Approaches to Consider Covers and Liners in a Low-Level Waste Disposal Facility Performance Assessment - 15300

Roger Seitz[*], Mark Phifer[*], and Linda Suttora[**]
[*]Savannah River National Laboratory, Savannah River Site, Bldg 773-43A, Aiken, SC 29808
[**]Department of Energy, Office of Environmental Management, 19901 Germantown Road, Germantown, MD 20874-1290

ABSTRACT

On-site disposal cells are in use and being considered at several USDOE sites as the final disposition for large amounts of waste associated with cleanup of contaminated areas and facilities. These disposal cells are typically regulated by States and/or the USEPA in addition to having to comply with requirements in DOE Order 435.1, Radioactive Waste Management. The USDOE-EM Office of Site Restoration formed a working group to foster improved communication and sharing of information for personnel associated with these Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) disposal cells and work towards more consistent assumptions, as appropriate, for technical and policy considerations related to performance and risk assessments in support of a Record of Decision and Disposal Authorization Statement. One task completed by the working group addressed approaches for considering the performance of covers and liners/leachate collections systems in the context of a performance assessment (PA).

A document has been prepared which provides recommendations for a general approach to address covers and liners/leachate collection systems in a PA and how to integrate assessments with defense-in-depth considerations such as design, operations and waste acceptance criteria to address uncertainties. Specific information and references are provided for details needed to address the evolution of individual components of cover and liner/leachate collection systems. This information is then synthesized into recommendations for best practices for cover and liner system design and examples of approaches to address the performance of covers and liners as part of a performance assessment of the disposal system.

INTRODUCTION

The USDOE manages numerous waste disposal facilities, for example:

- Uranium Mill Tailings Remedial Action (UMTRA) facilities,
- Low-level waste (LLW) disposal facilities,
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) disposal facilities, and
- Solid waste (Subtitle D) facilities.

All of these facilities have or will have some type of cover over the buried waste. For some facilities the covers will include high density polyethylene (HDPE) liners, geosynthetic clay layers (GCL), and/or compacted clay layers (CCL). Other covers are based on more simplified designs. Regulations specific to the waste type being disposed and local site conditions drive the design requirements of a particular facility.

In the cases of LLW disposal under DOE Order 435.1, there are no prescribed cover design requirements beyond being compatible with the waste and based on DOE Order 435.1 performance assessments. Engineered structures (vaults) and waste forms can also be used to provide additional barriers. Liner and leachate collection systems are also required to be included in many facilities that are typically engineered to meet prescriptive Resource Conservation and Recovery Act (RCRA) Subtitle C requirements specific to disposal of wastes containing hazardous constituents. Liner and leachate collection systems are not specifically required for DOE LLW that is deemed to not meet the definition of mixed waste. There can be substantial uncertainties associated with the effective life of these design features, which introduces challenges when trying to assess the long-term performance of disposal facilities.

Recent efforts to develop PAs for lined disposal facilities have highlighted the need for a more common approach to address the performance and evolution[a] of cover and liner systems. There can be a range of expectations and perspectives regarding approaches to address long-term performance of cover and liner systems from different regulators. Additionally the extent to which the evolution of cover and liner systems is taken into account and justified within PAs depends upon the extent to which credit must be taken for the performance of the cover and liner system within the PA. The need to justify and take into account cover and liner system evolution generally diminishes as the cover and liner system become a defense-in-depth component for which little credit is given within the PA relative to reducing contaminant release out of the disposal facility (a caveat must be made for potential counter-intuitive results discussed in *Timing Considerations for Covers, Liners and System Performance* below).

A report [1] was prepared including suggestions for a strategy and approach that can be considered to develop the basis for assumptions for these assessments and how to integrate assessments with defense-in-depth considerations such as design, operations and waste acceptance criteria to address uncertainties. This paper is a summary of that report. Specific information and references are provided for details needed to address the evolution of individual components of cover and liner systems. This information is then synthesized into suggestions for cover and liner system design and examples of approaches to address the performance of covers and liners as part of a PA of the disposal system.

STRATEGIC CONSIDERATIONS

Each facility and disposal site will have unique characteristics that influence how a PA is implemented. Long-term performance of covers and liners involves significant uncertainty that needs to be managed differently in the specific context of each disposal facility. Effective management of uncertainties involves integration of design, assessment, waste acceptance criteria, stakeholder engagement, etc. Stakeholder interests and the hazards posed by the waste to be disposed have an important influence on the approach and focus of efforts for a given facility. These considerations lead to the need for a process or strategy to efficiently implement the assessments rather than simply laying out a computational approach that will be applicable for all cases. It is also generally suggested to avoid the use of worst case type assumptions or, if such assumptions are used, to do so cautiously and clearly document those assumptions including a discussion of expected performance. The intent is to place the assumptions in perspective.

Given that the goal is to demonstrate that results are below a regulatory performance objective rather than predicting exactly what will occur, a graded and iterative approach is generally applied to implement a PA. Another way of thinking is an emphasis on determining what you need and don’t need to take credit for in the context of efficiently and defensibly demonstrating compliance. Application of such an approach needs to be conducted in a thoughtful manner balancing a desire for increased realism with the need to efficiently make a decision. It is important to recognize when simplification or over-conservatism

[a] Terms such as “evolution” and “alteration” were discussed at the NRC Workshop on Engineered Barrier Performance to reflect that over time there are processes that can degrade or improve the performance of cover and liner components [2]. “Evolution” is used generally used in this paper to address potential degradation or improvement of performance over time.

may adversely impact a decision or lead to unnecessary design measures or disposal limitations that would not be necessary if more realistic assumptions were made.

From a practical perspective, given the uncertainties involved, there can be a significant burden to take credit for long-term performance of individual components of cover and liner systems. To this end, this report provides a strategy that focuses on describing and understanding the behavior of the total system, especially focused on determining those aspects of the system that have a significant influence on performance. Detailed information is provided to assist with considering long-term evolution of individual components in those cases where it is deemed important to address performance in greater detail.

Graded and Iterative Approach

The graded approach involves starting with initial screening analyses to identify unimportant aspects and to focus efforts on the aspects that have the most significant influence on the results. The first step is development of an initial conceptualization of the total disposal system based on available information. The total system includes covers, waste and backfill, liner systems, and the natural environment. The waste can also include barriers such as the waste form or containers that may need to be considered. The importance of maintaining a total systems performance perspective and being able to understand and describe the interrelationship among the different layers is reinforced throughout this report. As the analysis evolves, the initial conceptual model is refined in areas that are determined based on initial modeling to have a significant impact on the ability to meet the performance requirements. This focused refinement is a key for the graded and iterative approach.

Implementation of the graded and iterative approach is driven to a large extent by the source term in the facility. The source term represents the inherent risk associated with what is placed in a disposal facility and the level of effort required for a PA is typically correlated with the level of risk associated with the waste being disposed and the local site conditions. Initial screening calculations will typically focus on narrowing the list of waste forms and radionuclides that need to be addressed in detail. Relatively simple screening calculations can generally be used to reduce the scope of the modeling effort to focus on a short list of longer-lived and more mobile radionuclides prior to detailed consideration of the role of engineered features. If the concentrations of longer-lived radionuclides are relatively low and the site conditions are favorable, a PA may be able to be completed using relatively simple approaches that only require consideration of short-term performance of engineered features that can be easily defended. For example, in some cases, it can be assumed that engineered features fail at the end of active institutional controls and the performance objectives can be met. However, the report identifies a caution about the potential to miss peak impacts by not taking credit for the expected lifetime for a liner system. This is an example of the need to describe the expected performance when making simplifying assumptions and to consider whether or not the assumption can be defended as being conservative relative to expected performance.

In cases where the concentrations of longer-lived radionuclides may be higher and/or site conditions are not as favorable, it can become necessary to add detail to address the longer-term evolution of cover and liner systems and waste forms/containers. The focus of the more detailed assessment then transitions to consideration of how engineered features impact: 1) the timing of when releases of the longer-lived radionuclides can occur, and 2) the rate at which releases can occur. The intent of the PA process in this case is to identify and focus efforts on those features that have a strong influence on performance. This report provides information to support more detailed consideration of performance of individual components in cover and liner systems. While the presence of longer-lived radionuclides may drive the need to address the longer-term evolution of the cover and liner systems, highly mobile, short-lived radionuclides may also be a significant consideration relative to the projected compliance with the standards particularly relative to the initial design.

Experience has shown that assessments cannot always adequately resolve all of the uncertainties associated with long term performance of a disposal facility. As discussed above, in order to address areas where the uncertainties are difficult to resolve using more in-depth assessment, the assessment strategy can work in tandem with the use of defense-in-depth, including operations and design principles to mitigate potential issues and waste acceptance criteria to limit what can be disposed. Monitoring and institutional controls can also be highlighted as features to help build confidence. The approach described in this report also involves suggestions for presenting information to stakeholders to explain how the disposal system functions and the multiple layers of defense to provide the level of protection that is needed.

Stakeholder Engagement

The approach for addressing long-term performance of cover and liner systems in a PA needs to be determined on a case-by-case basis through negotiation and/or technical reviews with the appropriate regulators, typically DOE (LFRG), EPA and the State regulator. This is appropriate because each liner and cover system is designed and assessed individually in the context of the climate, hydrogeology, waste and current technical standards at the time of construction. Early discussions with the regulator and other stakeholders should seek to understand specific concerns and interests relative to long-term performance.

Inevitably, there will be comparisons between assumptions being made at one facility relative to assumptions made at other facilities across the DOE complex. This is the reason for the need to document the assumptions made for the purposes of a PA versus what would actually be expected (e.g., identify and clearly document assumptions that are intended to over-predict releases). While reference to the negotiated credit applied to other facilities may be made, the inherent uncertainties associated with site and facility specific effects on long-term performance must be recognized. Likewise, it must be realized that the knowledge base to support assumptions regarding liner and cover performance increases with time and that different regulators approach the issue with different interests and concerns. Thus, although assumptions made at other sites may provide a point of comparison, often there are site-and facility-specific considerations that limit the utility of assumptions from one facility at another facility.

Care must be taken to clearly identify assumptions believed to over predict consequences (e.g., higher infiltration rate through a cover than expected, early failure of liners) and to place any negotiated scenarios in context of how the scenarios relate to performance that would typically be expected. This can be viewed in the context of defense-in-depth. Such documentation can be used to provide proper context relative to comparisons that may be made and to support conducting additional cases, where it is desirable to provide a more realistic representation.

Timing Considerations for Covers, Liners and System Performance

PAs conducted to date have identified some common concerns related to timing assumptions for failure of covers and liners in the context of a demonstration of compliance. It is important to develop an understanding of the significance of the relative timing of assumptions for the loss of performance for cover and liner systems. Two examples of timing related concerns are:

1) If too much credit is taken for cover and liner performance, peak impacts can be artificially delayed beyond the 1,000 year compliance time, and

2) If the liner system is assumed to fail early allowing early releases to the environment, the assessment could be portrayed as not addressing the potential for cover degradation prior to liner degradation, increased infiltration, and potential for accumulation of water on the intact liner and overflow (e.g., bathtub effect). This could result in an increased release rate when the liner system does fail (potential pulse release), as the accumulated water drains potentially leading to higher peak concentrations in the environment.

These two topics illustrate some of the challenges associated with addressing performance of cover and liner systems given the uncertainty regarding the timing of when cover and liner systems will cease to be effective. Example 1 is associated with a concern about over-predicting the effectiveness of covers or liners (taking too much credit). In this case, the concern is that taking too much credit for the effective life of cover and liner systems could lead to peak impacts occurring after 1,000 years, the time of compliance in DOE Order 435.1. Although, in principle, design features that delay releases should be considered a positive, concerns with the magnitude of any delayed peaks should be addressed. Such concerns can be addressed in the context of DOE Order 435.1 by discussing the significance of any peaks that would be expected to occur after 1,000 years in the context of risk-informed decision-making.

Example 2 is associated with intentionally assuming a liner system increases in permeability early, allowing early release of leachate, to avoid having to defend a longer lifetime for the liner system. Allowing for early releases can give the impression of leading to larger peak doses, but it can miss the potential impacts of water accumulation in the facility prior to liner failure (e.g., bathtub). This highlights the interrelationship between cover and liner system performance. If the cover begins to allow increased infiltration prior to loss of performance of the liner system, there is potential for accumulation of water on the liner system. The accumulated water would be in contact with the waste for an extended time prior to release. This could, under certain circumstances, result in a pulse release as the liner system increases in permeability and lead to greater impacts than assuming failure of the liner system, for example, at 100 years. Although, it will be important to consider how flow through flaws in a multilayer liner system would actually occur (i.e., it would not be expected to freely drain with no resistance).

Defense-in-Depth Principles

Defense-in-depth principles should be considered as part of design, operations, assessment and closure of a disposal facility. In many cases, features are included in cover and liner systems, but no credit is taken in the assessment. It is important to capture such considerations in the context of defense-in-depth (i.e., expected performance that is not credited in the PA). The role of design and operational considerations is emphasized in this report as means to help manage uncertainties that may be difficult to resolve in an assessment. Any DOE LLW disposal system must be designed, constructed, operated, and closed with a reasonable expectation that DOE O 435.1 requirements and performance objectives will be met. For CERCLA cells, in addition to meeting performance objectives they must also meet the CERCLA threshold criteria. Defense-in-depth in the context of this report means considering, and possibly including the following in the requirements for an on-site disposal facility:

- Siting and Design requirements,
- Waste form requirements,
- Performance-based requirements such as dose limits, operational requirements, etc., and
- Closure requirements.

The CERCLA ARAR’s process performs much of this function by selecting applicable or relevant and appropriate chemical-specific, action-specific, or location-specific ARARs most appropriate for the remedial action (disposal cell development). Where there are identified gaps in the requirements/safety envelope, to-be-considered (TBC) guidance or other non-promulgated specifications (such as DOE Order requirements) can be added to enhance the response action.

GENERAL APPROACH TO ADDRESS COVER AND LINER SYSTEMS IN A PA

A number of years of DOE experience have been gained from assessments of the long-term performance of disposal facilities involving covers, liners and leachate collection systems. For example, the Office of Legacy Management currently provides surveillance and maintenance on numerous closed disposal facilities including three CERCLA disposal facilities: Weldon Spring, Fernald, and Monticello. The Monticello Site is an UMTRA facility that was completed under CERCLA. There are three active CERCLA disposal facilities including Oak Ridge, Hanford, and Idaho National Laboratory (INL) that all dispose of LLW, HW and MW. There are a total of twenty-four (24) Title I UMTRA disposal facilities around the DOE complex.

This practical experience of design, build, operate and closure of radioactive and hazardous waste disposal facilities has reached a point where it is timely to formulate and offer a more consistent approach to address long-term performance of covers and liners; especially the uncertainties associated with the evolution of such barriers over time. Recently, the NRC Office of Nuclear Regulatory Research held a workshop in 2010 on this topic [2] and supported a large study on long-term cover performance [3]. These activities also provided insights into consideration of long-term performance of cover and liner systems.

A structured approach has been proposed for such assessments. This paper provides information that can be used to help explain cover and liner system performance to stakeholders, starting at a higher level and working towards detailed information for calculations. The actual approach is presented in four steps:

1) Define the assessment of cover and liner systems in the context of a total system perspective, considering the evolution over time of water balance and how water migrates through the cover, waste, liners and the natural system,
2) Develop conceptual models starting with identification of the functional roles (safety functions) of the different components of covers and liners. This is done in the context of limiting releases from disposal facilities, including identification of the relative importance of different components depending on the local climate (e.g., “wetter” versus “drier” sites, freeze-thaw),
3) Identify events and processes that can result in changes to those components and how those changes can influence the performance of given components, including perspective regarding their relative significance based on existing experience, and
4) Synthesize information into integrated scenarios to be used to meet the performance requirements of DOE Order 435.1.

Additional information for each of these steps is summarized below. In practice, there will be iterations among the different steps and there should be substantial interaction with the LFRG and stakeholders (e.g., EPA, state agencies, members of the public) to ensure that their concerns are addressed. The remainder of this report provides increasing detail to implement each of the steps in the approach. The information is intended to help with implementation of the graded approach and can also be used to develop information for stakeholders to explain the performance of cover and liner systems.

The primary emphasis is placed on considerations related to water flow and associated transport of contaminants. However, for example, covers may include layers that can also serve a role as barriers to biotic or inadvertent human intrusion into the waste and liner systems can be designed to serve as “chemical” barriers targeting specific contaminants in addition to managing water.

Step 1: Develop Initial Representation of Total Disposal System

The first step in the process is to consider the full disposal system and to begin to define the overall approach. This starts with development of an initial perspective regarding the expected water balance and flows through the system, and how the water balance is expected to evolve over time. Initially, the focus can be at a level of cover, waste, liner, and natural system rather than the detailed layers within each of these. This perspective can be helpful for a high-level description of the system for stakeholders. Considerations related to potential accumulation of water have proven to be a significant area of interest (e.g., bathtub above the liner system) and should be an emphasis. This will have a significant influence on how ranges of values for assumed performance of different layers are developed and scenarios for evolution of the system are defined. The definition of water balances within each layer will be refined over time as the specific features within each of these layers are better defined. Additional information for this step is provided in Section 4.0, *Total Disposal Systems Perspective* of the report [1].

Step 2: Develop Initial Conceptual Models for Each Layer

This step involves identification of the specific design components in each layer and the functional roles (safety functions) those components are expected to serve in terms of managing water and migration of contaminants. The intent at this point is to provide an initial perspective of the necessary performance for different features (e.g., evapotranspiration (ET) layer is expected to address "x"% of the average precipitation and "y" peak precipitation events). Initial perspective can also be provided about the relative significance of different layers in terms of performance (e.g., is it expected to be a primary feature or a redundant feature based on expected conditions). However, it is important to err on the side of inclusion rather than exclusion in cases where there is not a clear basis. Details regarding the material properties assumed for each layer should be specified at this time along with how different layers will be linked in terms of the actual modeling (e.g., cover and waste will be addressed independently, then linked assuming an infiltration rate through the base of the cover as a boundary condition for the waste layer). Detailed information to support development of the initial conceptual models is identified in Section 5.0, *Conceptual Description of the Disposal System* of the report [1]. Specific information and detailed tables are also provided in Section 6.0, *Functional Roles of Cover System Components*, and Section 7.0, *Functional Roles of Liner System Components* of the report [1]. The details from the report are briefly summarized later in this paper.

Step 3: Quantify Evolution/Degradation

This step involves identification of events and processes that can impact the performance of the design components over time. The term evolution is used to reflect that changes can improve or degrade performance of different layers over time, but the general focus of this effort is on events and processes that result in degradation of the performance of design components in the context of their defined functional roles. The emphasis of this step should be prioritized based on the components deemed to be most critical to performance. This is generally viewed as the most challenging aspect for assessments of covers and liners. Specific information regarding identification of events and processes are provided in Section 8.0, *Factors Influencing Evolution of Covers and Liners* of the report [1]. Detailed approaches for quantifying the evolution are provided in Section 9.0, *Technical Information about Long-Term Evolution of Covers and Liners* of the report [1].

As discussed previously, the extent to which the evolution of cover and liner systems is taken into account and justified within PAs generally depends upon the extent to which credit must be taken for the performance of the cover and liner system within the PA. The need to justify and take into account cover and liner system evolution often diminishes as the cover and liner system become a defense-in-depth component for which little credit is given within the PA relative to reducing contaminant release out of the disposal facility recognizing that releases are likely being over-predicted (Although there is potential for counter-intuitive results as discussed in *Timing Considerations for Covers, Liners and System Performance*, above). In any case, it is important to document what is and is not credited in the PA.

There is expected to be significant uncertainty regarding the specific timing and extent of changes in performance of different materials. Thus, there is expected to be iteration on this step involving development of ranges of values and then considering the implications of those ranges of values in the context of the total system (e.g., timing of cover degradation relative to liner degradation assumptions). Sensitivity analysis can be used to help identify the components and assumptions that have the greatest influence. Evolution should be quantified in the context of changes in material properties and the timing of those changes. In many cases, it can be valuable to consolidate the detailed results for each component into lumped representations of the cover and liner systems, respectively (e.g., net infiltration to the waste, net permeability of the liner system). Such an approach can be easier to implement in the PA model used for compliance.

It is expected that assumptions regarding evolution of the covers and liners over time will be an area of interest for LFRG and stakeholders. Care must be taken to not make generic assumptions about what might overestimate the degradation of liners and/or maximize the release and exposures from the disposed waste. It is necessary to consider such assumptions in the context of performance of the total system (e.g., assuming immediate degradation of the cover or liner at 100 years may not always result in upper end estimates of contaminant release and/or exposure). Adopting some bounding assumptions as extremes can be useful for initial screening to provide perspective (e.g. complete failure of cover and liner at 100 years), but in general it is suggested to provide some ranges of values that are more representative of what would be expected to occur. This information will be specific to the site and facility considered. The output from this step should provide a basis for identification of evolution scenarios to be considered in a total system assessment.

Step 4: Identify Total System Scenarios to be Considered

This step involves a synthesis of the information identified in the first three steps into one or more representative scenarios that address evolution of the different components of the system over time. These scenarios should be defined from a total system viewpoint, where the cover is represented by a net infiltration rate as a function of time and the liner system is represented with a changing rate of drainage to the vadose zone with time. Such approaches would rely on the detailed quantification of performance considering the individual components in the cover and liner system conducted in Step 3.

The LFRG and stakeholders have shown high levels of interest for this step in the process. It is desirable to work with them as the scenarios to be considered are developed. Generally, it should be expected to consider a few scenarios to capture the impacts of different timing assumptions that impact the water balance and eventual releases from the disposal system to the environment. For example, it can be useful to include cases expected to represent relatively early degradation, if such extreme cases can illustrate the robustness of the system. However, it should not be considered essential to consider extremes for a compliance calculation and it is not advisable to include scenarios that are clearly beyond the realm of reasonable possibilities. A logical approach is to strive to develop a realistic set of scenarios that capture the ranges of conditions that are developed in Step 3. In the end, the final design and assumptions can be integrated into a facility WAC that will establish limits for what can be accepted for disposal.

TOTAL DISPOSAL SYSTEM PERSPECTIVE

A total systems approach considers the inter-relationship among assumptions regarding covers, the waste, liners, and the natural system as a unit when addressing overall performance. The roles of these different features need to be considered together in the context of the impact on water flow through the system and migration of contaminants. These interactions can change as a function of time as the facility evolves from operations to institutional controls to the time frame where the system is no longer actively maintained. The detailed PA considerations described later in this report emphasize cover and liner performance, but from a systems perspective, the role of the waste as a water storage buffer also needs to be considered. Fig. 1 is a rough schematic illustration of considerations for water balance and the links between the different parts of the system. Note that the potential for lateral migration of water from areas outside the facility (e.g., surface or via natural capillary barriers) into the facility also needs to be addressed.

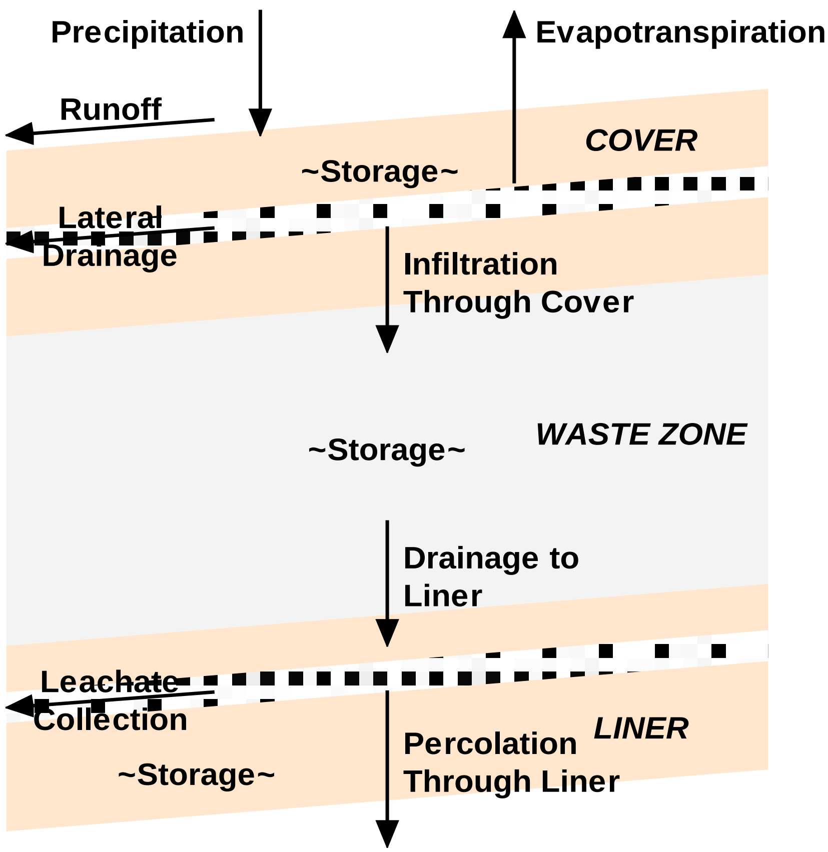

Fig. 1. High-level perspective of water balances.

The links from a water balance perspective between each layer are straightforward (water flux). When the barriers and materials in a disposal facility are considered as a system, it provides the ability to identify the interplay among different parts of the system. As discussed previously, a systems approach helps to identify circumstances that may not be intuitive at a first glance, for examples:

- Assuming that a cover loses effectiveness early in time allowing greater percolation does not always result in the greatest dose (e.g., a cover that performs extremely well for a long time, when combined with disposal of radionuclides with progeny of concern, can delay releases allowing in-growth of progeny posing greater risks in the waste form at the time when flow through the cover increases).

- Assuming that a liner increases in permeability early does not always result in the greatest dose (e.g., a lined disposal facility where the liner is very effective and remains intact for a longer time than the cover, can result in accumulation of water in the waste providing a larger hydraulic driving force and potentially enhanced contaminant concentration that could result in greater releases when the liner system increases in permeability and also leachate to migrate to the environment).

From a practical perspective, key factors to consider as part of the total systems approach to improve understanding and refine designs include evolution of water balance over time and links between water balance and the evolution of the source term (inventory, waste form, containers). Given the large uncertainties associated with long-term performance of liners and covers, it is generally suggested to consider approaches that address ranges of values for degradation of different layers to illustrate how assumptions influence overall performance of the system. These topics are briefly introduced in the context of the total system perspective in the following sections.

Evolution of Water Balance in the System

Although “chemical” barriers can be incorporated into liner systems, tracking water through the system as a function of time is a key starting point to understanding the relative significance of different design features and to examine how roles change over the life of the facility. Such an approach is also an effective tool to help communicate an understanding of the system to stakeholders and explain expected performance of the system over time. Fig. 2 is an example illustration of how the movement of water changes for different components with time using arrows to illustrate the flow of water.

The figure also provides perspective regarding the timing of the effectiveness of different barriers and the changes of moisture levels in the waste. During operations, significant amounts of water are introduced and will drain through the waste. This leachate will be collected. The waste is relatively moist during this time. When the cover is in place and leachate collection continues, excess moisture from the waste will drain. While the cover continues to effectively minimize any infiltration into the waste, the waste will remain at a relatively dry equilibrium state. As the layers of the cover begin to degrade, increased infiltration into the waste occurs and the moisture content increases again and flow will begin to occur through the waste. As infiltration increases through the cover and the liner is intact, there is potential for moisture contents to reach a point where there can be accumulation of water above the liner (i.e. positive head). Finally, as the liner system becomes more permeable, any accumulated water would drain at a rate based on the permeability of the liner system (i.e., synthetic and natural materials) and then the system will approach a steady state flow from the cover through the waste and the liner.

Table 1 provides additional information related to water balance considerations for covers, the waste and liners during operations, institutional controls, and following institutional controls. Conceptual model development to address these considerations is discussed in Section 5.0, *Conceptual Description of the Disposal System* of the report [1].

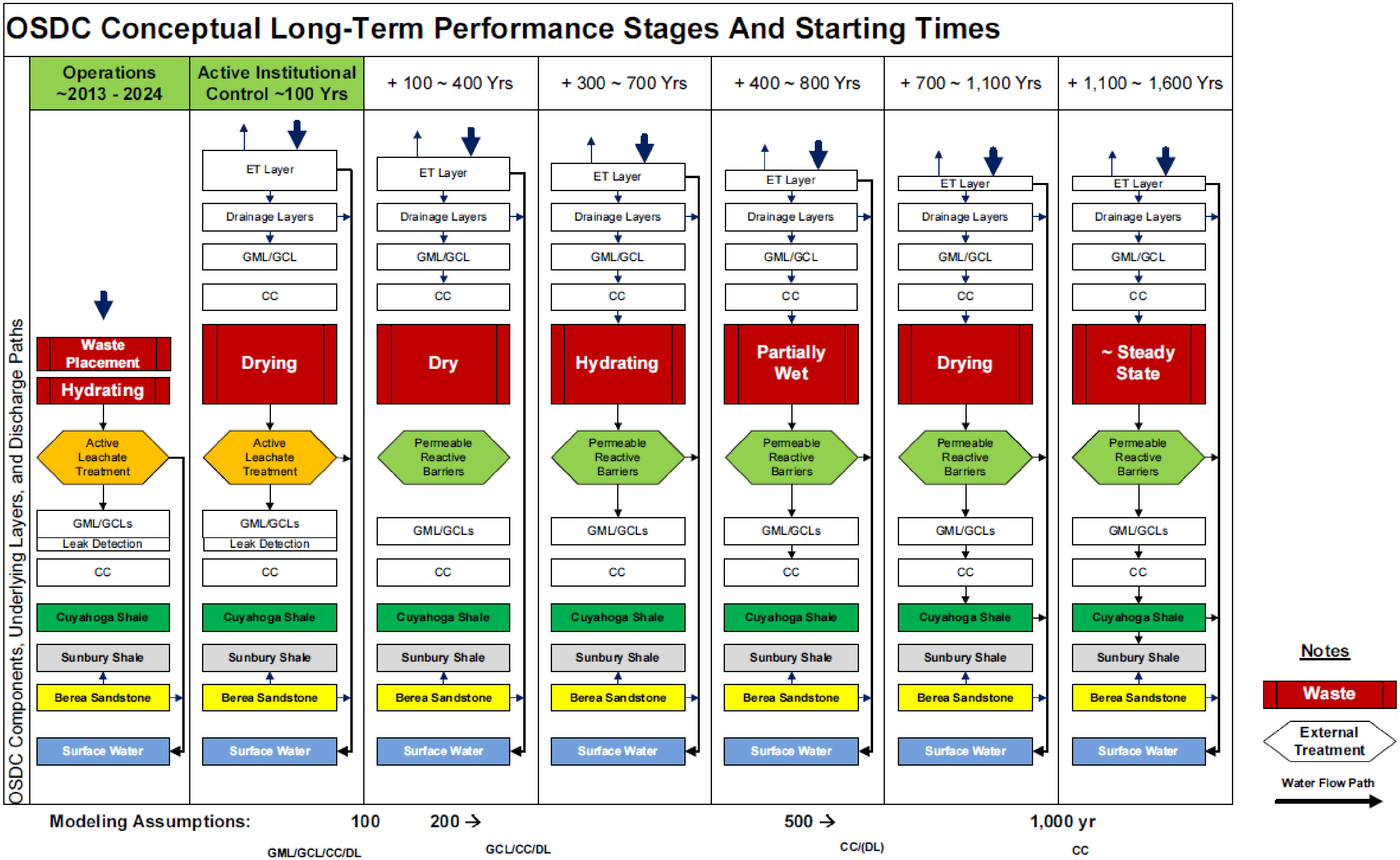

Fig. 2. Example of the evolution of water balance over time (Arrows denote water movement) (Courtesy: FBP).

Table I. Summary of water balance considerations at different times.

	Operations (10s of years)	Institutional Control (typically 100 years)	Post-Institutional Control (hundreds/thousands of years)
Cover	Precipitation on operational covers - Runoff - Promote ET - Limited effectiveness to decrease infiltration to waste	Precipitation on Final cover - Runoff - Promote ET and storage - Lateral drainage (i.e., interflow) - Infiltration to waste significantly reduced	Cover performance can degrade with time - Runoff - Promote ET (storage) - Lateral drainage - Increasing infiltration to waste
Waste	Direct precipitation and water introduced for dust suppression/compaction - Increased moisture content (storage) and drainage to liner system - Large quantities of leachate - Source depletion in leachate	Limited added Infiltration to waste - Moisture content (storage) decreases - Drainage of stored water accumulated during operations to liner system - Source depletion in leachate	Increasing Infiltration to waste - Moisture content (storage) based on infiltration rate - Potential accumulation of water on primary barrier (inactive leachate collection system) - Can also be situations where infiltration decreases over time, such as an aggrading or depositional environment
Liner	Leachate drainage to liner system - Active leachate collection - Synthetic liner intact, minimal percolation to natural system	Leachate drainage to liner system - Active leachate collection - Potentially discontinue leachate collection as excess water in waste layer drains - Potential accumulation of water in sump - Synthetic liner intact, minimal percolation to natural system	Leachate drainage to liner system - Lateral migration to leachate collection sump while liner intact - Potential accumulation of water in leachate collection sump - Clay or other materials below synthetic liner limit releases - Percolation to natural system increases as cover and liner system degrades
Natural System	Minimal potential percolation from liner system - Reduction in moisture content below liner system	Minimal potential percolation from liner system - Moisture content remains lower under liner system	Increasing percolation from liner system - Moisture content below liner system increases as liner system degrades - Flow will be primarily controlled by unsaturated hydraulic conductivity - Can also be constant or decreasing percolation in cases where recharge is constant or decreasing over time

CONCEPTUAL DESCRIPTION OF THE DISPOSAL SYSTEM

From a high-level functional perspective, covers and liner systems serve the general purpose of managing water/leachate. It is important to clearly describe the intended roles of the different components of the disposal system. In the case of a cover, the purpose is to limit the amount of water that reaches the waste beneath the cover. The purpose of a liner system is to limit downward migration of leachate that has formed due to prolonged water contact with the waste and mitigating contamination of the underlying vadose zone and groundwater. This includes collecting water that passes through the waste during operations and time of institutional controls, and to serve as a barrier limiting flow rates and potentially chemically serving to retard migration into the natural system over longer times.

From a general perspective, two general classes of covers can be identified. In areas where precipitation exceeds the evapotranspiration (ET) rates, a more conventional cover design includes multiple layers to promote ET as well as lateral drainage to control the eventual infiltration of water into a facility. These designs tend to be more complex and by their nature involve more reliance on the different features to control infiltration. This implies a greater burden to demonstrate that the design features will continue to perform as intended. In drier environments, cover designs focus on ET without depending on additional layers to promote lateral drainage. These covers are generally robust with an emphasis on water storage, which is largely based on thickness and storage capacity of soils rather than depending on more sophisticated design layers that are prone to changes in performance over time.

The waste layer influences water flow and can also influence the release rate of contaminants from a waste form into leachate. From a water management perspective, the waste layer serves as pore space for water storage and a delay between infiltration from the base of the cover to collection of water on the liner. Although “design” of the waste layer is largely based on the properties of the waste to be received, there can be design considerations for specific waste forms (especially for subsidence considerations). For DOE CERCLA disposal cells, a double liner system is typically utilized where both leachate collection and leak detection are required. The leachate collection system provides for lateral drainage and for the collection and removal of leachate from the LLW disposal facility during the operations and institutional control periods. Materials can also be included in the design that target sorption of specific radionuclides or other contaminants. The leak detection system is designed to detect leaks through the primary liner during the operation and institutional control periods and to provide a secondary barrier against releases to the environment.

FUNCTIONAL ROLES AND FAILURE MECHANISMS

The conceptual description serves as the basis to identify functional requirements for the different components of the system (e.g., cover, waste, liner) and then at greater detail, individual layers within those components. It is helpful to view the system starting with fundamental components, which are then comprised of individual layers. Starting from a view of expected performance for each component (e.g., infiltration through cover), it is then possible to describe the roles of each layer in a cover in the context of meeting the expectations for the cover as a whole. The report [1] provides a detailed listing of functional roles of different layers that can be included in each of the components of a disposal system. Simply discussing functional roles of different layers can provide perspective regarding the overall performance of the disposal system and relative importance of different features.

The discussion of the functional roles leads into the next step which is to consider processes and events that can compromise the function of a given layer. For example, what events and processes can potentially compromise the performance of the drainage layer (e.g., plugging, settling/subsidence) and negatively impact the ability of the cover to perform as expected. The report [1] also includes a detailed discussion of failure mechanisms for the typical features that are included in covers and liners. The challenge is to identify those mechanisms that are applicable at a given facility and whether a given mechanism can compromise performance. Furthermore, it is also a challenge to quantify the timing and magnitude of the impacts of changes in performance of any given design feature. It is often the case where decisions will need to be made about what features can be credited in the assessment and other layers that may be difficult to quantify. In practice, it becomes a type of optimization problem where it is decided which layers will be credited in the analysis (and justified) and where it is determined to avoid the need to justify performance and consider a layer from the perspective of defense-in-depth rather than quantifying performance. As mentioned previously, it is important to carefully consider whether an assumption will truly lead to an over-prediction of impacts or could lead to counter-intuitive effects. The report [1] concludes with details regarding reference materials and information to help quantify the timing and significance of the failure of different design features and provides examples from existing assessments at USDOE sites.

CONCLUSIONS

A number of new disposal facilities are being considered at USDOE sites. These facilities are being designed to meet requirements for radioactive and hazardous wastes, which involves the need to quantify the performance of liner and leachate collection systems, which were not commonly used on disposal facilities for radioactive waste. Recognizing the importance of considering performance of the total disposal system, a report has been prepared to serve as a reference for information to support consideration of the performance of cover and liner systems as part of performance assessments for disposal facilities. The report provides information on strategic considerations including stakeholder involvement, considerations related to defense-in-depth and a general approach to follow to assess the total disposal system including specific features of cover and liner systems. The approach includes detailed information on conceptual designs, functional roles of design features and potential failure mechanisms for those design features. Detailed technical information is provided to help quantify the performance of different layers including a summary of assumptions from existing performance assessments.

REFERENCES

1. Phifer, M., R. Seitz, and L. Suttora, 2014, “Consideration of Liners and Covers in Performance Assessments,” SRNL-STI-2014-00409, Revision 0, Savannah River National Laboratory, Aiken, SC.

2. Nicholson and Arlt, 2011, Proceedings of the Workshop on Engineered Barrier Performance Related to Low-Level Radioactive Waste, Decommissioning, and Uranium Mill Tailings Facilities, NUREG/CP-0195, August 2011.

3. Benson et. al 2011, Engineered Covers for Waste Containment: Changes in Engineering Properties and Implications for Long-Term Performance Assessment, NUREG/CR-7028, US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, December 2011.