collection. All DOE LLW sites contain a cover system, and many contain some form of liner system, though neither DOE nor NRC regulations require a liner. The site properties component includes the natural processes and characteristics of the disposal site, such as climate (rainfall, temperature, humidity), site geology (subsurface rock layers), site hydrology (subsurface moisture flow, distance to groundwater), and vadose zone geochemistry. The waste characteristics component is a combination of the waste form and the waste package. Waste form includes unstabilized contaminated clothing, machine components, resins, and filters, as well as material that has been stabilized through the use of cementitious material to reduce leaching potential. Waste packages can range from cardboard and wooden boxes to more robust steel boxes, cylinders, and grouted vaults. Each of these subcomponents can affect long-term facility performance on their own and in combination with one another.

A review of major DOE disposal sites across the country was conducted to assess and compare characteristics for each of the three system components as a first step in developing an understanding of how each system component affects overall facility performance. Data collected from the site reviews will be used to create site conceptual models of each disposal facility. The conceptual model can then be used for scenarios based on event tree analyses to provide risk insights into the disposal facility performance. The eventual goal is the development of a risk-informed and performance-based tool that can help build confidence in PAs and thereby assist decision makers. This tool will be able to address the DOE's interest in consistency in the performance of PAs across the DOE complex while recognizing the need to incorporate variability in site conditions, waste characteristics, and engineered barrier design.

The five initial sites that were selected for the review were the Savannah River Site, Hanford, the Idaho National Laboratory, the Oak Ridge Reservation, and the Nevada National Security Site. These sites were selected for their range of site parameters (precipitation, distance to groundwater), differences in engineered barriers, and availability of documentation on each facility. Additional sites that may be incorporated in the future are the Portsmouth site in Ohio, the Paducah site in Kentucky, and the Los Alamos National Laboratory to provide more data for the decision-making tool.

Savannah River E-Area Slit and Engineered Trenches

The Savannah River Site is a 777 km^2 site located in south-western South Carolina and contains two LLW disposal facilities, the E-area disposal cells and the Saltstone Disposal Facility (in Z-Area) [2, 3]. Average annual rainfall is 122 cm while average annual temperature is around 18 ^oC. The uppermost aquifer unit of the site can be divided into three hydrostratigraphic zones. The base of this unit is a fully saturated zone, with an overlying intermittent clay confining layer below a top partially saturated sand and clay zone [2, 4]. The average distance in the E-Area and Z-Area from the bottom of the disposal cells to the bottom of the vadose zone is around 7 m [2, 5]. The geochemistry of the site was calculated for sandy environments and clay environments in two geochemical states, a baseline case and one modified to include the presence of cellulose degradation products, which may become present in future leachate and affect radionuclide transportation rates [2, 6]. A range of waste types based on concentration and activity are disposed of within E-Area. The majority is lower level wastes, which are placed in either excavated below-ground narrower trenches called Slit Trenches or wider and deeper trenches called Engineered Trenches [2, 5]. Waste forms for both types of trenches include soil, rubble, wood, debris, concrete, equipment, contaminated clothing, and plastic sheeting. Disposal within the Slit trenches can be either within a container or as bulk uncontainerized waste. Containerized waste is placed in each trench first and void spaces are filled with bulk waste or soil. The Engineered Trenches generally accept waste in B-25 boxes, with each trench designed to hold approximately 19,000 B-25 boxes. Slit Trenches are designed with earthen bottoms, while each engineered trench contains compacted soil underlain by a geotextile filter fabric and a base of granite crusher run. Previously excavated soil is placed over each completed trench section and compacted by a bulldozer [2]. An interim cover of additional soil with a water-resistant HDPE geomembrane will be placed after closure of the facility and maintained for the 100-year period of institutional control. This cover will allow for subsidence, and following the end of this period a final closure cover using an integrated system of multiple layers of soil and geosynthetic materials will be placed over each trench.

Hanford Integrated Disposal Facility

The Hanford site is situated in the south-central part of Washington State along the Columbia River and occupies 1517 km^2 of territory [7]. Hanford contains a currently operating CERCLA disposal cell for site LLW environmental remediation activities, the Environmental Remediation Disposal Facility (ERDF), and a proposed low activity waste facility [7, 8]. The proposed Immobilized Low-Activity Waste Disposal facility (also known as the Integrated Disposal Facility) is scheduled to receive 200,000 m^3 of glass logs containing immobilized non-radioactive and low-activity tank waste. Climate at Hanford is characterized as midladitutde semi-arid, with average annual precipitation around 16 cm [7]. The average temperatures at the site range from -11.1 to 6.9 ^{O}C in winter to 17.2 to 27.9 ^{O}C in summer. Site geology is comprised of a basalt base overlain by 95 m of fluvial gravel sediments layers below 116 m of alternating layers of gravel and sandy sediments [7]. At the IDF site the water table is historically 103 m below surface, though activities at the Hanford site have artificially raised the water table 5 m above normal. Geochemical values for the area were calculated for five different conditions: near field within the disposal cell, degraded concrete vault, chemically impacted in far-field sand sequence, chemically impacted in far-field gravelly sequence, and far-field gravel sequence [7, 9]. Disposal of the low activity waste fraction from tank waste operations is expected to use thousands of stainless steel cylinders placed within a number of remote handled waste trenches. Preliminary designs for each disposal cell involve a base layer of bentonite clay/soil admixture, overlain with a high-density polyethylene (HDPE) geomembrane followed by a geocomposite drainage layer [7]. A similar but thinner liner system would be placed over the base liner system, and an upper operational layer consisting of crushed concrete and soil would be at the top. The candidate waste form for the IDF is to immobilize the non-radioactive and low-activity waste fraction of the tank waste within silicate glass monoliths [7]. Around 14,000 waste packages grouped into four layers are estimated to fit within each disposal trench. Once placed within the disposal cell, each layer of waste would be covered by a layer of soil to limit infiltration, provide a surface for machinery to use, and help shield workers from radiation. Temporary plastic sheeting over the exposed surface of the disposal cell would also help limit infiltration. A potential closure plan would be to use a modified RCRA-subtitle C multilayer cover containing a topsoil layer, a lateral drainage layer, and a barrier layer.

Idaho Radioactive Waste Management Complex

The Idaho National Laboratory (INL) is located on the high desert terrain in Southeastern Idaho and occupies close to 2,305 km^2 [10]. INL contains two LLW disposal facilities, the Idaho CERCLA Disposal Facility (ICDF) and the Radioactive Waste Management Complex (RWMC). The second of these facilities, the RWMC, is located in the southwestern portion of the site and covers an area of 70.4 ha, with currently active LLW disposal operations occupying 3.14 ha of the 39 ha disposal area. Climate at INL is semi-arid sagebrush desert, with average annual precipitation around 21.4 cm [10]. Average monthly temperatures in winter range from -9 to -1 ^{O}C, while in the warmer summer months average temperatures vary from 5 to 20 ^{O}C. Site geology is characterized by alternating layers of basalt and interbedded sediments, with the water table beginning around 180 m below the surface [10]. Geochemistry information for subsurface movement of radionuclides was calculated along with fractional release and corrosion rates for disposal cell components, waste forms, and waste package materials. Active waste disposal at the RWMC is being carried out within Pits 17-20, a large subsurface pit with a base liner of soil and the ability to accept a maximum of 130,000 m^3 of waste [10]. Waste forms disposed at the site include contaminated protective clothing, paper, rags, packing material, glassware, tubing, resins, activated metals, beryllium blocks, fuel-like materials, and vycor glass, equipment (i.e. gloveboxes and ventilation ducts), filters cartridges, and sludges [10]. Waste packages include metal and wooden boxes, drums, soft-sided reinforced containers, and some specialty containers for non-uniform size waste. An interim cover of soil is placed over full areas. Final closure of the disposal site will be done through the CERCLA process [10, 11]. The proposed final cover is a multilayer evapotranspirative cover. Several different current and experimental cover designs are also being evaluated using tests plots at INL, including a modified RCRA subtitle-C cover. The current base cover layer design is comprised of soil followed by grading fill to create a 3% cover slope over the entire disposal pit. The final top layer is an engineered ET cover containing layers of topsoil, fine soil fill, sand, and gravel, with an optional cobble biointrusion layer.

Environmental Management Waste Management Facility at Oak Ridge

The Oak Ridge Reservation is located partially within and adjacent to the city of Oak Ridge and occupies 140 km^2 of land [12]. The current operating disposal site at Oak Ridge is the Environmental Management Waste Management Facility (EMWMF), and is designed to take all site CERCLA LLW, RCRA regulated hazardous waste, regulated Toxic Substances Control Act (TSCA) wastes, and other mixed wastes [13]. The facility is currently undergoing expansion to ultimately hold approximately 1,682,000 m^3 of waste. Climate at Oak Ridge consists of average annual precipitation around 137 cm and average temperature around 14.4 ^{O}C [12]. Historic faults and upwards thrusts at the Oak Ridge Reservation (ORR) have resulted in layers of interbedded carbonate-dominated and clastic (sand and silt) shale rock groups becoming compressed and folded over one another. Groundwater flow at the site occurs through areas of either solution conduits or fractured flow [14]. The vadose zone is highly variable, ranging from nonexistent to a thickness of 50 m, with an average of 20 m. The EMWMF sits in an area of the ORR Aquitard, and depth to the groundwater layer is roughly 20 m from the surface, 3 m below the clay buffer layer installed between the disposal cell liner and the underlying soil [13, 15]. Site geochemistry was calculated on an order of magnitude basis [14]. The EMWMF disposal facility is divided into five currently finished cells with a sixth cell in the planning stages [13, 15]. Total constructed volume for waste stands at 1,300,000 m^3, with an additional 382,000 m^3 of disposal space planned for cell six [13, 15, 16]. Each disposal cell contains a double composite liner and leachate collection and detection system based on EPA RCRA prescribed designs for hazardous waste. The base of the liner system is a layer of clay overlain by a HDPE geomembrane [15]. The leak detection system is above this layer and consists of a geonet placed between two non-woven geotextiles, followed by a second HDPE geomembrane. The leachate collection system sits on top of the liner system and consists of a granular layer covered with an operational soil protective layer. Waste forms include demolition debris, contaminated soil with and without a RCRA hazardous waste component, contaminated clothing, trash, contaminated sediments/sludges with and without a RCRA component, and miscellaneous solids. Waste is disposed of as unconsolidated material with no waste package. The EMWMF ensures adequate disposal space and compliance with radionuclide disposal limits by employing a complex set of algorithms to determine optimal waste mixtures [16]. Each full cell is covered with an interim soil layer over the waste to reduce infiltration. The final post-closure cover design for the EMWMF is a multi-component cover system including layers of compacted clay, geosynthetics, and geomembranes [15, 16].

Nevada National Security Site Area 5 Radioactive Waste Management Site

The Nevada National Security Site (NNSS) is located in the desert areas of Southern Nevada and occupies over 3,500 km^2 [17, 18]. NNSS hosts two LLW disposal facilities, the Area 3 Radioactive Waste Management Site (now closed) and the Area 5 Radioactive Waste Management Site (RWMS). The Area 5 site is located in the southeastern portion of the NNSS within the Frenchman Flat formation, an alluvium filled closed basin containing a dry lake bed (playa) [17]. The entire Area 5 site takes up about 296 ha, with the active waste disposal portion, the RWMS, operating on 58 ha of Area 5 [18]. The NNSS is situated in a transitional region between the Nevadan and Mojave Desert, with climate typical of an intermountain desert [17]. Average annual precipitation at Area 5 is around 12 cm, and average temperature ranges from 2 ^{O}C in January to 24 ^{O}C in July. The Area 5 geology is characterized by basement sedimentary rock covered by layers of volcanic tuff and infilling alluvium [17]. The alluvium located beneath the RWMS has an estimated thickness of 360 to 460 m, and is composed of tertiary volcanic rock mixed with carbonates, quartzites, and other sedimentary rocks. The water table sits at a depth of 280 m, and the combination of low precipitation with high evapotranspiration rates results in groundwater movement upwards towards the surface within the upper 35 m of soil. This effectively eliminates the potential for radionuclide transport by moisture to the groundwater pathway. The RWMS contains both trenches and pits and continues to expand the size of disposal operations. The site receives and has received wastes from sites across the country, including Rocky Flats, Fernald, and Mound [17]. This has meant a large variety of waste forms, including cement-solidified tritium, cement-solidified sludge, sewage sludge with fly ash, laboratory waste, equipment, oil in absorbent, soil, D&D debris, trash, construction wastes, uranium residues, and thorium residues. Early waste packages included plywood and cardboard boxes, though at present only steel boxes are used for disposal. Each disposal cell contains an earthen bottom and a layer of soil placed over completed sections, and the final cover design calls for a multilayer evapotranspirative cover.

CURRENT PROGRESS AND GOING FORWARD

Building upon the site profiles, the next portion of research is to analyze the site conceptual models for each site in an effort to identify the main risk drivers and risk insights that drive and control site performance. The site conceptual model is a way to link the sources of contamination within each disposal cell to a potential receptor through transport pathways in the environment and exposure routes for the receptor. Each section of the conceptual model can be tied to some or all of the three disposal cell system components. The contaminated material that is available to the environment is dependent both upon the waste characteristics and the engineered design, and can be combined into a parameter called the source term. This includes the radionuclide inventory of the each disposal cell, the fractional release of each radionuclide from the waste form and waste package, and the degradation mode of the engineered barrier. There are many types of potential degradation modes, such as ecological succession, erosion of the cover, burrowing animals, and cover subsidence. The end result is the reduced ability of the engineered system to contain releases of waste to the environment. The transport pathway and exposure routes are dependent on site characteristics along with the source term. Release scenarios are typically transport to the groundwater through the vadose zone or as gases through the air pathway, though other scenarios can be used such as soil transport by burrowing animals. Pathway scenarios to exposure can include ingestion, deposition on surfaces, inhalation, or immersion in material tainted by contamination.

The Savannah River E-Area disposal facility can provide an example of the challenges in analyzing risk drivers. After the one hundred year institutional control period, the cover system will be planted with shallow rooted bamboo trees to reduce infiltration and prevent erosion of the cover layers [2, 19]. Over the ensuing several hundred years, there are three expected natural processes that will increase the hydraulic conductivity of the cover system. Succession of the bamboo forest to a pine forest will lead to holes in the geosynthetic layers as tree roots seek out moisture and puncture the synthetic material. Migration of colloidal clay within the cover system will clog up the pores in the drainage layer, slowly decreasing the hydraulic conductivity of that layer. The pine forest will also be substantially worse at retaining topsoil compared to the bamboo forest, and following ecological succession erosion of the surface storage layers will decrease the cap water storage. Each process or a combination of processes could degrade the performance of the cover system and lead to increased infiltration of moisture into the disposal cell, thus increasing the LLW source term available to the environment. There is also an alternate scenario in which waste packages are not adequately compacted at the end of the institutional control period before the placement of the final cover system. This could be a result of either poor compaction techniques or waste packages that have retained significant structural integrity to resist compaction. At some time following the installation of the final cover, the non-compacted waste corrodes further and collapses, causing subsidence within the disposal cell and failure of the cover system. Therefore, in order to limit subsidence following cover placement, adequate degradation of the waste packages must take place. However, degraded waste packages could also increase the source term by reducing barriers between the contaminated material and the environment. This example highlights the risks and uncertainties of assessing the affect each system component can have on long-term facility performance, and the need to consider the overall performance of the system as a whole.

Through drawing on the risk insights gathered from analysis of the site profiles and site conceptual models, the path forward is the use of event tree analysis to further develop an understanding of how system components affect overall performance. This understanding will help provide insights into how the disposal cell could change over time, identify aspects of vulnerability to cell performance, and highlight scenarios that could reduce a disposal cell's ability to meet the performance objectives. The final goal is the development of a semi-quantitative decision informing tool that will assign in the design of an effective engineered system to contain a certain type of waste in a given environment. Such a tool would be applicable to the range of site, waste, and design characteristic that can be found across the DOE complex. This in turn could help improve confidence in the PA process and performance evaluation results by providing a consistent methodology for evaluating performance while allowing for the inherent variability and uniqueness of each disposal facility.

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