Technology Needs for Developing the Next Generation of U.S. Department of Energy Landfills/Disposal Areas - 10013

Vincent Adams[*], Dinesh C. Gupta[*], Craig H. Benson[**], and John S. Smegal[***]
[*] U.S. Department of Energy, Washington, D.C. 20585
[**] University of Wisconsin, Madison, WI 53706
[***] Legin Group, Inc., Germantown, MD 20874

ABSTRACT

This paper identifies applied research and technology development intended to resolve many key issues affecting current and future low-level radioactive waste (LLRW) on-site disposal facilities (OSDFs) across the U.S. Department of Energy (DOE) complex. Over the past two years, DOE sponsored a team of experts to provide an independent technical review of DOE LLRW and mixed waste (MW) disposal operations to ensure that applicable complex-wide lessons learned from its waste disposal operations are implemented effectively at all DOE waste management sites. The team's efforts culminated in a workshop held in October 2008 that was attended by technical leadership within DOE, National Laboratories, the disposal industry, and academia. A key outcome of this workshop was a broad-based consensus on a set of technical issues that should be addressed as DOE embarks on designing and constructing its next generation of landfills.

Four key topics were identified for applied research and technology development through independent technical reviews of DOE operations and from a collective discussion at the October 2008 landfill workshop: 1. Radionuclide Transport in Engineered Barriers, 2. Life Span of Engineered Barriers, 3. Long-Term Mechanical Behavior of DOE Waste Forms, and 4. Evolutionary Final Covers of On-site Disposal Facilities. All these issues are important to multiple sites in the DOE complex, and to DOE stakeholders such as regulators and community groups. Tackling theses and other evolving technology issues will permit development of cost-effective solutions to some of the key technical issues, avoid potential future problems in meeting performance objectives, and ensure near and long-term safe waste disposal at DOE sites.

INTRODUCTION

The U.S. DOE owns and operates a collection of OSDFs used to permanently store solid wastes generated from decommissioning of infrastructure associated with historical activities in the weapons complex. Wastes stored in these facilities typically include contaminated soils and building debris containing radionuclides or other constituents traditionally requiring waste containment in an engineered disposal facility. These wastes include low-level radioactive wastes, hazardous wastes, mixed wastes, or Toxic Substances Control Act wastes.

DOE is presently undertaking and/or planning large decontamination and decommissioning (D&D) efforts at numerous sites. Large volumes of LLRW and mixed wastes (MW) will be generated as a result of these activities. One cost-effective way to manage these wastes will be to dispose it in highly-engineered DOE operated containment facilities, or landfills, that provide long-term protection of human health and the environment. DOE Order 435.1 requires that all such on-site disposal facilities be designed and operated to ensure that radiation exposure to the public is acceptable for at least 1,000 years following closure of the facility. Designing, constructing, and monitoring these facilities to function and meet performance objectives for at least 1,000 years is a formidable engineering challenge. In contrast, municipal and hazardous waste landfills are only required to meet a 30 to 40 year post-closure care period.

There remains a high level of uncertainty with projecting performance of waste disposal facilities for at least 1,000 years. A recent National Research Council (NRC) Report [1] concluded that, “most engineered waste containment barrier systems that have been designed, constructed, operated, and maintained in accordance with current statutory regulations and requirements have thus far provided environmental protection at or above specified levels.” However, the report also stated that although extrapolations of long-term performance can be made from existing data and models, such extrapolations will have “high uncertainties until field data are accumulated for longer periods, perhaps 100 years or more.” In view of the large uncertainties due to availability of limited field data over a relatively short duration and with models and theoretical results, there is a set of technical issues that should be addressed using advanced research and development.

APPROACH FOR IDENTIFYING TECHNOLOGY DEVELOPMENT OPPORTUNITIES

Between March 2007 and October 2008, DOE conducted technical and management reviews of selected LLRW disposal operations at its facilities. The reviews were conducted by an independent technical review (ITR) team (Craig H. Benson – University of Wisconsin, William H. Albright – Desert Research Institute, David P. Ray – US Army Corps of Engineers, and John Smegal – Legin Group) who were supported in their efforts by DOE and contractor staff at headquarters and across the DOE complex. The reviews were conducted of existing and proposed operations at Hanford, Idaho, Oak Ridge, Portsmouth, Paducah, the Nevada Test Site, and the Savannah River Site [2-8]. The facilities reviewed by the ITR team were exceptionally diverse, located in arid and wet climates, influenced by different geological and hydrogeological conditions, and existing in various stages of development –

from conceptual design to fully operational. The goal of the reviews was to provide an independent perspective on the disposal operations that could identify factors that might hinder the achievement of long-term performance goals or improve the effectiveness of operations. The team considered technical, regulatory, and management issues, and attempted to provide advice and recommendations helpful to DOE sites and HQ.

The reviews resulted in many lessons learned applicable to complex-wide waste-disposal facility performance and also concluded that DOE needs to undertake further research in several areas [9]. The need for applied research in this area was further emphasized by NRC in a February 2008 report [10]. The report concluded that, "The long-term performance of trench caps, liners, and reactive barriers cannot be assessed with current knowledge." This report also identified future DOE research and development approaches that have promise for providing better insights into solving technical issues.

In October 2008, the ITR team's efforts culminated in a landfill/disposal facility technology development workshop that brought together a wide range of experts – both practitioners and theorists – in the waste containment field. Attendees included representatives from academia, DOE sites and HQ, other federal agencies, as well as the private sector. The intent of the workshop was to discuss the key technological issues and to identify future research and technological development opportunities. The workshop recommendations covered a wide range of issues. A key outcome of this workshop was a broad-based consensus on technical issues to be addressed as DOE designs and constructs its next generation of landfills. Four key topics identified for applied research and technology development were: 1. Radionuclide Transport in Engineered Barriers, 2. Life Span of Engineered Barriers, 3. Long-Term Mechanical Behavior of DOE Waste Forms, and 4. Evolutionary Final Covers of On-site Disposal Facilities.

APPLIED RESEARCH NEEDS

DOE's Office of Environmental Management (EM), Office of Technology Innovation and Development has an ongoing research and development program. To achieve maximum value for its research funding, the program prioritizes its needs, utilizes sound project management practices, addresses high-risk areas to reduce technical uncertainties, and tracks progress of its research results using disciplined performance measures [11]. As shown on Table I, the current EM activities pertaining to DOE landfills/LLW disposal areas include development of advanced computational schemes to perform more robust performance assessments and study reactive transport behavior to develop advanced analytical approaches for predicting long-term performance of landfills/disposal areas. The identified gaps and the technology needs in the landfill/LLW disposal areas are discussed below. A significant impact can be made by bridging these technology gaps through development of innovative technical approaches and/or through improved understanding of the processes affecting near-term and long-term performance.

Table I. Identification of Technology Gaps

<table>
<tr><td colspan="4">Rationale for Identification of Technology Gaps: The long-term performance of covers, liners, and reactive barriers for DOE landfills/LLW disposal area trenches designed to contain waste and prevent contamination of groundwater for 1,000 years cannot be predicted with high confidence using the current state of knowledge.</td></tr>
<tr><td colspan="4">Desired Outcomes: Robust technology available to incorporate modeling and data uncertainty. Performance assessment techniques reliably account for natural, spatial and temporal changes together with field data to calibrate models. Scientific bases available to identify unacceptable barrier behavior as a function of time.</td></tr>
<tr><th></th><th>Basic Research</th><th>Applied Research</th><th>Implementation at DOE Sites</th></tr>
<tr><th>Current Activities</th><td>• Develop advanced computational schemes to perform more robust Performance Assessments.
• Study reactive transport behavior to develop advanced analytical approaches for predicting long-term performance of landfills/disposal areas.</td><td>• Conduct External Technical Reviews of complex-wide landfill/disposal area design and operations.
• Participate in Technical Forum/workshop discussions with experts to identify perspective of landfill experts.
• Develop lessons learned from siting, design, operations, and monitoring of landfills around the complex.
• Prioritize technology gaps and leverage research and development opportunities.</td><td>• Implement recommendations from HQ External Technical Reviews.
• Upgrade current procedures to dispose of waste and monitor landfill operations.
• Conduct sensitivity analyses to account for data uncertainty in performance assessments.</td></tr>
<tr><th>Remaining Gaps</th><td>• Characterize transport properties of radionuclides in barrier materials.
• Evaluate time-dependence of engineering properties of cover and liner system components, and develop tools to incorporate temporal changes in predictions.</td><td>• Develop understanding of transport processes that delay or reduce the flux of radionuclides from OSDFs.
• Understand the service life of engineered barriers relative to the half-life of long-lived radionuclides.
• Develop techniques to evaluate compression due to mechanical creep, biological degradation, of organic matter, and corrosion of metallic elements.
• Study alternative methodology for cover design employing an evolutionary cover where cover is modified or re-constructed in a series of steps at key points along the timeline of OSDF.</td><td>• Provide monitoring systems to reduce uncertainty related to long-term performance of engineered controls.
• Evaluate development and performance of evapotranspirative (ET) barriers.
• Explore design strategy involving perpetual periodic replacement of covers.</td></tr>
</table>

Transport of Non-Traditional Contaminants in Engineered Barriers – The contribution of the engineered barriers to the performance of DOE landfills needs to be evaluated on a case-by-case basis in accordance with the appropriate regulatory and technical requirements. A formal decision framework is considered to be useful to assess various circumstances, e.g., meeting a performance goal, enhancing engineered barrier performance, addressing perception of risk, and improving the ability to monitor performance. A long track record of engineered barriers performance now exists, and shows that modern engineered barriers are very effective in controlling the discharge of liquids and the migration of contaminants. Because a large fraction of DOE waste in landfills consists of LLW and MW, the design of the engineered barriers needs to take into account the radionuclide transport in engineered barriers. However, the transport behavior of radionuclides and other non-traditional contaminants (e.g., mercury) in engineered barriers and other elements of containment systems is not well understood. There is a need to conduct studies to define the transport properties of barrier materials in LLRW environments using bench-scale and field-scale testing and to develop innovative barrier materials that can retard the movement of non-traditional contaminants. These tests can develop additional information to demonstrate attenuation capability of modern engineered barrier materials and understand the attenuation capability of the barriers to be used during performance assessments.

At DOE sites, very conservative assumptions are used for performance assessments despite the fact that sophisticated state-of-the-art engineered barrier systems are being used at many sites. For example, transport processes that delay or reduce the flux of radionuclides from OSDFs currently are not considered in performance assessments due to the absence of data regarding the transport behavior of radionuclides in engineered barriers. Understanding these processes and quantifying their impact on barrier performance would permit DOE to design more cost-effective and protective OSDFs, as well as provide greater flexibility on siting locations for new OSDFs.

Life Span of Engineered Barriers – The design of engineered barriers for landfills must consider the time period over which the performance objectives have to be met. For example, designing engineered barriers for municipal waste landfills for a 30-year post-closure time period is relatively straightforward. For municipal waste landfills, ensuring that the life span of the engineered barriers will be longer than the time period the waste contaminants remain hazardous is somewhat simpler and can be done with greater confidence. On the other hand, DOE landfills have to meet performance objectives for at least 1,000 years after closure. For these landfills, there is greater uncertainty regarding the life span of engineered barriers and the design has to consider potential degradation of the barriers with time.

Understanding the life span of engineered barriers is integral to an informed PA of an OSDF. Current practice in most PAs is to ignore the effectiveness of the barrier completely due to uncertainty regarding the service life of engineered barriers relative to the half-life of long-lived radionuclides. However, most liners used beneath OSDFs are likely to have an extremely long life-span that is comparable to geologic strata at depth. High overburden stress and isolation from the environment promote long-term effectiveness of the liners. Therefore, efficacy of liners for DOE wastes needs re-assessment. There is also a need to better define the life expectancy of barrier materials in LLRW environments, develop a comprehensive understanding of mechanisms that can degrade barriers and quantify life spans that can be expected. Natural analogs can be a great asset for validating life span predictions made from accelerated bench-scale tests.

Long-Term Mechanical Behavior of DOE Waste Forms – The majority of waste placed in DOE OSDFs is un-cemented and therefore compresses in response to mechanical creep, biological degradation of organic matter, and corrosion of metallic elements. Compression due to these processes is likely to occur non-uniformly in the waste mass over decades if not hundreds of years, and due to differential subsidence, may result in damage to final covers used for long-term waste isolation. Currently, most of the methods used to predict settlement are empirically based, although more sophisticated analyses using numerical models are conducted in some cases. In nearly all cases, input to empirical or numerical models used for prediction includes parameters estimated from information in the literature pertaining to other waste forms or materials, because data describing the compressibility of DOE-type wastes is scant. Techniques for reliably predicting settlement of soil-like and containerized waste forms, including parameters for design and performance prediction are currently not available.

Cover settlement is one of the common issues at all DOE sites. There needs to be a complex-wide applied research effort to evaluate settlement behavior of demolition and containerized wastes and its impacts on disposal facility performance. The scope of this research should augment previous work done by DOE in response to recommendations made by the Defense Nuclear Facilities Safety Board in the early 1990s [12, 13]. Potential strategies for addressing settlement (e.g., dynamic compaction, smaller cells) also need further evaluation. In addition, focused effort is needed to establish a program to collect, compile, analyze, interpret, and publish settlement data from DOE sites. Understanding the magnitude and rate of compression of waste forms is needed to inform DOE site personnel on optimal waste management and placement practices and for predicting the performance of OSDFs in PAs.

A study is also needed to determine the amount of differential settlement that covers can tolerate and to quantify settlement behavior of DOE wastes using large-scale laboratory testing, field observations, and inverse analysis. In particular, settlements induced by collapse of voids (e.g., containers or vessels) are the most problematic and difficult to predict, and require the greatest amount of attention for predicting impacts on cover behavior.

Evolutionary Final Covers for OSDFs – None of the facilities currently being constructed at DOE sites have fully installed final covers, and in many cases, the proposed covers have not progressed beyond the conceptual design phase. Nonetheless, it is envisioned that they will prove to be the most important engineering factor affecting the long-term performance of the waste disposal facility. The current paradigm for closure of OSDFs is to construct a final cover when filling is complete. These covers are intended to function effectively for at least 1,000 years. This paradigm results in an extremely uncertain design and overly complex cover systems intended to account for near-term processes (i.e., 100-200 years) such as settlement and landform development that can affect the integrity of the final cover. While RCRA/CERCLA regulated disposal systems have prescriptive requirements for final covers, DOE regulated systems establish performance objectives for disposal sites without specifying cover-specific requirements.

The performance of covers varies over time. Theses changes are related to the type of materials used to construct the cover and are difficult to predict with models a priori. The effectiveness of all covers is influenced by the presence and effectiveness of drainage layers above the barrier layer as well as biotic and abiotic interactions with the surrounding environment. DOE sites need to adopt a holistic ecological engineering approach to covers that includes traditional civil and geotechnical design along with the interaction of the cover with its surrounding environment. Another possible strategy would be to periodically assess and monitor the cover performance during the institutional control period and perform needed repairs or even replacement, as needed, to incorporate evolving technologies.

An evolutionary cover design would employ a cover that is modified or re-constructed in a series of steps at key points along the timeline of an OSDF. For example, simple and flexible cover systems consisting primarily of polymeric elements could be deployed for a few decades after closure when the waste mass is undergoing larger and less predictable compression. Surveillance of the facility during this period would also be more intense and the less robust flexible cover system would be monitored closely. Moderately flexible covers consisting of earthen and polymeric elements could be constructed after several decades when the rate and magnitude of settlements have diminished and monitoring is less intense. The ultimate long-term final cover would be constructed after one or two centuries when changes within the waste mass have ceased. An evaluation of this final cover strategy could consist of (i) predictive modeling and experimental design followed by (ii) prototype hydrological testing in the field at a DOE facility.

LEVERAGING STRATEGY

To have a successful and cost-effective applied research program, partnering and leveraging of technology development efforts with other relevant organizations will be required. As shown in Table II, other federal agencies, universities, regulators and private industry are exploring ideas for improving landfill design, performance and operations. Federal agencies, including Nuclear Regulatory Commission and Environmental Protection agency not only participate in research and development, but are also contributing funding. Cooperative research efforts and coordination of activities will be necessary to leverage programs and avoid duplication. A complementary research program will help foster a sound technology development program and meet the long-term performance objectives for DOE waste disposal facilities.

Table II. Leveraging Strategy

Research Program in Landfills/Disposal Area	NRC	EPA	MSE	Universities	CRESP	Regulators	Private Industry
Covers							
Life-span	●	●		▲	▲	▲	▲
Time-dependence	●	●		▲	▲	▲	▲
Monitoring	●	●		▲	▲	▲	▲
Waste Volume Forecasting							
Waste-form			▲	▲	▲	▲	▲
Staging			▲		▲	▲	▲
Prediction			▲	▲	▲	▲	▲
Liners							
Life-span	●	●		▲	▲	▲	▲
Source-term impact	●	●		▲	▲	▲	▲
Flux monitoring	●	●		▲	▲	▲	▲
Subsidence							
Monitoring	●	●		▲	▲	▲	▲
Impact assessment	●	●		▲	▲	▲	▲
Minimization	●	●		▲	▲	▲	▲

● Contributing Funds and Participating ▲ Participating

NRC – Nuclear Regulatory Commission; EPA – Environmental Protection Agency; MSE – MSE Technologies, Inc.; CRESP – The Consortium for Risk Evaluation with Stakeholder Participation.

CONCLUSIONS AND PATH FORWARD

All the issues identified in this paper are important to multiple sites in the DOE complex, and to DOE stakeholders such as regulators and community groups. Tackling theses and other evolving issues will permit development of cost-effective solutions to some of the key technical issues, avoid potential future problems in meeting performance objectives, and ensure near and long-term safe waste disposal at DOE sites.

The research and technology development needs for DOE facilities are likely to be phased using a prioritization process, so that sufficient resources can be allocated to issues that have the most potential for yielding optimal performance, disposal risk reduction and maximum value. As new technologies are advanced, operating procedures at DOE sites will benefit from internal and external reviews and updates on a regular basis so that operating procedures remain consistent with waste disposal needs and take full advantage of improvements in technology.

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