Summary of the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities - 11323

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ABSTRACT

On August 3 – 5, 2010, the U.S. Nuclear Regulatory Commission's Offices of *Nuclear Regulatory Research* and the *Federal and State Materials and Environmental Management Programs* hosted the *Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities*. The public workshop was organized and coordinated with the States (e.g., Texas, South Carolina, Utah, Colorado, Washington, and New York) and Federal Agencies (e.g., DOE, EPA, USGS, USDA/ARS and DOE National Laboratories).

The workshop facilitated communication among Federal and State regulators, contractors, and selected technical experts, on current engineered barrier issues and technical and regulatory experiences; lessons learned and new approaches to monitoring and modeling. Recommendations and insights have been compiled and were presented in a workshop summary The insights and recommendations from the workshop addressed (i) degradation processes affecting barrier components (e.g., geomembranes, compacted low-permeability soils, surface layer including biotope), (ii) direct and indirect monitoring of both short- and long-term performance processes, (iii) numerical modeling of engineered barrier systems and evaluation of performance monitoring, (iv) model support activities to provide confidence in model predictions for short- and long-term performance, (v) potential improvements to guidance, and (vi) knowledge gaps and future research needs. A formal workshop proceedings with detailed recommendations and insights along with extended abstracts of the presentations is in development.

INTRODUCTION

Recently, research from various organizations has raised technical questions regarding the assumptions and performance of engineered surface barriers. The need to discuss these technical issues was recognized by operators, regulators, and researchers of engineered barriers. Accordingly, the NRC convened a workshop on August 3-5, 2010 at its headquarters in Rockville, Maryland to provide a public forum to discuss issues related to the performance of engineered barriers. The workshop focused on engineered surface covers and bottom liners designed to isolate waste by impeding surface-water infiltration into the waste systems or by retarding the migration of contaminants from the waste disposal site. Session chairs organized technical topics which included: engineered barrier performance, modeling, monitoring, and regulatory experiences at low-level radioactive waste, decommissioning, and uranium mill tailings sites. Representatives from Federal and State regulatory agencies, contractors, technical experts, and concerned citizens shared their experiences, lessons learned, and latest scientific and engineer analysis findings. Workshop participants had the opportunity to comment on the presentations during the specially-convened panel discussions. The public was provided an opportunity to comment on the workshop issues at the end of each day. In addition to session summaries, insights and recommendations generated from the workshop are summarized in this paper.

SESSION 1a: Experience of the States in Regulating Facilities Involving Engineered Covers and Liners

by Stephen Salomon (NRC), Susan Jablonski (TCEQ, State of Texas), and Douglas Mandeville (NRC)

NRC Agreement States and the Navajo Nation have developed experience with the various technical and regulatory issues associated with engineered barriers at low-level radioactive waste, decommissioning, and uranium mill tailings sites. Representatives shared their experiences with engineering analyses of barrier designs, modeling, model verification; and monitoring programs. These activities are being utilized in support of licensing for demonstration of short- and long-term performance of engineered covers with monitoring and maintenance programs to provide feedback on cover performance and to help ensure ongoing barrier integrity.

Approaches to modeling and monitoring vary from site to site due to: site-specific conditions; regulations that vary between the States; differing waste and waste forms; and a range of design time periods. This site specific nature can create difficulty in maintaining a consistent and transparent approval process. Accordingly, Federal guidance and stakeholder communication are needed early in the process.

SESSION 1b: Federal Agencies and DOE National Laboratories

by Jacob Philip (NRC), Brian Andraski (USGS), and George Alexander (NRC)

Selected Federal agencies and several DOE National Laboratories were tasked to report and discuss their research activities and findings related to engineered cover performance. The presentations emphasized practical insights on modeling, monitoring and confirming the short and long-term performance of the engineered barriers systems. Research activities, which varied by agency as well as site, included laboratory and field studies to obtain barrier design parameters. Subsequently, hydrologic water balance codes were developed to evaluate potential effluent releases from the landfills. Model verification has been conducted by collecting and comparing leachate samples against pre-construction model predictions. This process of parameter determination or estimation, modeling, and performance confirmation is an iterative process which is systematically conducted by periodic reviews. Timely maintenance and repairs to engineered barriers have been performed as necessary.

The U.S. Environmental Protection Agency (EPA) is currently evaluating the performance history of Title I and Title II mill tailings sites against the standards as outlined in EPA regulations in the Code of Federal Regulations (CFR), specifically 40 CFR Part 192. These regulations are being reviewed for updating due to: changes in uranium industry technologies and practices; potential inputs to ground water; recent revisions in EPA drinking water protection standards; judicial decisions concerning the regulations, minimization of risks to the general public and environment; as well as potential inputs related to Tribes, environmental justice communities and children's health.

The U.S. Department of Energy (DOE), Office of Environmental Management (EM) presented DOE's perspective on performance assessment modeling, monitoring and performance confirmation. Reviews include probabilistic approaches for sensitivity and uncertainty analyses, and performance monitoring of a broad range of change indicators of performance of the facility at specific locations and time horizons.

The presenter for the DOE Office of Legacy Management (LM) discussed the long-term surveillance and maintenance of sites under UMTRCA and CERCLA. EPA regulations stated in 40CFR 192 sets forth standards for compliance with soil, air and ground water. Radon flux measurements are conducted during disposal cell construction and upon its completion, whereas ground water protection strategies require ground water monitoring and annual sampling at some sites at the point of compliance every year for 10 years, and once every 5 years thereafter.

Recommendations from Sessions 1a and 1b

- Federal guidance and stakeholder communication are needed early in the process.
- Knowledge, experience, materials, and public policy can change with time; flexibility to these changes can lead to improvements in barrier performance and can expedite the approval process.
- There is a large effort underway to improve understanding and performance of engineered covers. Often, these efforts are not coordinated and are limited to addressing specific needs at a particular site. Periodic meetings with a diverse group of technical experts can improve the efficiency for which data gaps are closed.
- Full cost accounting of long-term maintenance and monitoring is needed.
- The 100-year institutional control period for low level radioactive waste (LLW) may be inadequate. It may be necessary to continue some level of funding beyond the institutional control period.
- Post-construction performance monitoring is essential to substantiate model predictions.
- Water balance or evapotranspiration (ET) covers have shown potential in certain arid areas such as Colorado and Washington.
- Engineered barrier containment design covers in both humid and arid areas (New York, South Carolina and Utah) can be enhanced by geosynthetics but service life is dependent on material and construction quality, as well as, varying degradation mechanisms.
- Field-scale measurements for performance assessment parameter inputs are preferred. However, small-scale field measurements are likely to be relied upon and should account for temporal and spatial scaling.
- Deep vadose zone monitoring has been shown to be crucial for verifying the performance of waste facilities in both humid and arid environments.
- The use of sensitivity and uncertainty analyses should be continued to prioritize research needs.

SESSION 2: Degradation Processes and Performance Evolution of Engineered Barriers

by Craig Benson (University of Wisconsin), W. Jody Waugh (S.M. Stoller LLC), and Brooke Traynham (NRC)

The volume of water permeating through waste directly affects the potential flux of contaminants to the ground water. Accordingly, the significance of covers to site performance has promoted research studies, and the understanding of processes that affect the engineering behavior of earthen and geosynthetic layers in cover systems. Physical, biological, and chemical processes can induce changes in the structure and physical characteristics of cover materials. These degradation processes can affect barrier components (e.g., compacted soil layers, geomembranes, GCLs, drainage layers) and consequently, barrier performance.

Degradation processes include the following physical, biological, and chemical processes:

- Physical processes include freeze-thaw and wet-dry cycling, differential settlement, retention of borrow soil structure (peds or clods) during construction, UV degradation, thermal degradation, erosion, fire, and pedogenesis.

- Biological processes include root growth, burrowing animals, human intrusion, and microorganisms that can alter soil hydraulic properties.

- Chemical processes include oxidation of geosynthetic materials and cation exchange mechanisms in sodium bentonite clays.

The challenges of predicting cover performance in the context of the aforementioned degradation processes are: (i) the need to infer long-term conditions from short-term monitoring data; (ii) the difficulty in spatial and temporal scaling; (iii) understanding the non-linear interactions between cover components and degradation mechanisms; and (iv) unforeseen ecological consequences.

Strategies to reduce one degradation process may inadvertently impact other degradation processes; for example, activities that reduce erosion may unintentionally cause an increase in water percolation. Similarly, the current practice of using herbicides to control vegetation may actually be counter-productive to performance. Herbicide application may negate beneficial processes such as shrub establishment that would increase transpiration of infiltrating water, and soil development that would increase water storage. Hence, ecological succession and soil development may be a solution rather than a problem for water balance covers.

Although the knowledge base regarding changes in soil structure and hydraulic properties has advanced significantly, it only represents a small subset of the total evolution of covers. These advances have reduced uncertainty in performance assessments, but additional research investments are needed to more accurately and completely define very long-term properties of cover materials corresponding to hundreds or thousands of years.

Strategies can be enacted to reduce degradation processes; this requires an understanding not only of the degradation processes but also of the interactions and feedback mechanisms between individual components and these processes.

Recommendations

- Strategies for minimizing the negative impacts of degradation processes include: (i) identification of the risk-significant features, events, and processes including feedback mechanisms; (ii) construction quality assurance; and (iii) analysis of individual components with an understanding of the system as a whole.

- Attempts to minimize degradation processes may result in unintended consequences if the system as a whole is not adequately understood.

- The design and analysis of covers should appropriately account for the potential evolution of soil properties. Engineered systems that mimic favorable natural systems will degrade less rapidly, whereas larger and more rapid changes will occur in systems with greater deviation from the natural setting equilibrium.

- Future research should focus on: (i) using natural analogs to better understand and evaluate long-term degradation processes; (ii) designing covers that mimic the favorable attributes of selected natural analogs; , (iii) evaluating effects of subsidence on long-term cover performance; (iv) predicting and incorporating landform changes in cover and disposal cell designs; (v) accelerated laboratory experiments that can be used to develop predictive degradation models; and (vi) long-term monitoring of field site conditions and processes.

- Performance of current geomembranes appears promising (e.g., potential service life of hundreds of years). However, there is a paucity of relevant data related to the effect of low-level radioactive waste on the service life of geomembranes.

- Due to the fragility of geosynthetic materials, and the sensitivity of performance to material and emplacement defects, robust quality assurance and quality control programs are critical.

SESSION 3: Experience with Monitoring Devices and Systems Used to Measure Performance

by William Albright (Desert Research Institute/UNV), Craig Benson (University of Wisconsin) and Robert Johnson (NRC)

The simple objective of engineered barriers is to isolate waste from the environment; however, the strategy to ensure long-term isolation is more ambiguous. Monitoring of engineered cover barriers has typically focused on elevation surveys (i.e., to detect differential settlement) and ground water monitoring at the site boundary limits. These monitoring techniques provide important information regarding site stability and the integration of cover performance over the entirety of the system. However, close-in direct monitoring of the containment structure can provide early indication of changes in cover components and direct understanding of the processes that affect performance. Monitoring of percolation through the cover should be supplemented by additional data to understand deeper subsurface processes and changes in the components of the containment structure.

Historically, the connection between monitoring and modeling has been tenuous. Predictions are hampered by data limitations with respect to spatial and temporal distributions, as well as, processes relevant to system performance. Conversely, monitoring programs have often been uninformed by modeling. Monitoring and modeling should be an iterative process. Modeling can focus monitoring by identifying key processes and parameters or disconnects between field observations and the model. The results of monitoring provide feedback to refine models and improve the understanding of the system. Although technology exists to monitor almost all of the cover components, cost limitations dictate that monitoring be risk-informed by focusing on key elements.

Recommendations

- Direct monitoring techniques are generally favored over indirect measurements such as perimeter ground water monitoring. Direct monitoring provides early indication of performance and understanding of the specific processes that affect performance.

- Additional monitoring research would provide added confidence in the performance of engineered barriers by reducing existing data gaps and the resultant uncertainty. Furthermore, overly conservative parameterization due to uncertainty could be minimized.

- Methods to scale point samples, laboratory experiments, and lysimeter monitoring data to the field scale would improve understanding of overall system performance.

- Consideration should be given on how uncertainty in monitoring data is propagated through the performance assessment.

- Monitoring of flow and transport in the vadose zone within and beneath the emplaced waste should be considered in the development of a monitoring plan.

- Soil and ground water samples should include split samples and a documented chain of custody.

- Remote sensing can be utilized to assess environmental conditions indicative of performance e.g., vegetative cover and differential settlement.

- Ecological processes such as re-vegetation and plant succession should be monitored if they are significant to cover performance.

- Differential settlement and human intrusion can significantly impact performance and may warrant monitoring.

SESSION 4: Modeling Experiences in Performance Assessment and Evaluation of Performance Monitoring

by Thomas Nicholson (NRC), David Esh (NRC), and Chris Grossman (NRC)

Because of the extended timeframes involved with isolating radioactive materials from the environment, the future performance of engineered barriers (e.g. engineered covers and liners) must be estimated in prospective performance assessments of waste disposal and other similar systems. Modeling is a commonly employed tool to estimate future performance. Modeling results may be verified through performance monitoring. Without adequate guidance, modeling may be completed using inconsistent or disparate approaches. For example, analytical or numerical models are dependent upon the adequacy of the conceptual site model assumptions; parameter estimation methods to relate site-specific processes and conditions to model inputs at the appropriate temporal-spatial scale; and scenario development for current and future states.

Numerical modeling has experienced increased acceptance in the facilitation of decision-making, especially with regard to long-term waste management decisions. Increasingly more complex models and their more complex problem definitions are being assessed with numerical models. Modelers are faced with a variety of decisions, but guidance to help facilitate that decision-making is distributed over a very large number of information sources.

Workshop participants provided valuable insights and experiences with respect to the modeling of surface barriers and waste disposal liners. For waste disposal systems, integration of conceptual, biological, hydrologic and geochemical processes in modeling is essential because these processes are integrated in the real world. Influence diagrams and conceptual drawings can be useful in refining the scope of modeling. Graded (or hierarchical) and iterative approaches, common to performance assessments, have been found to be useful in the modeling of engineered covers and liners. Processes determining cover performance can be non-linear and typically their uncertainty is large, especially for longer-term assessments. Therefore, integration is extremely important and cover modeling needs to take into account the uncertainty in performance predictions.

Model completeness is difficult to assess. At a minimum, models must include water flow and transport, soil loss by erosion, surface-water runoff, and bioturbation by animals and plants. Model validation can be useful to assess the completeness of models, however most models have limited validation. Model calibration assessments are frequently implemented, but validation studies are rather infrequent. Inter-code comparisons may be useful in understanding code limitations. Probabilistic modeling has been found to be useful to incorporate uncertainties, and to identify high and low performance conditions.

Field data should be collected to confirm as-built properties and confirm post-closure performance. Site characterization data and design information are generally available to parameterize the models, although information is somewhat lacking for some geochemical modeling and biotic transport processes. Although data is generally available, much information must be site-specific and high-frequency site-specific information is the exception rather than the rule. High resolution data may be obtained from thermal infrared sensing and other similar techniques.

Long-time frames are very difficult to account for in modeling of engineered covers and liners. Participants identified processes, especially hydrologic, that require high frequency data (e.g. daily or hourly) in order to capture observed events and their responses (e.g., wetting front advances). In addition, simulations of long-term performance must incorporate a variety of potential degradation mechanisms such as extreme weather events, freeze-thaw cycling, fire, and biointrusion. Modeling coupled processes with substantially different response times can be computationally and intellectually challenging, but progress is being made.

Ecological modeling has been progressing, and is a very important component to assessing the performance of engineered covers. Roots penetrate natural barriers, and plant succession occurs everywhere. Two common aspects of the succession are an increase in vegetation structure and an increase in the relative amounts of woody plants. Both of these aspects have profound implications to the function of engineered barriers. Ecological modeling needs to consider a variety of processes, such as, but not limited to, wind throw of trees causing overturning of roots, changes to soil microbial communities, and variation of erosion rates with vegetation cover. Of primary importance are the life forms and species of plants, animals, and their impacts on the characteristics of the materials overlying the barrier. Model scenarios need to capture these changing conditions and ecological system development over anticipated time periods.

It is important to collect monitoring and performance validation information, and to couple that information with the modeling activities. Sometimes performance indicators can be identified through the iterative performance assessment approach, and those performance indicators can be measured in the monitoring program.

Recommendations

- A graded and iterative approach to modeling of engineered covers and liners should be used. In many cases, data is collected during and after engineered barrier implementation. That data is useful to refine and improve the models.

- System-level modeling, rather than the summation of isolated components, may create a more accurate representation of the processes and their couplings even if it means abstracted, or simplified, representations are used.

- Engineered cover and liner performance modeling must appropriately integrate and couple processes. Many near-surface processes (e.g., hydrology, erosion, and plant succession) are tightly coupled, and elimination of those couplings may result in incomplete or inadequate conceptual models and their numerical models.

- Conceptual, parameter, and scenario uncertainties should be assessed in light of alternative conceptual models including features, events and processes that can affect long-term performance.

- The creation of compilations of relevant data would improve modeling and realize economies in parameter estimation to reduce over parameterization of models for engineered covers and liners performance assessments.

- Model validation is essential, and should be a necessary step in performing modeling of engineered covers and liners.

SESSION 5: Experience with Model Support and Multiple Lines of Evidence to Gain Confidence in Long-Term Performance

by Hans Arlt (NRC), George Alexander (NRC) and Brooke Traynham (NRC)

Model support is a critical element in the application of engineered barriers to limit risk from low-level radioactive waste disposal facilities, decommissioning sites, and uranium mill tailings facilities. Many engineered barriers are not amenable to model validation in the true sense, therefore model support is expected. The use of multiple lines of evidence provides confidence that the projected future performance of the system will reasonably approximate actual future environmental conditions.

Multiple lines of evidence are recommended since in many cases the supporting information will not be direct observation of the output metrics of concern, but rather will likely be indirect observations of intermediate metrics. Use of multiple lines of evidence should reduce the likelihood of errors associated with interpretation of incomplete and inferential information. Types of model support include: analogs, laboratory experiments, field experiments, formal and informal expert judgment, engineering calculations to demonstrate reasonableness of the results (e.g. hand calculations when numerical models are used), alternative model calculations, monitoring data, and comparison to the impacts from past activities such as paleofloods, and other geologic evidence of ancient events.

Common principles and good practices that should be considered when developing model support for the use of engineered barriers include:

• Multiple lines of evidence are preferred.

• Direct observations are preferred over indirect observations.

• The level of model support should be commensurate with the risk significance.

• Model support for barriers with a longer experience base can be more limited.

• For very long-term performance, natural analogs should be considered.

• Support should encompass the full range of expected future boundary and exposure conditions.

Model support is specific to the barrier component due to differences in component functions, materials, and the relevant time intervals for which they pertain. The near-term performance of engineered barriers often relies on geosynthetic materials. These materials can provide a substantial reduction in infiltration; however, their performance and longevity is dependent on degradation process which includes: exposure to ultraviolet light, radiation, oxidation, elevated temperatures, and system stresses. The use of laboratory and field experiments coupled with monitoring data can provide confidence for model predictions.

In the long term, the ecology of a cover system will change in ways that cannot be accurately predicted by models alone. However, analogs can provide tangible evidence linking the potential evolution of an engineered ecosystem from the influence of the surrounding environment. Side slope stability can be examined with an ancient hill analog or glacial debris flow (long-term erosion protection). Shifts in plant abundance provide information on how precipitation and temperature may have changed over time. Furthermore, chronosequences can provide evidence for the recovery of an ecosystem after a fire, the effects of climate change, and the natural evolution of soils.

The modern landscape provides a record of soil evolution pathways that can support long term assessments of covers. Soil development is a function of parent material, topography, biology, climate and time; these pedogenic processes affect hydraulic processes and plant communities at various scales, both spatially and temporally. Pedogenesis for a compacted clay, or engineered silt loam will likely evolve much faster than natural environments, which exist in closer proximity to equilibrium. Soils transition from micropore dominated soils to a system of macropores as a function of both biotic and abiotic processes e.g., root growth, faunal burrowing, nutrient cycling, and resource translocation. These processes dictate the hydraulic properties of the soils.

Recommendations

- Decisions often have to be made with incomplete information, but model support can provide confidence that the projected future performance of the system will reasonably approximate actual future environmental conditions performance.

- Model support should continue after licensing to improve confidence in the system performance. Re-evaluation should occur every 5 to 10 years to ensure that design and construction information and as-built properties and conditions match monitored performance indicators. If there are significant changes, re-analysis of the engineered system is warranted for possible remediation.

- Model support should be risk-informed, site-specific, and able to evolve with different stages of the project.

- Strategies should be developed and implemented to obtain and evaluate information needed to support both short- and long-term modeling results.

- Develop a “Catalogue of Natural Analogs” for different climatic and environmental settings throughout the United States.

- Analogs can assist in cover design, as well as, prediction of cover properties and environmental conditions over time. By characterizing and evaluating natural ecosystems, systems can be imitated (ecosystem engineering) to produce favorable conditions such as high rates of evapotranspiration and reduced deep percolation.

- Soil development will be a function of climate, parent material, topography, biology, and time. Pedogenic features will affect hydraulic properties and evolution of plant communities at various scales, both spatially and temporally. The assessable natural landscapes provide a record of soil evolution pathways that can support long-term assessments of covers.

- Independent reviews can be a useful tool to envision future environmental conditions, augment limited conceptualizations, consider alternative conceptual models and address uncertainties.

- A gap currently exists in the communication between model developers and those who provide model support. These communications should be formalized (e.g., model abstraction strategies) and documented in the QA/QC program.

SESSION 6: Recommendations on Assessing Engineered Barrier Performance, Identifying Future Research Needs, and Discussing Existing Guidance

by Thomas Nicholson (NRC), Hans Arlt (NRC), Mark Fuhrmann (NRC), and Allen Gross (NRC)

Overarching comments and recommendations from the workshop were discussed and compiled in Session 6, which included:

- The properties of cover systems change more rapidly than originally anticipated (with the exception of geomembranes where the longevity of these components may have been conservatively estimated in earlier research). The alteration or evolution of covers can lead to a natural transition from an infiltration-resistive cover to an evapotranspiration cover.

- There were no urgent problems identified with engineered surface covers at Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) sites; however, uranium mill tailings sites may need monitoring in the cover, tailings, and below the tailings so there is more of a system approach. Without this monitoring, evaluation of actual performance is uncertain.

- General consensus of a total systems approach to integrated monitoring and modeling programs. Engineered covers and liners should not be looked at in isolation from the overall waste disposal system. A graded and iterative approach should be used to identify significant processes and components requiring further detailed modeling and/or monitoring. Performance indicators common to both models and monitoring programs would greatly improve performance assessments.

- The level of monitoring and model support should be site-specific, risk-informed and performance-based.

- The function of each cover component (e.g., plants) should be clearly identified and evaluated to diminish the risk of unintended consequences. The level of engineering design should be aligned with the level of risk, the costs of monitoring, the cost of cleanup, and the total system performance.

- General consensus that groups (e.g., engineers, hydrologists, ecologists, modelers) involved with engineered barrier performance need to formalize communication and interact more frequently to coordinate performance assessments.

- A common data repository would be highly advantageous for assessing current and future information on engineered barrier performance. This proposed data repository could be a multi-agency effort with ongoing maintenance. This repository could facilitate education and development of integrated environmental models.

- Updated guidance is needed on covers, liners, and construction techniques that incorporate new knowledge and techniques. This guidance should be flexible and allow for changes in knowledge, experience, and techniques over time.

CONCLUSIONS

The long-term performance of engineered barriers is subject to significant uncertainties. Yet these challenges are often critical in meeting regulatory compliance criteria. Understanding of the performance of engineered barriers has increased substantially due to recent research studies involving post audits and exhumations of engineered cover systems, and detailed analyses of experiences in cover design, modeling, model support, construction, monitoring, and maintenance. These studies and experiences have highlighted the need to formulate integrated monitoring and modeling programs, and for additional research, as well as the importance of a community of practice. A summary of presentations, significant insights, and recommendations will be posted on the NRC Public Website as a NUREG/CP, tentatively scheduled for April 2011. In addition, the meeting summary, links to the presentations, and the transcripts for the different sessions are located on the NRC public website[1].

[1] http://www.nrc.gov/about-nrc/regulatory/decommissioning/public-meetings/materials2010.html