A Risk-Based Evaluation of Lined Verses Unlined Disposal Cells for Future Low Level Radioactive Waste Disposal Sites - 10437

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ABSTRACT

Sufficient isolation of low level nuclear waste is essential to the long-term protection of human health and the environment. The use of liner systems in the design of future Department of Energy engineered disposal systems has been proposed as a way to better meet site performance objectives. This study was conducted to evaluate lined verses unlined disposal designs from a risk-based perspective. Performance was defined as limiting the release of waste from the disposal cell without an increase in secondary performance concerns. Information was gathered and assessed for operational, near, and long-term phases from previous studies on specific DOE and commercial disposal operations, each selected for unique site and design characteristics. Findings showed that under certain conditions, liners may improve site performance for shorter lived nuclides through operational phase leachate collection and near term prevention of waste release. However, this may be overshadowed by the creation of a secondary waste stream and potential buildup of liquid behind the liner. A key uncertainty was the lack of long-term liner field performance data. In addition, since liner influence diminishes with increased time scales, future work could focus on other potentially more effective methods to improve site performance.

INTRODUCTION

Since the beginning of the atomic age, the question of how to best manage the radioactive waste streams that were produced from various commercial and government nuclear activities has been a very important issue in the protection of human health and the environment. Initial disposal options consisted of releasing the material straight to the local soil and groundwater, or in the case of High Level Waste, storage in large metal tanks, essentially handing off the problem to the following generations. One of the first efforts to clean up the mistakes of the early nuclear programs was the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 and the associated UMTRA project, which sought to remediate the large uranium mill tailings sites left behind from the mining companies by placing them in engineered disposal cells to limit the escape of radon gas [1, 2]. With regards to low level radioactive waste, the next step came during the 1980s with two huge pieces of regulation; the first being the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), which created remediation requirements for legacy waste sites [3]. The second was the promulgation of 10 CFR 61 by the Nuclear Regulatory Commission (NRC) [4]. These regulations addressed land disposal requirements for low level radioactive waste, and set limits on the amount of radioactive material that could be released from the disposal site. The NRC regulations however only covered commercial entities that would be licensed by the NRC, requiring the Department of Energy, the single largest producer of low level waste and a self-regulating body, to establish its own guidance documents on how to properly dispose of LLW. The DOE regulations went through several iterations before 1998, when DOE Order 435.1 was issued, which created performance based criteria for how a disposal cell must operate for the compliance period [5].

There have been many different types of disposal cells used both currently and historically to contain Low Level Waste; an important component in a number of these designs employs the use of a liner system to separate waste from the surrounding soil (in this paper the term "liner" refers to engineered barriers that are placed below the waste). Liners in disposal cells can range from simple layers of compacted clay to complex composite systems that employ multiple layers of clay along with geomembranes and other geosynthetic layers [6]. There are a number of historical aspects behind the decision of whether to incorporate a liner system into a disposal cell. Some of the more prevalent ones include: pressure from affected stakeholder groups; requirements imposed by regulations; a large amount of annual precipitation at the disposal site; a lack of data concerning the geological and hydrological conditions at the site; and historically poor understanding of long-term waste cell performance. In regards to regulations in the United States, CERCLA mandates the use of a composite liner system with leachate collection, while the DOE Order and NRC regulations do not call for any type of liner so long as the disposal cell meets its performance objectives [3-5]. However, only a few sites nationwide have based the decision to construct a liner solely on how it will affect the performance objectives set forth for the site from the perspective of risk to human health and the environment. Recently, senior DOE Office of Environmental Management officials have proposed the idea of using liner system more frequently at future DOE disposal sites to further ensure that performance objective are met. This study was undertaken to provide initial risk-based recommendations on the usage of lined vs. unlined disposal cells based on previous research and lessons learned from historical and currently operating DOE and commercial Low Level Waste facilities.

METHODOLOGY

The performance of six waste disposal sites was investigated based on their ability to limit the release of waste from the disposal cell without an increase in secondary performance concerns. Each facility was selected for certain design criteria and site characteristics, such as the amount of annual precipitation and types of waste at the site (described in detail below). Three of the sites employed liner systems while the other three were unlined. Two of the facilities were in humid climates, three were in semi-arid, and one is located in an arid environment. All of the data from the sites were then combined to evaluate various positive and negative performance characteristics for lined disposal and unlined disposal, using a given site as an example of a certain attribute or combination of attributes. Finally, recommendations were drawn to help provide a rough template as a reference to use in determining whether to use a liner system given certain qualities of the proposed waste site.

Site Descriptions

Clive Disposal facility operated by Energy Solutions

Located in Utah near Salt Lake City, the Clive facility is licensed to accept NORM and Class A low level radioactive waste, and is the only commercially operating facility currently accepting new waste streams outside of the state compact system [7, 8]. The climate around the disposal cell is classified as semi-arid, with average rainfall in the area around 41 centimeters (16 inches). Waste packages are situated above-grade, and the facility incorporates a liner system constructed of a compacted 61 centimeter (2 foot) thick low-permeability (10-6 cm/sec [4 x 10-6 inches/sec]) clay layer, which sits approximately .45 – .60 meters (15 – 20 feet) above the water table [7].

Ambrosia Lake UMTRA site (New Mexico)

The Ambrosia Lake site was one of the simpler designed projects completed under UMTRCA, beginning construction in 1987 and containing over 4.6 million cubic meters (6 million cubic yards) of material and a total Ra-226 inventory of 1,850 curies [1, 9]. The site receives less than 28 centimeters of annual precipitation, and is considered to be in a semi-arid climate. It is far removed from any nearby population centers (no one lives within 3.2 kilometers (2 miles) of the site) and there are less than 60 people in a 10 kilometer (6 mile) radius. The site is unlined and relies solely on a 1.2 meter (4 foot) thick multilayer cover system with a radon and frost barrier.

Durango UMTRA site (Colorado)

The Durango site was moved from the town of Durango to nearby Bodo Canyon beginning in 1986, and was smaller than Ambrosia Lake at close to 1.9 million cubic meters (2.5 million cubic yards) of contaminated material, with a total inventory of 1,400 curies of Ra-226 [1, 10, 11]. This site is also semi-arid but receives a noticeably greater amount of annual rainfall of around 48 centimeters (11 inches). The facility is also much more complex in design, consisting of a compacted clay liner with a 2.1 meter (7 foot) thick extensive cover system comprising of a radon barrier, geosynthetic clay liner, sand drainage layer, and a rock/soil matrix layer with natural vegetation. As a result of the dust from the movement of the mill tailings, the debris was wetted down before final emplacement. This has led to seepage concerns and a toe drain had been installed in the cell to allow for the drainage of leachate.

Area 5 Radioactive Waste Management Site at the Nevada Test Site

The Waste Management Area 5 of the Nevada Test Site is located near the eastern edge of the site, with the closest permanent settlement being over 42 kilometers (26 miles) to the southwest [12 - 20]. The area is very dry, receiving less than 12.7 centimeters (5 inches) of rain per year, while at the same time sufficient annual potential evapotranspiration rates to cause water less than 35 meters (115 feet) below the surface to migrate upwards [12, 14, 17]. This large draw of moisture to the surface makes it very difficult for precipitation to infiltrate to the groundwater located 240 meters (790 feet) below, and it is estimated that it takes more than 50,000 years for liquids to reach groundwater [14]. This feature is very unique, as it essentially eliminates the pathway for contaminants to reach the aquifer during the 10,000 year performance objective, thus reducing the amount of uncertainty in predicting long term performance. The waste is disposed of in unlined pits and trenches, with temporary covers of soil backfill until the site is full and subsequently closed.

E – Area Engineered Trenches at Savannah River

The Savannah River Site E-Area is located near the town of Aiken, SC, and is one of the two humid sites in the study, receiving on average 132 centimeters (52 inches) of rain a year. Waste is buried in 2 below-grade earthen trenches and is characterized as Class A [21, 22]. The trenches do not contain a liner system; instead the base is compacted soil overlain with 15 centimeters (6 inches) of granite crusher run that is sloped to a sump. This allows for liquids to be pumped out of the trenches during the operational phase, similar to leachate collection in lined systems [21]. As a result of the large amount of precipitation and a water table that is around 12 meters (40 feet) below the surface, strict operational controls are in place while the waste is being deposited, meaning that only the section that is receiving waste is excavated and uncovered, with a temporary soil cover over waste that is already in place. Most of the waste in these trenches is encased in B-25 metal boxes stacked 4 high [23].

EMWMF at Oak Ridge (CERCLA Cell)

The Environmental Management Waste Management Facility (EMWMF) at Oak Ridge incorporates the most complex design of the six sites chosen, with multiple barriers above and below the waste packages. The site is also the wettest, with annual rainfall around 137 centimeters (54 inches) per year. The facility is comprised of 5 lined CERCLA cells underlined by a 3 meter (10 foot) barrier system consisting of compacted clay, HDPE liners, drainage layer, and a leachate collection system [24 - 26]. This was done for two reasons; because CERCLA requires the use of a liner system, and the water table (only around 5.1 meters (17 feet) below the base of the waste layer) is predicted to rise into the lower levels of the barrier layers during the compliance period. The other unique feature of the site is the use of a sophisticated system to determine Waste Acceptance Criteria for each individual waste lot. This is based on a combination of analytical formulas that take into account waste already in place and future disposal with the aid of a Waste Forecasting modeling package [27, 28].

RESULTS

Initial Observations

One of the first findings was that all current and past disposal operations continue to successfully meet their performance objectives, regardless of whether a disposal cell is lined or unlined. While four of the sites are still in the operational phase and thus under extensive observation, the two closed UMTRA sites are also meeting their performance objectives. Though the Durango Site has issues with leachate draining from the tailings due to water used at the time the pile was relocated, it has still managed to meet its objectives [10, 11]. The effectiveness of using a liner on the overall performance of a given disposal cell was found to be closely associated with three areas of importance. The first is site-specific conditions, for example the amount of precipitation that falls upon the site and the underground hydrogeology. A site that has a water table near the surface and lots of rainfall will receive greater benefit from a liner than an arid site. The second is the condition of the waste being placed in the cell, such as whether it is containerized or not and the robustness of the containers. Sites with large amounts of non-containerized waste tend to have liner systems, which provide the same function a container would of isolating waste from the environment. Third is the effectiveness of the cover system, which is tied to the design of the cover and the various operational and cost-closure time periods during the lifespan of the disposal cell. The cover system is the primary means of preventing moisture from infiltrating through to the waste. These points corresponds with the assumption that limiting the contact time between infiltrating moisture and the waste packages is one of the more important variables in controlling the mobilization of the disposed radionuclides and thus meeting the long term performance objectives, which fits well with the design criteria outlined in 10 CFR 61 [4]. To that extent, arid sites will almost always perform better than similarly designed cells at humid sites, barring any extreme climactic or geological events at the arid site.

Benefits and Drawbacks of Incorporating Liners

Disposal cells that incorporate liner systems were found to each have a number of benefits along with some drawbacks. When taking credit for the performance of the liner in the PA analysis, it was found that liners can be very useful in the collection of liquids during the operational phase, when the waste packages are most exposed to the exterior environment. Infiltration water passing through a cell is much greater before the construction of a closure cap, and if the waste is non-containerized or the waste packages contain defects then the more mobile radionuclides have the potential to migrate out of the cell and into groundwater. Liner systems can help retard the movement of mobile radionuclides in the near term, assuming that liner integrity is maintained and the leachate is collected periodically to prevent the accumulation of liquid inside the active cell. This in turn could allow for higher disposal limits of mobile shorter lived radionuclides by establishing greater confidence in the performance of the liner over the near term.

However, liners also create a number of problems that must be addressed as the cell matures. A failure in the leachate collection system can result in a buildup of hydraulic head behind the liner; this can subsequently lead to an increase in the contact time between waste and liquids. Waste packages will degrade and mobilize faster the longer they are in contact with liquids; this can be a substantial problem at sites that experience large or frequent rainfall events and that accept waste in forms that are either defective or subject to rapid corrosion. The very need to collect leachate raises the amount of institutional control and complexity of liner system needed, while creating a secondary waste stream that will need to be treated and then potentially stored as a hazardous waste. Another issue emerges with the degradation of the cover system following closure of the disposal cell, either through conceptual flaws in the cover design or after the end of institutional controls. Assuming that the liner degrades at a slower rate than the cover system, both liquid and mobilized radionuclides will start to accumulate at the boundary between the waste and the liner. This creates two problems, the first being the potential for the liquid level inside the cell to rise until it fills and overflows the structure (the bathtub effect). The second comes from the potential for a large instantaneous release of the radionuclides that have built up and concentrated at the waste/liner boundary should the liner fail. This last point goes against the performance criteria for disposal cell design, which is based on the concept of a controlled release of radionuclides below acceptable limits from the cell; a large slug release would cause the site to fail regulatory compliance and possibly endanger human health. As well, concentrating radionuclides along the liner boundary could cause chemical incompatibilities to develop with barrier materials in unforeseen ways that could render liners inefficient to both diffusive and advective transport.

Benefits and Drawbacks of Using Unlined Disposal

Similar to lined disposal cells, the option of going with an unlined design involves a number of advantages and limitations. Taking no credit for the performance of the liner in the PA analysis adds another layer of conservatism to the overall disposal cell design, while lowering the complexity of modeling how the cell will perform through the elimination of the performance and degradation aspects of the liner over the lifespan of the disposal cell. This can also help to reduce the cost and complexity of the actual cell. Another major advantage to using unlined disposal is that it allows liquids that might transverse through the cap to exit the cell rapidly, corresponding to a decrease in contact time between liquids and waste packages (when compared to lined disposal). This can lead to a slower rate of mobilization for the waste and slower degradation rates for the waste containers.

The lack of a liner between the disposed waste and the exterior environment does have its issues; chief among them is the fact that should radionuclides become mobilized from infiltrating liquid (following the degradation of any waste containers holding them), they have a high probability of migrating into the native underlying soils. Eliminating a liner from cell design also removes a safety net should other components of the disposal cell fail, which creates a much heavier reliance on the performance of the closure cap. It also creates a situation where there is a potential to lower the public confidence in the long-term performance of the site and the perception of safety among concerned stakeholders. Although this point is not a risk-based issue it certainly has the ability to significantly alter the cell design, especially should anything go wrong with other areas of the disposal site.

DISCUSSION

While the data extracted from the six sites in this study is by no means exhaustive, it does allow the ability to draw some preliminary conclusions that can assist in designing a low level waste disposal facility. The first is that lined disposal has a larger impact on the ability to control mobilized radionuclides during the operational and early post-closure phases when infiltration into the disposal cell is greatest, compared to diminishing importance in the longer term, when cover designs and waste packages take over. This is evident at Oak Ridge, where the proximity of the waste to groundwater, large amount of rainfall, non-containerized waste, and the several exposed cells combine to make collecting and treating all incoming precipitation necessary in preventing radionuclide migration [28]. As the amount of annual precipitation decreases by location, the ability of infiltrating liquids to mobilize radionuclides during the operational phase likewise diminishes. The Clive site in Utah, which is more arid than Oak Ridge, contains a simple compacted clay liner [8], while the dryer still Ambrosia Lake site contains no liner [9]. There is also a point where liners would have no effect on liquid migration, in areas with low precipitation and very high potential evapotranspiration rates, such as Area 5 at the Nevada Test Site [14].

However, the E-Area Trenches show that even with high amounts of annual precipitation, a liner is not necessarily needed. This site accomplishes the required performance objectives without a liner by tightly controlling the waste containers (only metal containers are used) and how long the waste is exposed after it is emplaced. Once a section of the trench is full, it is backfilled with a thick layer of soil (122 cm [4 feet]) that is sloped to allow precipitation to run off the cover [21]. Any infiltrating liquid flows around the metal containers, and is collected by a sump in the trench. Therefore, even though Oak Ridge and Savannah River receive close to the same amount of annual precipitation, the closer proximity of the EMWMF to groundwater/surface water and the use of containers at E-Area are more important to radionuclide migration and the selection of lined disposal. When comparing the E-Area to the Clive site, which is lined but much more arid, the waste acceptance policies and level of operational controls at each site (much stricter at E-Area) again show to be of greater importance than the amount of annual precipitation in deciding on lined disposal.

A second conclusion is that the usefulness in preventing discharge of cell leachate during the operational phase must be balanced by the potential to create secondary waste streams and liquid retention behind the liner following an end of institutional controls. This latter point is much harder to evaluate, since no site is near the end of the 100 year institutional control period. The creation of a liquid waste stream that is classified as both hazardous and radioactive does however add another layer of complexity and cost to modeling long term performance. Oak Ridge has worked to mitigate the secondary waste pitfall with their use of a sophisticated WAC that uses waste forecasting models to reduce the toxicity of the leachate produced [27]. However, a failure of the leachate collection system could still lead to liquid retention. By contrast, the Durango Site (semi-arid) and the E-Area Trenches (humid) both contain methods to remove leachate without the use of liners, thus reducing the likelihood of liquid buildup. At Durango, the seepage from the mill tailings can be used as an analogy for the buildup of liquid behind a liner (Durango has a clay liner) [10]. Installation of a toe drain to release seepage liquid in a controllable fashion partially circumvented the usefulness of the liner, shifting to a reliance on the cap to prevent further infiltration of rainwater. The E-Area trenches contain no liners and uses simple sumps to remove excess liquids [21]. As with the first conclusion, the lack of significant amounts of precipitation at the Nevada Test Site excludes the creation of leachate for the Area 5 Radioactive Waste Management Site.

A third conclusion addresses the tradeoff between shorter and longer lived radionuclides. Shorter lived nuclides such as Cs-137 and Sr-90 could be more successfully contained by liners if they were to become mobilized, especially if the waste is not confined in containers. A place similar to Clive, a semi-arid site with a variety of different waste streams and a compliance period of only 500 years, could benefit from a simple liner system to ensure compliance. Problems arise when longer performance periods are considered; then if the system cover fails before the liner does, mobile radionuclides could concentrate in the leachate near the liner boundary as more moisture enters the disposal cell. This could lead to a surface release of longer lived radionuclides should leachate fill and overflow the disposal cell, or a slug release into the surrounding groundwater following failure of the liner.

Ultimately, liners rarely contribute to the reduction of contact time between liquids and waste following site closure, as they are specifically designed to keep all material, including moisture, from leaving the disposal cell. While useful for collecting leachate, this also creates the potential to accelerate waste mobilization and create scenarios for compliance failures if liquids do buildup behind the liner.

GOING FORWARD

The large amounts of historical knowledge and lessons learned through experience have been very useful in modeling conditions during the operational and near-term institutional control phase. However, the lack of long term liner field performance data, especially data tied to site-specific conditions, could lead to a rise in future modeling and operational complexity without reducing the long term uncertainty associated with cell performance. It is important to continue to study disposal systems and building test pads to observe changes in liner composition and integrity that would not be possible to observe with actual waste over them. This has been suggested for DOE sites by a number of professional in the field [29].

Looking beyond the importance of liners, it is useful to investigate other aspects of disposal cell design that could be more effective at improving site performance. One area of focus could be the better implementation of monitoring equipment to detect and fix problems within the disposal cell cover. A second could be the improvement in designing engineered waste disposal containers that could maintain proper integrity for extended periods of time under a wide range of conditions. The tight control of waste acceptance criteria found at Oak Ridge and Savannah River is a third example, while the use of more natural evapotransporative covers like the one at Ambrosia Lake is another. One final possible future avenue would be the intentional creation of preferential pathways within the disposal cell. This has not been attempted at any major waste site to date, but the principle is that known engineered pathways would allow liquid to pass through the disposal cell in known ways that could be designed to avoid contact with waste packages, thus slowing the rate at which they degrade. This could be accomplished using one or a combination of methods, including installing physical drains through the cover and liner systems, using specialized waste containers to divert liquids around them, and dividing large waste cells into clusters of smaller ones to better allow precipitation to run off of covers. All of these concepts would help improve the reliability of long-term performance modeling while reducing the need for a liner as a safety net through better management of moisture flow around and through the disposal cell. It is therefore important as work progresses on cleaning up the nation's historic and current nuclear legacy to keep studying and improving on future disposal facilities to ensure the continued protection of the natural environment and human health.

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